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Heavy Metal Contamination and Its Risk for Swampy Agricultural Soils of Keffi, Nasarawa West, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author UR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors UR and AAA managed the analyses of the study. Authors UR and SM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Swampy agricultural soils could be contaminated as a result of accumulation of heavy metals through emission from industrial areas, mines tailings, metal wastes, gasoline, paints, fertilizers, manure, sewage sludge, pesticide, waste water irrigation, coal combustion residue, spillage of petrochemicals and atmospheric deposition. This study aimed at evaluating the carcinogenic and non-carcinogenic risk of the study area using X-Ray fluoroscopy. The results shows that, mean concentration level in the area was in decreasing order Ni(525) > Cu(515.9) > Zn(367.6) > Cr(336.6) > Cd(260.9) > Pb(219.5) > As(18.9). The Hazard Quotient (HQ) was all recorded to be low except ingestion adult which is higher than unity. The Hazard Index (HI) was also recorded to be 2.3 a value greater than one (>>1). This makes non-carcinogenic effects significant to the population and poses serious effects in the area under study. The total excess life cancer risk were found to be (5.0×10^{-2}), a value greater than that of U.S (1.0×10^{-4} to 1.0×10^{-6}) and above that of South Africa (5.0×10^{-6}). This implies that there is a probability that one person in 1,000 may be affected. Regular monitoring and evaluation of the soils and the crops cultivated at the sample locations is recommended.

Keywords: Heavy metals; swampy agricultural soils; sewage sludge; health risk.

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1. INTRODUCTION

Heavy metals are found throughout nature. Detectable amounts occur naturally in soils, rocks, water, air and vegetation from which it is contacted, inhaled and ingested into the body. Historically, agriculture was the first human influence on the soil [1]. Swampy agricultural soils could be contaminated as a result of accumulation of heavy metals through emission from rapidly expanding industrial areas, mines tailings, disposal of high metal wastes, leaded gasoline, paints, application of fertilizers, animals manure, sewage sludge, pesticide, waste water irrigation, coal combustion residue, spillage of petrochemicals and atmospheric deposition [2]. Elements.

That pose major threat to human health that are commonly found in contaminated soils are Lead (Pb), Chromium (Cr), Arsenic (As), Zinc (Zn), Cadmium (Cd), Copper (Cu) and Nickel (Ni).Soils are the major sink for heavy metals emission into the environment. The sources are the anthropogenic activities and unlike organic contaminants. As such their total concentration in soils persists for a long time after their introduction [3,4]. Changes in their chemical forms (speciation) and bioavailability are however possible. The presence of heavy metals in soils can severely inhibit the biodegradation of organic contaminants [5].

Heavy metals contaminants in soils may pose risk and harmful effects on human being and the environment through contact with contaminated soil or direct ingestion, drinking of contaminated ground water, the food chain. The Standard Organization of Nigeria (SON), Department of Petroleum Resources of Nigeria (DPR), United State Food and Agricultural Organization (USFAO), European Union Environmental Protection Agency (EUEPA) and the World Health Organization (WHO) characterize chemical properties of environmental phenomena, specifically on food chain [6]. While soil characterization will provide an insight into heavy metals bioavailability and speciation, an attempt to remediate heavy metals contaminated soils will entail knowledge of the source of contamination, basic chemistry, associated health and environmental effects (risks) of these heavy metals. Risk assessment will go a long way as an effective scientific tool which enables decision makers (government and stake holders) to manage site so contaminated in a cost effective way and manner while preserving the ecosystem and public health [7]. This work centered on some swampy agricultural soils where food crops like rice, vegetables, sugar cane, etc. are cultivated. These crops followed food chain by deriving their nutrients from the plants, the plants derive their nutrients from the soil and the soil may probably contain heavy metals as the case may be. The consumption of food could be classifying as ready to eat food (those that are consumed without further preparation after cultivation and purchase, e.g. sugar cane and fruits) and not ready to eat food (those that are prepared before consumption e.g. rice). This study aimed at evaluating the carcinogenic and non-carcinogenic risk of the study area and will serve as a baseline data for ecological integrity and human wellbeing in Keffi, Nasarawa West, Nigeria.

2. METHODOLOGY

2.1 Sample Size

Ten (10) random soil samples were collected from Keffi Local Government Areas in order to conduct this elemental analysis.

2.2 Sample Techniques

Consideration was employed by randomly collecting the soil samples on each of the swampy agricultural soil area under investigation and the soil samples were collected thirty centimeter (30 cm) depth from the top soil so as to obtain the desired standard result.

