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Exposure Study and Health Risk Assessment of Heavy Metals in Soils around Tanneries in Challawa Industrial Estate, Kano, Nigeria

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Abstract

Exposure assessment was carried out to evaluate the health risk associated with heavy metals in soils around tanneries in Challawa Industrial Estate, Kano, Nigeria. Atomic absorption spectrophotometer was used to determine the metal levels in the soil in the study area, and comparison was made with background soils. Monte Carlo method was successfully applied to obtain a precise metal concentration on the appropriate probability distribution. The exposure to carcinogenic risk (> 10^{-4}) and non-carcinogenic health threat (HI > 1) was ranked in the order: dumpsite of the tanneries > vicinity of the tanneries > farm near the dumpsite, with children receiving the highest exposure than adult. Among the metals studied, chromium (Cr) was the major contaminant and could pose a health threat (HQ >>1) in tannery soils. This is quite alarming and needs a special attention considering Cr toxicity and high carcinogenic tendency. Generally, the trend of heavy metal probabilistic health risks associated with ingestion of soil from the studied sites was Cr > Cd > Pb.

Keywords: Health risk, tanneries, heavy metals, soil, Monte Carlo analysis, Challawa

1. Introduction

Investigation into the exposure risks of heavy metals in environment is a priority to environmental scientists in recent time. Soil contamination by heavy metals has become a critical problem of many parts of the world [1]. The sources of these metals are due to anthropogenic and natural activities resulting in elevated concentrations that could be toxic to humans, plants and animals [2]. Among the anthropogenic sources of heavy metals are industrial activities such as tanning which contributed significantly to the economic development of the state. Environmental pollution due to skin and hide processing releases effluents to the surrounding environment and contaminates the soil, thereby raising the metal levels beyond tolerable limit, which consequently threatens the health of the inhabitants either by direct ingestion or through the food chain [3]. Tannery operations are of a great concern due to indiscriminate release of heavy metals such as Cr, Pb, Cd, Cu, Zn, and Mn in concentration above permissible limits in the environment. Several physical and chemical processes are involved in the conversion of animal skin to leather from trimming and soaking up to finishing stage [4]. Most of these production stages generate pollutants, but the heavy metals are mostly accompanied in the chemical processing stages and are discharged to the environment as effluent or solid wastes [5].

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Several chemicals are extensively used during tanning processes, among which are H_2SO_4, $Cr(SO_4)_3$, and $Ca(OH)_2$. Consequently, the final tannery effluent discharged contains significant concentration of Cr and other heavy metals considered as impurities in the acids and other chemical used. The dominant Cr is basically in less toxic trivalent form (Cr(III), however, when released to the soil is oxidized to the toxic hexavalent state (Cr(VI)) due to variations in environmental conditions [6]. Heavy metals threaten the health of human beings by exposure to ingestion in drinking water, vegetables, and other food substances; this necessitated the need to fully embark on evaluation of risks associated with the metals to safeguard the health of the society [7]. Though some heavy metals such as Fe, Cu, and Zn are vital for normal growth and body metabolism, high concentrations of Zn causes sideroblastic anemia [8], Cu causes Wilson disease, and Fe causes liver, heart disease, and hormonal dysfunction [9]. Though Cr at a very low concentration is essential to humans, high dose of Cr is toxic [10]. Other metals such as Cd, and Pb are considered toxic to humans [7]. Chronic exposure to Cd can cause kidney dysfunction, lung cancer, and hypertension. Intake of Pb can damage the immune, nervous, and circulatory systems of the exposed individual. Moreover, exposure to Cr can result in adverse effect on upper respiratory track and kidney [11, 12].

The dumpsite of tanneries in Challawa is a central incineration point of all the tanneries and other factories around the industrial estate. Local farmers utilize the ash, soil and other industrial wastes as manure without considering the possible health implication due to heavy metals via food chain. Due to the longer period of industrial operations in the area, the soils of the surrounding farms and villages may also be contaminated with heavy metals resulting in a significant level of exposure [13]. Toxic heavy metals can transfer from soil to the plants and subsequently to humans causing a health threat [14]. Various studies have been carried out to evaluate human health risks [15, 16]. However, deterministic approach was applied which gives unprecise risk and exposure estimation resulting in underestimation of the health hazard associated with the toxic heavy metals. In this study, Monte Carlo method was employed to give a precise estimation of the health risks at reasonable maximum exposure (RME). At RME, an individual could have a health threat of cancer and non-cancer effects [17]. Therefore, this study aims to evaluate the exposure and potential health impacts of selected heavy metals on the population exposed to soil around the tanneries in Challawa Industrial Estate, Kano.