2.3 Study Area

This research work centered on Keffi Local Government Area of Nasarawa State in Nasarawa West. The sample points are abbreviated as PT1, PT2, PT3, PT4, PT5, PT6, PT7, PT8, PT9 and PT10, located at 8°52'16.506''N and 7°52'22.801''E, 8°52'15.522''N and 7°52'23.268''E, 8°52'14.976''N and 7°52'28.128''E, 8°52'17.284''N and 7°52'35.958''E, 8°52'19.854''N and 7°52'36.930''E, 8°52'44.688''N and 7°52'44.712''E, 8°52'44.424''N and 7°52'47.358''E, 8°52'31.804''N and 7°52'14.646''E, 8°50'44.881''N and 7°51'39.091''E, 8°50'44.394''N and 7°51'38.448''E. Rice was cultivated in all the ten sample points as represented in Fig. 1.

Table 1. The materials used for this research work are presented

S/N	Materials	Quantity	Specifications
1	Small Trowel	1	Metal Type
2	Permanent Marker	1	Plastic Type
3	Field Work Book	1	Paper Type
4	A Hand Held Global Positioning System	1	URIC. Type
5	Agate Pestle and Mortar	1	Ceramic Type
6	Sieve (2.0mm)	5	Plastic Type
7	Masking Tape	1 Roll	Paper Type
8	Hand Gloves	1Pkt	Polythene
9	Safety Boot	1Pair	Rubber Type
10	Nose Mask	1Pkt	Cotton
11	Laboratory Coat	2	Cotton
12	Meter Rule	1	Plastic Type
13	Mentholated Spirit	10 Bottles	Emzo Brand
14	Paper Bag/Brown Envelope	5 Dozens	Paper Type
15	X-Ray Fluorescence Machine	1	XR-100CR

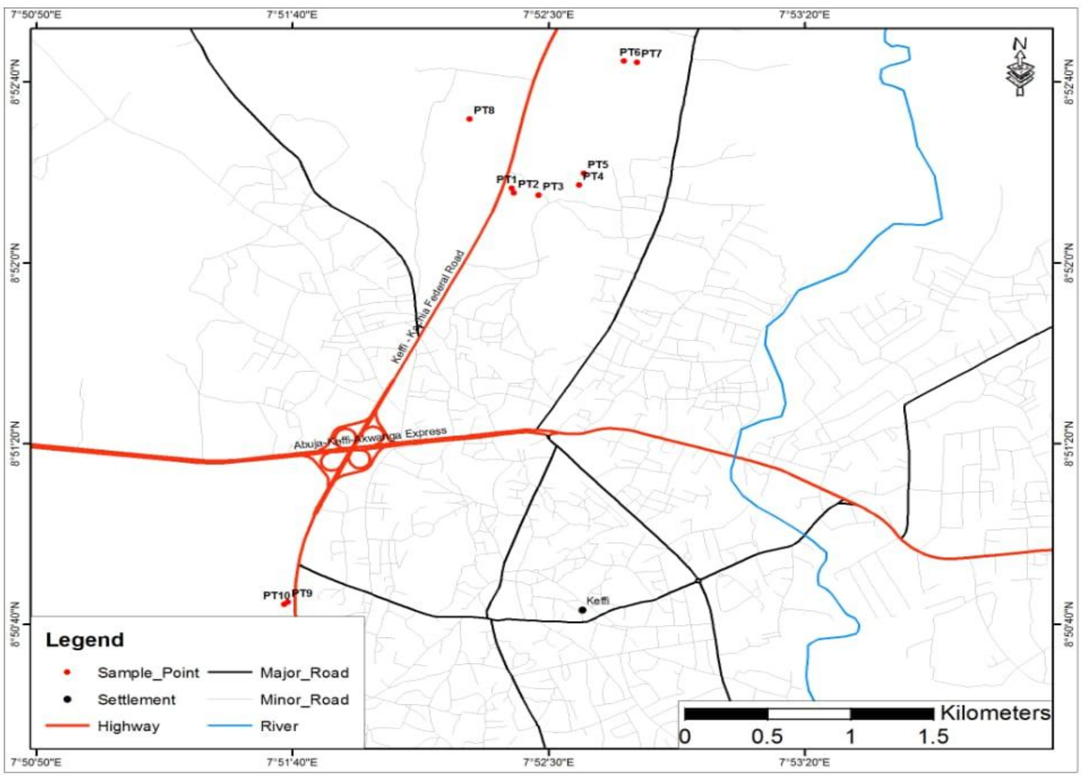

Fig. 1. Map of the study area (DPR, 2000)

2.4 Samples Preparation

The soil samples were collected between 30th October, 2019 and 11th November, 2019. The collected swampy agricultural soil samples were air dried under ambient temperature, pulverized, using agate pestle and mortar, and allowed to pass through 2.0 mm meshed sieved, packaged properly in paper bags and labeled with code numbers for easy identification. The soil samples were then taken to Center for Energy Research and Development. ObafemiAwolowo University, Ile Ife. Osun State for X.R.F elemental analyses.