2. Materials and Methods

2.1. Study Area

Challawa Industrial Estate is located on latitude 11° 54' 26.96″ N and longitude 8° 27' 55.81″ E, it is one of the active industrial sites in Kano State, Nigeria. Bordering Madobi, Rimingado, Gwale, and Tarauni Local Government Areas by Southwest, Northwest, North and East direction, respectively. The area is dominated by tanneries and few other industries such as Nigeria bottling company, and cotton processing factories. Figure 1 presents the map of the study area indicating sampling points lettered R to Z, and their respective coordinates in Table 1.

Figure 1. Map of Challawa Industrial Estate Showing Sampling Locations

2.2. Sampling

Soil samples were collected from the locations indicated in Figure 1 at the depth of not more than 10 cm using plastic scoops. Three samples each were collected at the vicinity of the tannery, surrounding tanneries, dumping site, and a farm near the dumpsite. Control samples from Challawa, and Karfi town (Q) were also collected for comparison. A distance between 5 to 10 m was maintained between each sampling point to study the metal distribution of the study area [18]. Samples were placed in polyethylene bags, sealed and transported to laboratory.

Table 1. Sample Locations and their Coordinates

Code	Description	Coordinates
Q	Karfi Town	11º27´00.77″N, 9º09´00.16″E
R	Farm away from Tanneries	11º54´02.78″N, 8º28´50.28″E
S	Challawa Town	11º54´04.27″N, 8º27´34.36″E
T	Farm near dumpsite	11º53´33.87″N, 8º28´03.90″E
U	Dumpsite of Tanneries	11º53´44.84″N, 8º28´08.64″E
V	10 m away from U	11º53´44.45″N, 8º28´03.57″E
W	10 m away from V	11º53´41.72″N, 8º28´07.82″E
X	Vicinity of Tannery	11º54´09.43″N, 8º28´17.80″E
Y	5 m away from X	11º54´08.39″N, 8º28´19.06″E
Z	10 m away from X	11º54´07.19″N, 8º28´16.57″E

The soil samples were air dried, grinded and sieved through 2 mm sieve [19], a representative of the sample was further crushed for the digestion process.

2.3. Analysis of Samples

A 0.2 g of the prepared soil sample was accurately weighed into platinum crucible. The soil sample was heated on a hot plate in a mixture of 6.0 mL conc. HCl and 1.0 mL HF. After cooling the mixture, follows the addition of 5.0 mL HF and 1.0 mL conc. HCl. It was heated on a sand bath at a temperature of 200 - 230 ºC until the acid evaporates to dryness. After cooling, 6.0 mL of 1.0 M HCl was poured and heated for 10 min. The resulting solution was filtered and made up to 25.0 mL mark in a volumetric flask. Atomic absorption spectrophotometer (Varian 1200) with air acetylene flame was used for the metal analysis [20].

2.4. Statistical Analysis

Descriptive statistics and analysis of variance (ANOVA) were calculated using Microsoft - Excel 2013. ANOVA was employed for the mean comparison of metal concentrations of the sampling locations. Prior to Monte Carlo simulation, metal concentrations were fitted in appropriate probability distribution to evaluate the goodness-of-fit with Kolmogorov-Smirnov (K-S) using JMP Pro 12 software. Normal distribution of body weight was obtained for adult [21] and child [22]. About 20 thousand iterations were performed by independently sampling the parameters from their respective distributions.

2.5. Human Health Risk Assessment

In the evaluation of human health risk, it is important to examine the doses that cause adverse effect on humans. There is likelihood that people exposed to contaminated soil around the tanneries and dumpsites are at risk, this call for estimation of the health risks. The exposure pathways and risk estimations were evaluated using United States Environmental Protection Agency health risk hand book [23]. The exposure risk was evaluated separately based on daily dose for each metal. The exposure dose of ingestion was calculated using Equation 1.

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad 1$$

where EDI is the average daily intake by ingestion (mg/kg/day), C is the concentration of metals (mg/kg), IR is the ingestion rate (kg/day), EF is the exposure frequency (365 days/year), ED is the exposure duration (70 years), BW is the body weight (61 kg for adult, 30 for child), AT is the time period over which dose is averaged, considered to be 70 years.

In this study, the cancer health risks associated with Cr, Cd, and Pb are considered due to their toxicity and high carcinogenic tendency [4], while Fe, Zn, and Cu are included in the non-cancer health risk evaluation only.

2.5.1. Non-carcinogenic Risk

The non-cancer health risk due to exposure to heavy metal is characterized by hazard quotient defined as the ratio of the average estimated daily intake to the oral reference dose. Oral reference dose (RfD) also known as the toxicity threshold obtained from Integrated Risk Information System is the daily exposure estimate of humans without a deleterious non-carcinogenic health effect over a lifetime [24]. Hazard quotient is defined as the ratio of the approximate average daily intake resulting to exposure to the reference dose of specific pathway of the metal as given in Equation 2.

$$HQ = \frac{EDI}{RfD} \qquad 2$$

where HQ is the hazard quotient, EDI is the average daily intake in µg/kg/day, RfD is the reference dose in µg/kg/day. When considering a health threat due to more than one metal to assess the general potential risk, hazard index (HI) is used which is the sum of hazard quotient of the metals under consideration as shown in Equation 3.

$$HI = \sum(HQ_{Cr} + HQ_{Pb} + \ldots\ldots HQ_n) \qquad 3$$

where HI is the hazard index and HQ is the hazard quotient of the metals.

2.5.2. Carcinogenic Risk

Cancer risk of an individual is estimated by calculating the increasing chances to develop cancer over a life time due to exposure to a contaminant. This is achieved using cancer slope factor (SF) which converts the approximate daily intake of a toxic substances for exposure in a life time to the increasing risk of an individual to develop cancer [25]. Cancer risk is calculated using Equation 4.

$$\text{Risk} = \text{EDI} \times SF \qquad 4$$

where Risk is the probability of an individual to develop cancer, EDI is the average daily intake in mg/kg/day, SF is the carcinogenic slope factor $(mg/kg/day)^{-1}$.

3. Results and Discussion

3.1. Metal Concentration in Soil Samples

The results of ANOVA revealed a significant difference ($p < 0.05$) in metal concentrations especially for Cr, Pb, Fe, and Cu with concentration ranges of 8.61-3890, 0.28-45.26, 1090-2610, and 0.33-7.23 μgg^{-1}, respectively. The metal concentrations are much higher in the industrial site including the dumpsite than the control sites which had no industrial activity. The dumpsite has the highest metal levels for all the metals studied, variations in metal concentrations is attributed to the chemicals used in the tanneries, dumping of tannery waste and other industrial activities around Challawa Industrial Estate. The main concern on contamination of soil due to tannery operation is elevated levels of toxic Cr (VI). Soil samples of dumpsite have the highest Cr concentrations 3278 ± 459 μgg^{-1} much higher than USEPA guideline of 1500 μgg^{-1} [26]. The lowest value of 9.21±0.52 μgg^{-1} was observed in soil from Karfi town. Table 2 reveals the metal concentrations and their distribution values at $p > 0.05$. The result of K-S reveals that metal concentrations of most of the soil samples followed normal distribution, while others were log-normally distributed. Metal concentrations were found to decrease with increasing distance from the vicinity of the tannery, but show no regular distribution pattern at the dumpsite.

Table 2. Statistical Distribution of Metals in Soil from Different Samples

Code	Description	Cd	Pb	Cr	Fe	Zn	Cu
Q	Karfi Town	ND	ND	10.43, 0.85	1595.47, 62.96	23.15, 1.46	0.19, 0.03
R	Farm away from Tanneries	ND	1.64, 0.16	241.53, 7.21	1768.02, 121.27	23.46, 0.98	0.36, 0.08
S	Challawa Town	ND	ND	33.78, 0.94	1502.46, 72.28	17.81, 3.10	0.36, 0.08
T	Farm near dumpsite	ND	1.48, 0.03	2411.7, 57.56*	2201.88, 159.94	21.58, 1.46	2.01, 0.16
U	Dumpsite of Tanneries	1.56, 151*	18.26, 3.70*	3295.28, 442.79*	2412.71, 206.55	18.67, 2.03	3.35, 1.25
V	10 m away from U	2.12, 2.01*	7.41, 2.86*	3804.48, 466.26*	2528.84, 210.84	13.67, 2.19	0.54, 1.25*
W	10 m away from V	9.95, 5.04*	29.87, 4.10*	2607.48, 476.33*	2047.31, 209.31	16.15, 1.99	2.68, 1.24
X	Vicinity of Tannery	ND	8.64, 1.54*	2528.26, 299.58*	1821.17, 256.17	19.31, 1.27	15.98, 5.09
Y	5 m away from X	ND	3.19, 1.24	2488.26, 300.66*	1164.76, 250.28	16.23, 1.30	6.33, 5.60*
Z	10 m away from X	ND	0.95, 1.43	2208.56, 88.93*	1718.51, 255.46	16.60, 1.33	3.03, 5.29*