2.5 Method of Sample Analyses

X-ray Fluorescence (XRF) Spectrometry analysis is used for routine, non- destructive spectrometric determination of food, rocks, soils, minerals and liquid samples with little or no pre-treatment needed. It enables chemical composition to be determined in seconds. It involves mass analysis and every component in the irradiated substance is included. However, X.R.F. cannot generally make analysis at the small spot sizes (2-5microns). It is typically used for bulk analysis of larger fractions of geological materials. The relative ease, low sample preparation and the stability and ease of use of X-Ray Spectrometers make it one of the most widely used methods for analysis of major and trace elements in rocks, soil, water, mineral sediment etc.

When an X-ray emission from a radioactive source strikes a sample, the x-ray can either be absorbed by an atom or scattered through the material after absorption. The atom becomes exited and gives off a characteristics x-ray whose energy level is unique to the element impacted by the incident x-ray. The emission of this characteristics x-ray is called X-Ray lorescence. Measurement of the number of emitted x-ray provides a quantitative indication of the concentration of the metal present in the sample.

2.6 Data Analysis

In other to compute the analyzed result for the carcinogenic and non-carcinogenic health risk assessment (that is ingestion of heavy metals through soil, inhalation of heavy metals through soil and dermal contact of heavy metals with soil), the following methods and formulas were used as pointed out by USEPA [8]:

$$MDI_{ing} = \frac{C_S * IR * EF * ED * CF}{BW * AT} \quad (1)$$

$$MDI_{inh} = \frac{C_S * IR_{air} * EF * ED}{BW * AT * PEF} \quad (2)$$

$$MDI_{derm} = \frac{C_S * SA * FE * AF * ABS * EF * ED * CF}{BW * AT} \quad (3)$$

$$RiskPathway = \sum_{k=1}^{n} MDI_K CSK_K \quad (4)$$

$$Risk_{(total)} = Risk_{(inj)} + Risk_{(inh)} + Risk_{(derm)} \quad (5)$$

$$HQ = \frac{MDI}{RfD} \quad (6)$$

$$HI = \sum_{k=1}^{n} HQ_k = \sum_{k=1}^{n} \frac{MDI_k}{RfD_k} \quad (7)$$

Where,

MDI_{ing}, MDI_{inh}, and MDI_{derm} are the Mean Daily Intake for the Exposure Dose via ingestion, inhalation and dermal contact in mg/kg/day respectively. HQ, HI, RfD and CSK are the hazard quotients, hazard index, reference dose and cancer slope factor respectively. C_s is the concentration of heavy metal in soil in mg/kg. The abbreviated parameters in equation (1), (2) and (3) are explain in Table 2. Also, the values for the conversion factors in equation (4), (5), (6) and (7) are presented in Table 3. Equation (4) and (5) are the equations for the carcinogenic risk assessments while (6) and (7) are the non-carcinogenic risk assessments.

Table 2. Exposure parameters used for the health risk assessment through different exposure pathways for soil

Parameter	Unit	Children	Adults	References
Body Weight (BW)	Kg	15	70	[9]
Exposure Frequency (EF)	Days	350	350	[9]
Exposure Duration (ED)	Years	6	30	[9]
Ingestion Rate (IR)	mg/day	200	100	[9]
Inhalation Rate (IR air)	m^3/day	10	20	[9]
Skin Surface Area (SA)	cm^2	2100	5800	
Soil Adherence Factor (AF)	mg/cm^2	0.2	0.07	[9]
Dermal Absorption Factor (ABS)	None	0.1	0.1	[9]
Dermal Exposure Ratio (FE)	None	0.61	0.61	[9]
Particulate Emission Factor (PEF)	m^3/kg	1.3×10^9	1.3×10^9	[9]
Conversion Factor (CF)	mg/kg	10^{-6}	10^{-6}	[9]
Average Time (AT)				[9]
For Carcinogens	Days	365 x 70	365 x 70	
For Non- Carcinogens	Days	365 x ED	365 x ED	

Table 3. Reference Doses (RfD) and Cancer Slope Factors (CSF) for different heavy metals