ND - Not Detected; Data follow log-normal distribution ln (µ, σ)* based on p > 0.05Other values reported follow normal distribution N (µ, σ) based on p > 0.05

3.2. Metal Distribution in Soil Samples

Cr and Fe are the dominant metals in all the soil samples studied. The high metal concentrations are plausibly related to tanning and other industrial activities [27]. The source of Cr was linked to the popular chrome dyes used to give good colorations to leather, and other chemical substances used as preservatives and in the hair removal. High Cr concentrations were reported in previous studies related to leather and processing industries [28, 29]. High concentrations of Cr^{6+}, Cr^{3+}, Ni^{2+}, Zn^{2+}, Cu^{2+}, Cd^{2+}, and Hg^{2+} were reported in soil around the tanneries [30]. Fe has high natural percentage abundance in the earth crust, and is present in dyes, tanning agents, and animal skin [31, 32]. Cd and Pb were not detected in the samples used as control, but significant concentrations were observed in soil at the dumpsites. This could be related to dumping and incineration of different tannery solid wastes [33]. Cd was employed in the tanning process as pigment, and exists in complex form with other metals in tannery affected soil [29]. Significant concentration of Zn was detected in all the soil samples including the control samples, while Cu concentrations were relatively low in all the samples except the vicinity of the tanneries with slightly high Cu concentrations. Source of Zn could be related to the industrial activity, while copper is possibly linked to the preservatives and dyes used in the tanning process [28].

3.3. Preliminary Risk Assessment

Several research findings have been carried out on soil contamination with heavy metals and potential risks associated with the human exposures. Contamination of soil by tannery waste involves relatively high concentration of toxic metals especially Cr, Cd, and Pb. The potential risks associated with each metal therefore depend on its toxicity, and the exposure duration [34]. In order to accurately evaluate the health risk related to heavy metals in the soil, independent parameters in Tables 2 and 3 were used to simulate EDI using Equation 1, eventually Equations 2 and 3 were used to calculate the HQs and HIs, respectively. If HQ and HI exceed 1, the non-carcinogenic risk is high and there may be concern for potential health risk. For value less than 1, implies there could be no possible non-carcinogenic health threat [35]. Estimation of cancer risk due to exposure to heavy metals was evaluated using Equation 4, and risk value exceeding 1×10^{-4} is considered a cancer threat and unacceptable, while cancer risks in the range of 1×10^{-6} to 1×10^{-4} are generally considered acceptable [36].

Table 3. Exposure Parameters for the Risk Estimation

Parameters	Values	Source
C ($\mu g g^{-1}$)	Refer to Table 1	This study
IR (kg/day)	Adult (0.0001), Child (0.01)	[37]
EF (days/year)	Adult (210), Child (27)	[38, 39]
ED (years)	Adult (30), Child (7)	[38]
BW (kg)	Adult (61.3±7.1), Child (29.8 ± 4.4)	[21, 22]
AT^{*} (days)	Adult (25,550), Child (25,550)	[20, 40]
AT^{**} (days)	Adult (10,950), Child (2555)	[18, 40]

AT^{*} = Average time for the carcinogenic risk (70 × 365); AT^{**} = Average time for the non-carcinogenic risk (ED × 365)

3.3.1. Non-carcinogenic Risk

The results of non-carcinogenic risk showed the highest exposure to Cr, while all the remaining metals have HQ value less than 1 except for Cd and Pb near the dumpsite with HQ greater than 1. These results indicate that exposed population around the tanneries and especially the dumpsite may experience adverse health effect due to Cr, Cd, and Pb by ingestion in both adult and children as shown in Table 4. The ingestion reference doses (RfD) for the studied metals used for the non-cancer risk analysis are; 1.0, 3.0, 4.0, 40, 300, 300 $\mu g g^{-1} d^{-1}$ for Cd, Cr, Pb, Cu, Zn, and Fe, respectively [20]. The largest contribution to the HI in all the sites comes from Cr. The levels of toxic Cr in the soil are due to the fact that most tanneries worldwide use Cr bearing chemicals in leather processing [41].

The variations in the non-carcinogenic risk are attributed to the uneven distributions of the metals in the sample locations. In this study, adults may likely be exposed to Cd near the dumpsite, while health threat due to Cr may occur to all the sites except Karfi town used as a control. Challawa town also considered as control has HQ of 1.26 indicating that potential health risk of Cr may exist. Tanneries operating in decades are the dominant industries in Challawa which might have resulted in significant Cr exposure. Industries were confirmed to influence the metal levels in soil of neighboring communities thereby polluting the environment and increasing the health threat [12, 42]. Figure 2 reveals that the highest HQ of 142.7 was obtained from soil near the dumpsite; this value is highly critical considering the ability of Cr to cause deleterious health effects beside the cancer such as lung infection and skin rashes.

The observed exposure levels for the children exposure reveals a significant health threat due to Cr with HQ of 205.5 notably higher than adult exposure as shown in Figure 3. Many research findings emphasizes that children exposure to toxic metals in soil is due to their frequent contact with soil as a result of behavioral and physical factors, and high ingestion rate compared to adult thereby affecting development of brain and nervous system [43]. This finding is supported by the reports on elevated blood lead level (BLL) of children in Zamfara State leading to death of about 970 of the victims, and significant BLL and behavioral problems of school aged children in China [44, 45].

Analyzing the non-carcinogenic health threat from Cr at sampling point V with the highest HQ, about 59% of the children in the exposed population are at greater risk, while adult constitute 41%. This result agrees with established conclusions of the vulnerability of children to environmental hazards [46], and therefore an urgent need to device means for ensuring their safety and to protect their health. The high Cr HQ of 9.06 and 13.04, respectively for adult and children in farm near the dumpsite indicates a likelihood of health threat via food chain.

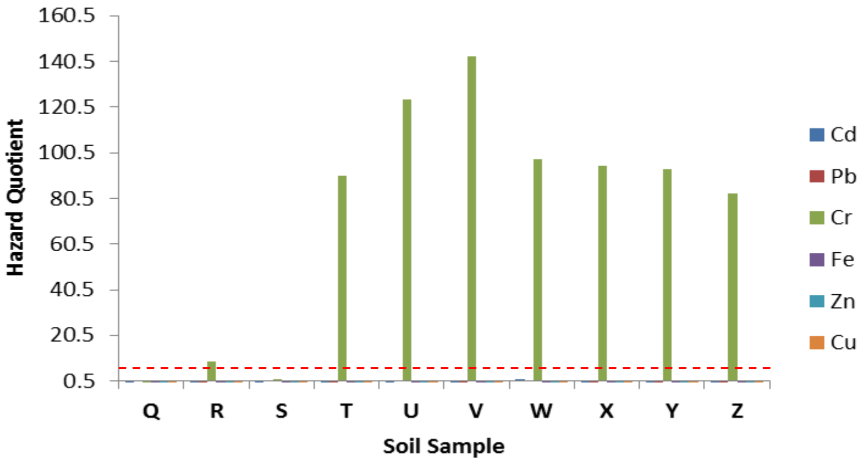

Figure 2. Adult Non-carcinogenic Risk on Exposure at 95th Percentile to Soil in Challawa Industrial Estate (Dotted line indicates maximum acceptable risk)