Heavy metal	Oral RfD	Dermal RfD	Inhalation RfD	Oral CSF	Dermal CSF	Inhalation CSF	References
As	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	1.5 x 10	1.5 x 10	1.5 x 10	[10]
Pb	3.6×10^{-3}	NA	NA	8.3×10^{-3}	NA	4.2×10^{-2}	[10]
Hg	3.0×10^{-4}	3.0×10^{-4}	8.6×10^{-5}	NA	NA	NA	[10]
Cd	5.0×10^{-4}	5.0×10^{-4}	5.7×10^{-5}	NA	NA	6.3 x 10	[10]
Cr (VI)	3.0×10^{-3}	NA	3.0×10^{-5}	5.0×10^{-1}	NA	4.1 x 10	[10]
Co	2.0×10^{-2}	5.7×10^{-6}	5.7×10^{-6}	NA	NA	9.8 x 10	[10]
Ni	2.0×10^{-2}	5.6×10^{-3}	NA	NA	NA	NA	[10]
Cu	3.7×10^{-2}	2.4×10^{-2}	NA	NA	NA	NA	[10]
Zn	3.0×10^{-1}	7.5×10^{-2}	NA	NA	NA	NA	[10]

NA = Not Available

If the (HI) value is less than one (<1), the exposed population is unlikely to experience adverse health effects. However, if the (HI) value exceeds one (>1), then there may be concern for potential non-carcinogenic effects [11].

3. RESULTS AND DISCUSSION

3.1 Results

The data collected from different Swampy Agricultural Soils from Keffi L.G.A were analyzed using X-ray Fluorescence (XRF) Spectrometry. The results of the analysis were obtained and presented in Table 4, which are the Concentration Level of Heavy Metals such as Chromium (Cr), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Cadmium (Cd) and Lead (Pb). Further evaluations were made for the carcinogenic and non-carcinogenic risk assessments such as Mean Daily Intake (MDI), Hazard Quotients (HQ), Hazard Index (HI), Risk Pathway and Total Rick and are presented in Tables 5, 6, 7 and 8.

3.1.1 Result analysis

In order to analyze the results obtained and presented in Table 1, charts were plotted and comparison was made with World Health Organization for all the Carcinogenic and Non-Carcinogenic Risk Assessment.

3.2 Discussion

3.2.1 Concentration level (Table 4 and Fig. 2)

Seven heavy metals along with their respective concentrations in mg/kg (Cr (336.6), Ni (525), Cu (515.9), Zn (367.6), As (18.9), Cd (260.9) and Pb (291.5)) were found in the soil samples.

Finding of this study have revealed that the mean Concentration of the analyzed heavy metals in all the soil samples for all points arranged in decreasing order is Ni > Cu >Zn > Cr >Pb>Cd >As. These values were found to be higher than the safe limit recommended by WHO for all heavy metals except arsenic (As) which was found to be lower.

Table 4. Concentration levels of elements in some swampy agricultural soils from Keffi L.G.A

S/N	Sample Points	Cr (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)
1.	PT1	249.0	790	453.0	403.0	11.0	522.0	302.0
2.	PT2	201.0	452	890.0	329.0	N.D	302.0	365.0
3.	PT3	116.0	429	780.0	430.0	29.0	155.0	344.0
4.	PT4	23.00	499	364.0	429.0	22.0	68.00	N.D
5.	PT5	117.0	452	444.0	397.0	19.0	50.00	285.0
6.	PT6	819.0	523	449.0	255.0	23.0	99.00	294.0
7.	PT7	935.0	539	432.0	369.0	26.0	213.0	326.0
8.	PT8	295.0	433	369.0	349.0	16.0	233.0	311.0
9.	PT9	366.0	633	539.0	368.0	N.D	553.0	399.0
10.	PT10	345.0	500	439.0	347.0	43.0	414.0	289.0
Mean		336.6	525	515.9	367.6	18.9	260.9	291.5
WHO (2001)		300.0	50.0	200.0	300.0	20.0	3.000	100.0

Table 5. Mean Daily Intake (MDI) values of heavy metals for carcinogenic risk assessment (mg/kg/day)

Receptor	Pathway	Mean Daily Intake (MDI) values for heavy metals in soils							Total
		As	Cd	Pb	Ni	Zn	Cr	Cu	
Ingestion	Child $x10^{-4}$	0.250	2.80	3.10	5.70	4.000	3.80	5.60	25.3
Ingestion	Adult $x10^{-4}$	0.110	1.50	1.70	3.10	2.200	2.00	3.00	13.6
Inhalation	Child $x10^{-8}$	0.100	1.10	1.20	2.20	1.500	1.40	2.10	9.60
Inhalation	Adult $x10^{-8}$	0.210	2.30	2.60	4.70	3.300	3.10	4.60	20.8
Dermal	Child $x10^{-5}$	0.330	3.60	4.00	7.30	5.100	4.80	7.20	32.3
Dermal	Adult $x10^{-5}$	0.340	3.70	4.20	7.60	5.300	5.00	7.50	33.6
Mean	mg/kg/day x 10^{-4}	0.071	0.84	0.94	1.60	1.200	1.10	1.70	7.60
WHO (2001)	mg/kg/day x 10^{-4}	0.130	0.02	0.66	8.90	1.900	1.90	4.00	97.6

Table 6. Mean Daily Intake (MDI) values of heavy metals for non-carcinogenic risk assessment (mg/kg/day)

Receptor	Pathway	Mean Daily Intake (MDI) values for heavy metals in soils							Total
		As	Cd	Pb	Ni	Zn	Cr	Cu	
Ingestion	Child $x10^{-3}$	0.30	3.3	3.7	6.7	4.6	4.4	6.5	29.5
Ingestion	Adult $x10^{3}$	0.32	3.5	3.9	7.1	5.0	4.7	7.1	31.6
Inhalation	Child $x10^{2}$	1.50	1.6	1.8	3.3	2.3	2.2	3.2	15.9
Inhalation	Adult $x10^{-8}$	0.49	5.4	6.1	1.1	7.7	7.3	1.0	29.1
Dermal	Child $x10^{-4}$	0.38	4.2	4.7	8.5	6.0	5.6	8.4	37.8
Dermal	Adult $x10^{-4}$	0.10	0.9	1.0	1.7	1.2	1.1	0.8	6.80
Mean	mg/kg/day$x10^{3}$	0.078	0.61	0.68	1.2	0.87	0.82	1.2	5.5
WHO (2001)	mg/kg/day$x10^{-3}$	0.11	0.016	0.53	0.27	1.6	1.6	1.1	5.2

Table 7. Carcinogenic risk assessment

Locations	Pathways	Cancer risk	Risk total
Keffi	Ingestion	2.51×10^{-4}	5.0 x10-^{2}
	Inhalation	5.98x10-^{8}	
	Dermal	1.49×10^{-1}	
WHO (2001)		1.000	1.000

Table 8. Non carcinogenic risk assessment

Location	Pathways	Hazard Quotient (HQ)	Hazard Index (HI) = Sum of (HQs)
Keffi	Ingestion / Child	3.54×10^{-4}	
	Ingestion / Adult	2.25×10^{0}	
	Inhalation / Child	7.45×10^{-2}	
	Inhalation / Adult	2.46×10^{-11}	2.3
	Dermal / Child	4.48×10^{-6}	
	Dermal / Adult	9.28×10^{-7}	
WHO (2001)		1.000	1.000

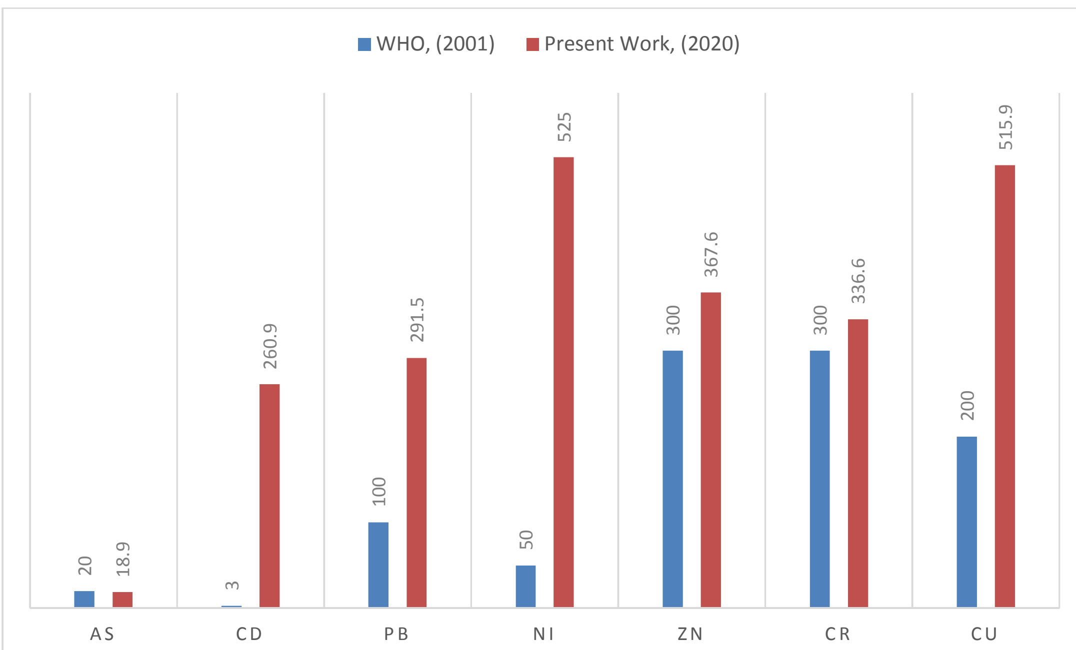

Fig. 2. Comparison of concentration level for present study with WHO

This implies that the mean concentration level of heavy metals in those areas is significantly high and may cause immediate radiological hazard to the populace of the study area.