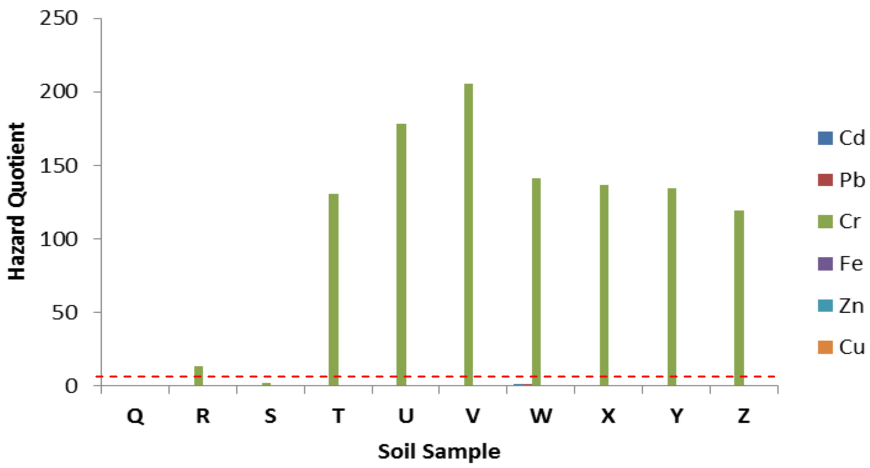

Figure 3. Children Non-carcinogenic Risk on Exposure at 95th Percentile to Soil in Challawa Industrial Estate (Dotted line indicates maximum acceptable risk)

Beside proximity to the dumpsites, the high Cr HQ value could be due to the use of incineration ash and other solid waste as manure by the local farmers [33]. Cr uptake and toxicity was reported, and evident that Cr interferes with uptake of some essential plant nutrients such as Ca, Mn, Fe, K, and Mg. Similarly, accumulation of toxic heavy metals and metal-loids (As, Cd, and Pb) in plant crops and foods were identified [47], hence, the toxicity effect of plant crops to humans from contaminated agricultural soil and sludge could occur. Generally, non-carcinogenic health risks of heavy metals from soil in both adult and children in Challawa Industrial Estate was found to be in the order Cr > Cd > Pb.

Table 4. Non-carcinogenic Risk of Adult and Child on Exposure at 95th Percentile to Soil from Challawa Industrial Estate, Kano

Adult Hazard Quotient								
Code	**Description**	**Cd**	**Pb**	**Cr**	**Fe**	**Zn**	**Cu**	**HI**
Q	Karfi Town	ND	ND	0.3913	0.2564	0.0087	0.0005	0.66
R	Farm away from Tanneries	ND	0.0461	9.0603	0.2842	0.0088	0.0010	9.40
S	Challawa Town	ND	ND	1.2672	0.2415	0.0067	0.0010	1.52
T	Farm near dumpsite	ND	0.0416	90.4683	0.3539	0.0081	0.0057	90.88
U	Dumpsite of Tanneries	0.1756	0.5137	123.6028	0.3879	0.0070	0.0094	124.69
V	10 m away from U	0.2386	0.2085	142.7145	0.4064	0.0051	0.0015	143.57
W	10 m away from V	1.1197	0.8404	97.8124	0.3291	0.0061	0.0075	100.12
X	Vicinity of Tannery	ND	0.2431	94.8489	0.2928	0.0072	0.0449	95.44
Y	5 m away from X	ND	0.0897	93.3402	0.1871	0.0061	0.0178	93.64
Z	10 m away from X	ND	0.0267	82.8480	0.2762	0.0062	0.0085	83.17

Children Hazard Quotient								
Code	**Description**	**Cd**	**Pb**	**Cr**	**Fe**	**Zn**	**Cu**	**HI**
Q	Karfi Town	ND	ND	0.5634	0.3692	0.0125	0.0008	0.95
R	Farm away from Tanneries	ND	0.0665	13.0463	0.4093	0.0127	0.0015	13.54
S	Challawa Town	ND	ND	1.8246	0.3477	0.0096	0.0015	2.18
T	Farm near dumpsite	ND	0.0599	130.2682	0.5095	0.0117	0.0081	130.85
U	Dumpsite of Tanneries	0.2528	0.7397	177.9798	0.5585	0.0101	0.0136	386.27
V	10 m away from U	0.3435	0.3002	205.4734	0.5852	0.0074	0.0022	206.71
W	10 m away from V	1.6124	1.2101	140.8174	0.4739	0.0087	0.0109	144.13
X	Vicinity of Tannery	ND	0.3500	136.5642	0.4215	0.0104	0.0647	137.41
Y	5 m away from X	ND	0.1292	134.4036	0.2695	0.0088	0.0256	134.84
Z	10 m away from X	ND	0.0385	119.2794	0.3977	0.0089	0.0123	119.74