3.2.2 Mean daily intake (Tables 5, 6 and Fig. 3)

The results of Mean Daily Intake of Heavy Metal for both carcinogenic and non-carcinogenic risk in swampy agricultural soils of Keffi, Nasarawa West, Nigeria, have been presented in Tables 5 and 6. The average Mean Daily Intake of various heavy metals for both carcinogenic and non-carcinogenic risk found in the soil samples are presented in Tables 5 and 6. Seven heavy metals along with their respective Mean Daily Intake for both carcinogenic and non-carcinogenic risk in mg/kg/day (Cr (1.1×10^{-4} and 0.82×10^{3}), Ni (1.6×10^{-4} and 1.2×10^{3}), Cu (1.7×10^{-4} and 1.2×10^{3}), Zn (1.2×10^{-4} and 0.87×10^{3}), As (0.071×10^{-4} and 0.078×10^{3}), Cd (0.84×10^{-4} and 0.61×10^{3}) and Pb (0.94×10^{-4} and 0.68×10^{3} respectively)) were evaluated for the soil samples.

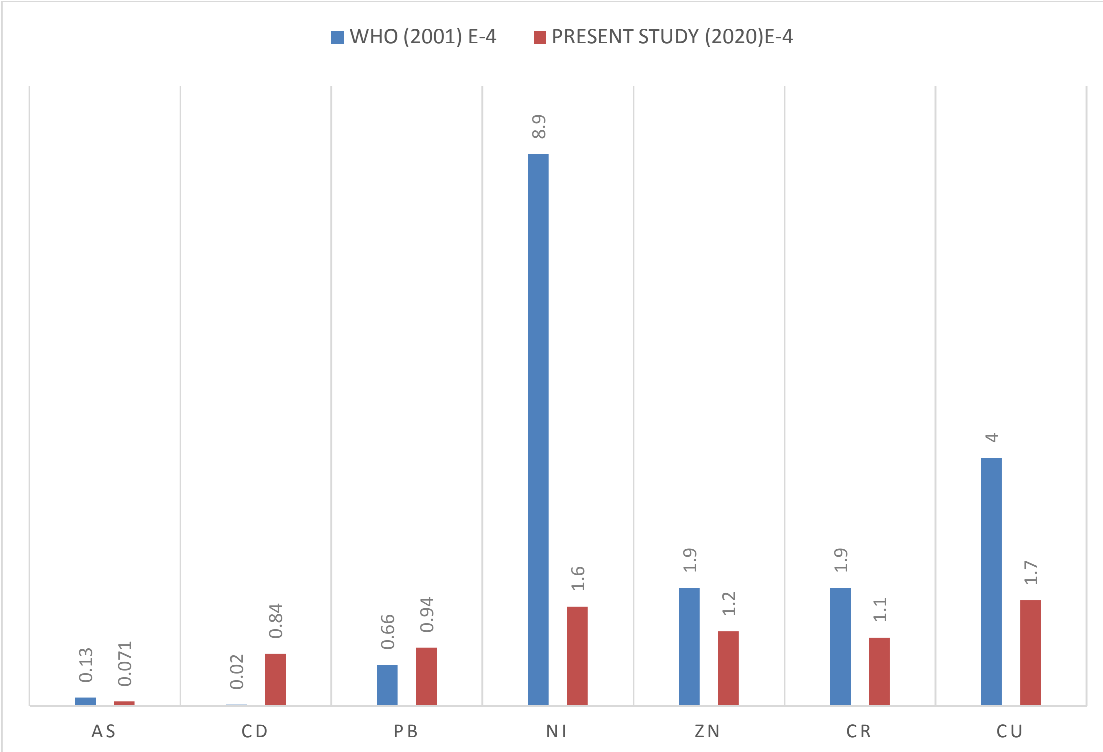

Fig. 3. Comparison of carcinogenic mean daily intake for present study with WHO

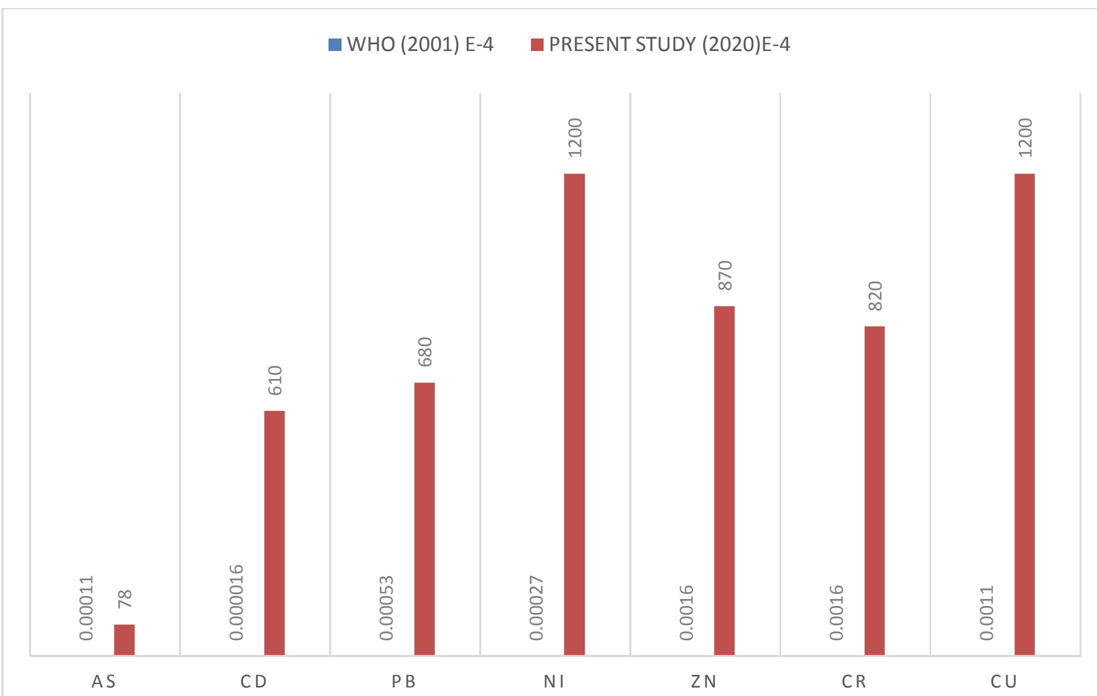

Fig. 4. Comparison of non-carcinogenic mean daily intake for present study with WHO

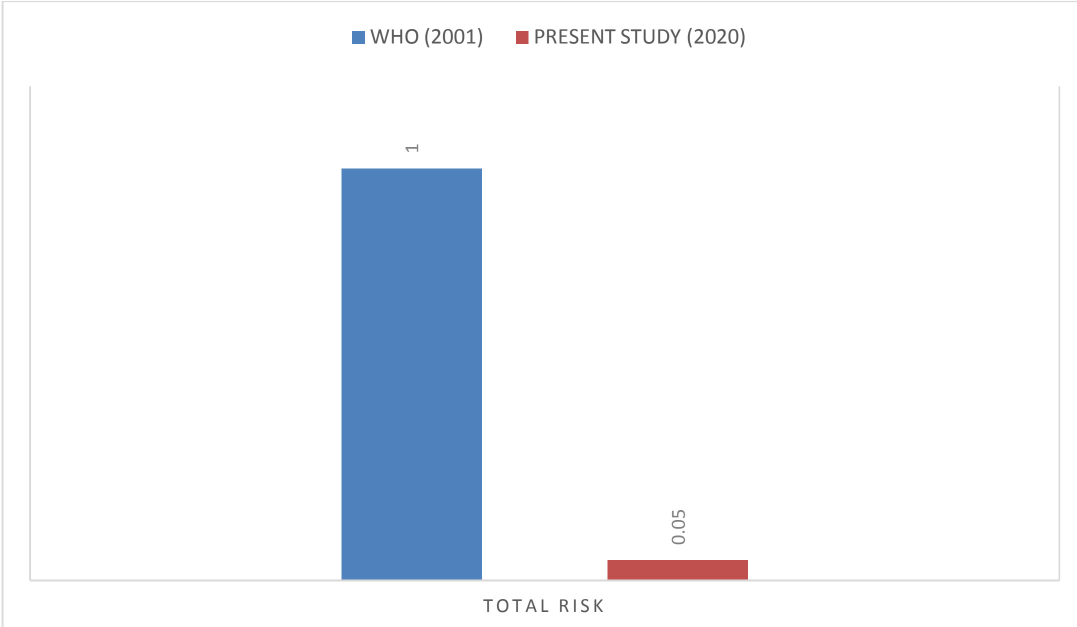

Fig. 5. Comparison of carcinogenic risk assessment for present study with WHO

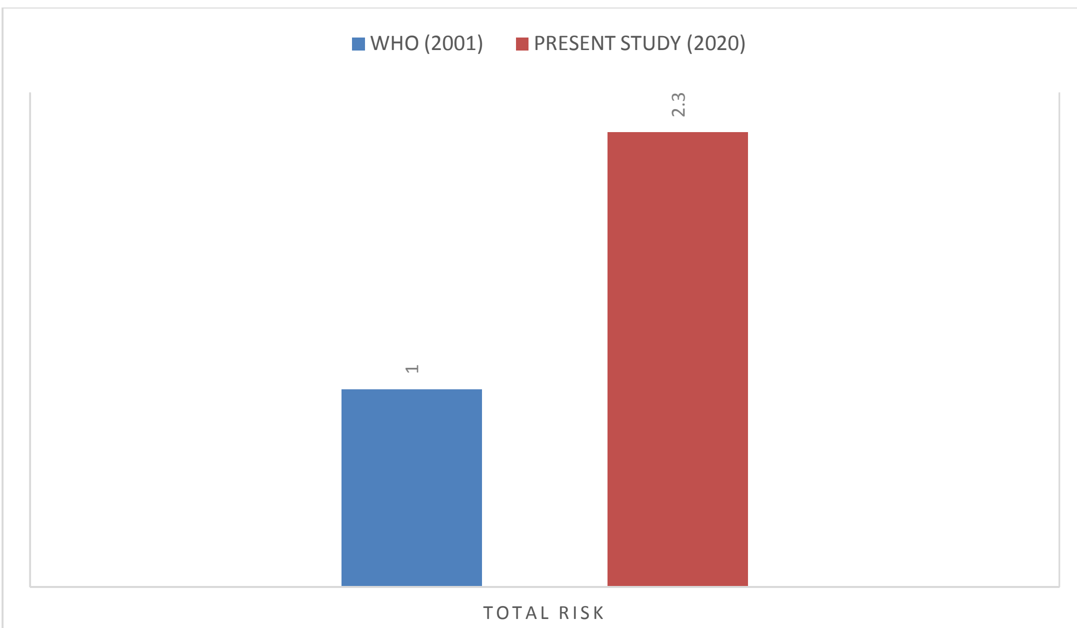

Fig. 6. Comparison of non-carcinogenic risk assessment for present study with WHO

Finding of this study revealed that Mean Daily Intake evaluated for heavy metals for both carcinogenic and non-carcinogenic risk in the soil samples for all points arranged in decreasing order is Cu > Ni > Zn > Cr > Pb > Cd > As and Cu, Ni > Zn > Cr > Pb > Cd > As respectively. The carcinogenic mean daily intake values were found to be higher than the safe limit recommended by WHO for all heavy metals except cadmium (Cd) and lead (Pb) which was found to be lower, while the non-carcinogenic mean daily intake values were found to be higher than the safe limit recommended by WHO for all heavy metals. This implies that the carcinogenic and non-carcinogenic mean daily intake of heavy metals in those areas is significantly high and may cause immediate radiological hazard to the populace of the study area.

3.2.3 Carcinogenic risk assessments

It was observed from Table 7 and Fig. 5 that, the cancer risk for the area under investigation followed the decreasing trend with dermal contact > ingestion > inhalation and the total cancer risk was found to be (5.0×10^{-2}), a value less than unity, indicating that the cancer risk is negligible according to USEPA [8].

3.2.4 Non-carcinogenic risk assessments

It was observed from Table 8 and Fig. 6 that, the Hazard Quotient (HQ) for both adults and children in terms of ingestion, inhalation and dermal contact pathways were all recorded to be low except ingestion adult which was recorded to be higher than unity. The Hazard Index (HI) was also recorded to be 2.3. A value greater than one (>>1) indicating that the area under study is not safe according to USEPA [8].