Values reported at 95th Percentile

3.3.2. Carcinogenic Risk

The carcinogenic risk of the metals is evaluated using a cancer SF of the selected heavy metals. SF of the metals are; 4.1×10^{-6}, 3.8×10^{-7}, and 8.5×10^{-9} (mg/kg/day)$^{-1}$, respectively for Cr, Cd and Pb [48]. SF of Zn, Fe, and Cu are not available. The results revealed that cancer risks estimated are within the acceptable limit of Cd and Pb, but significantly greater than the cancer safe limit of (1×10^{-4}) for Cr in both adult and children as shown in Table 5. The highest Cr carcinogenic risks of 2.53×10^{-2} and 4.09×10^{-3} for children and adult, respectively were recorded in soil near the dumpsite, these values are alarming and constitute a significant cancer risk (Figures 4 and 5).

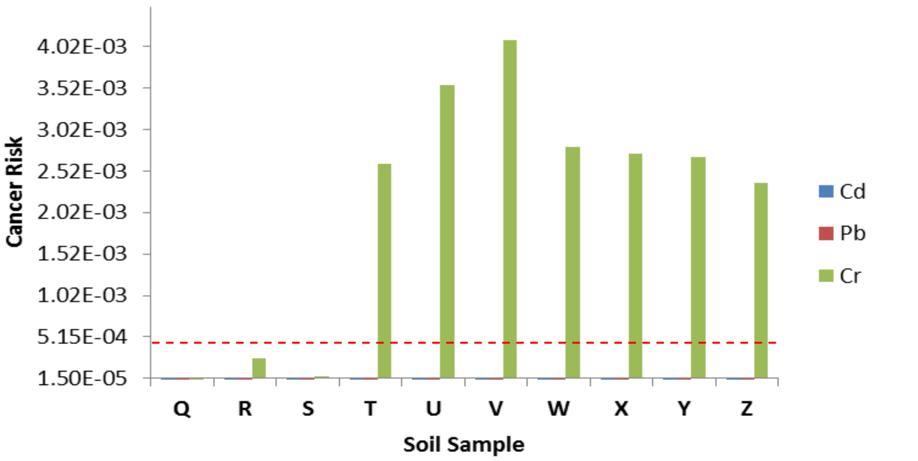

Figure 4. Adult Carcinogenic risk on exposure at 95th percentile to soil in Challawa Industrial Estate (Dotted line indicates maximum permissible cancer risk)

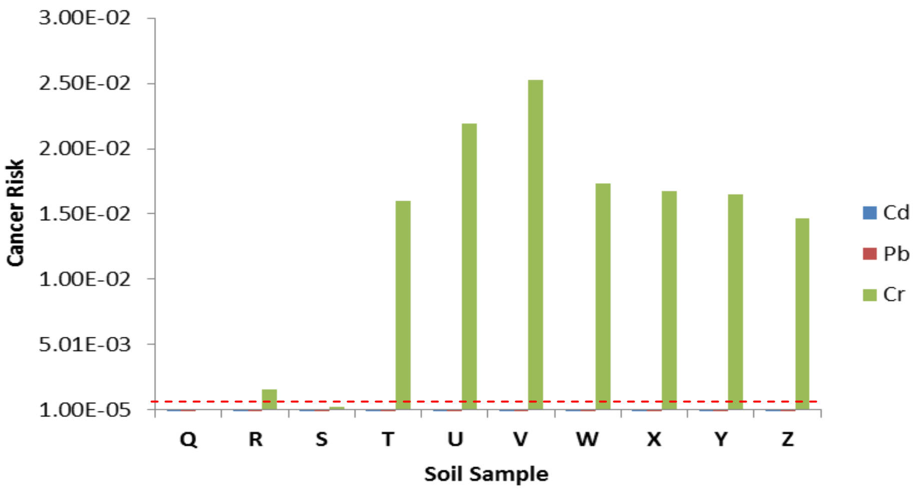

Figure 5. Children Carcinogenic risk on exposure at 95th percentile to soil in Challawa Industrial Estate (Dotted line indicates maximum permissible cancer risk)

Table 5. Adult and Children Exposure and Carcinogenic Risk Assessment from Soil in Challawa Industrial Estate, Kano