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The results shows that the mean concentration levels of heavy metals in some swampy agricultural soil from Nasarawa West, Nigeria varied significantly and decreased in the order of Ni > Cu > Zn > Cr > Cd > Pb > As. These high values could be attributed to the geological strata and the pollution of the studied area. The Hazard Quotient (HQ) was all recorded to be low except ingestion in adult which was recorded to be higher than unity. The Hazard Index (HI) was also recorded to be 2.3 a value greater than one (>>1). This makes non-carcinogenic effects significant to the population and poses serious non-carcinogenic effects in the area under study. This implies that there is a probability that one person (adult or child) in 1,000 may be affected. Consequently, this indicates threat to adverse health effects to consumer individuals and population in the area under investigation.

4.2 Recommendations

Remediation techniques are important in order to eliminate the human adverse health effects in contaminated swampy agricultural soils. To achieve that, regular monitoring and evaluation of the soils and the crops cultivated at the sample locations should be carried out to check the elevated concentrations of these harmful metals. The data from this assessment could serve as an index in which remediation variables in modeling could be anchored. Furthermore, Government authorities at all levels should create awareness on the health implications of human interaction with heavy metals contamination through ingestion, inhalation and dermal contact pathways.

Heads of cattle crossing from nearby communities should be restricted from grazing on the grasses in the study area as the cow dump deposits has great influence on concentration levels of these toxic heavy metals. Also, heavy metals content in different sites varied significantly in the plant and soil samples therefore, consumption of food sold along road sides should be discouraged. Also drying of eatable food on tarred roads in rural and urban community should be discouraged and agricultural farms should not be close to highways to prevent excessive buildup of heavy metals.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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