Adult Average Daily Exposure (mg/kg/day)					**Adult Carcinogenic Risk**		
Code	**Description**	**Cd**	**Pb**	**Cr**	**Cd**	**Pb**	**Cr**
Q	Karfi Town	ND	ND	2.7388	ND	ND	1.1229×10^{-5}
R	Farm away from Tanneries	ND	0.4306	63.4223	ND	3.6601×10^{-9}	2.6003×10^{-4}
S	Challawa Town	ND	ND	8.8701	ND	ND	3.6368×10^{-5}
T	Farm near dumpsite	ND	0.3886	633.2778	ND	3.3033×10^{-9}	2.5964×10^{-3}
U	Dumpsite of Tanneries	0.4096	4.7948	865.2932	1.5566×10^{-7}	4.0756×10^{-8}	3.5477×10^{-3}
V	10 m away from U	0.5567	1.9458	999.0018	2.1154×10^{-7}	1.6539×10^{-8}	4.0959×10^{-3}
W	10 m away from V	2.6127	7.8434	684.6868	9.9284×10^{-7}	6.6669×10^{-8}	2.8072×10^{-3}
X	Vicinity of Tannery	ND	2.2687	663.8848	ND	1.9284×10^{-8}	2.7219×10^{-3}
Y	5 m away from X	ND	0.8376	653.3814	ND	7.1200×10^{-9}	2.6789×10^{-3}
Z	10 m away from X	ND	0.2495	579.9362	ND	2.1204×10^{-9}	2.3777×10^{-3}
Children Average Daily Exposure (mg/kg/day)					**Children Carcinogenic Risk**		
Code	**Description**	**Cd**	**Pb**	**Cr**	**Cd**	**Pb**	**Cr**
Q	Karfi Town	ND	ND	16.9013	ND	ND	6.9295×10^{-5}
R	Farm away from Tanneries	ND	2.6575	391.3880	ND	2.2589×10^{-8}	1.6047×10^{-3}
S	Challawa Town	ND	ND	54.7389	ND	ND	2.2443×10^{-4}
T	Farm near dumpsite	ND	2.3983	3908.0465	ND	2.0385×10^{-8}	1.6023×10^{-2}
U	Dumpsite of Tanneries	2.5279	29.5895	5339.8464	9.6060×10^{-7}	2.5151×10^{-7}	2.1893×10^{-2}
V	10 m away from U	3.4354	12.0076	6164.9811	1.3054×10^{-6}	1.0206×10^{-7}	2.5276×10^{-2}
W	10 m away from V	16.1235	48.4029	4225.2988	6.1269×10^{-6}	4.1143×10^{-7}	1.7324×10^{-2}
X	Vicinity of Tannery	ND	14.0007	4096.9266	ND	1.1901×10^{-7}	1.6797×10^{-2}
Y	5 m away from X	ND	5.1692	4032.1084	ND	4.3939×10^{-8}	1.6531×10^{-2}
Z	10 m away from X	ND	1.5394	3578.8677	ND	1.3085×10^{-8}	1.4673×10^{-2}

Values reported at 95th Percentile

Soil samples of Karfi and Challawa towns did not appear to pose any cancer risk to both adult and children. However, farm near the dumpsite reveals cancer risk of 1.60×10^{-3} greater than the acceptable limit (Figure 5), indicating a significant carcinogenic threat to the population. There is about 86% cancer risk of children at a site near the dumpsite, while adult stood a chance of 14% cancer risk. Effort has been made by researchers to reduce Cr content of tannery sludge and waste due to fear of health threat, and the approach employed is mostly biological or physico-chemical technologies [49]. Using bioleaching technique as the most efficient method, most heavy metals have about 85% removal efficiency; however Cr is generally lower than 40% [50]. This shows the difficulty of Cr removal and handling from tannery wastes and soils.

4. Conclusion

The results of the exposure studies revealed that soil in Challawa Industrial Estate is polluted and the population are greatly exposed to the toxic heavy metals predominantly Cr. The carcinogenic and non-carcinogenic assessment shows health threat due to Cr, and Cd and Pb, respectively for both adult and children, and children only by ingestion at 95th percentile. High Cr in soil is of great concern due to its carcinogenic and allergenic properties. Other selected heavy metals (Cu, Zn, and Fe) do not appear to have any clear threat to the health of the inhabitants. It can be inferred from the results of this study that children are at obvious risk of health complications by ingesting the tannery contaminated soil. Children are more exposed to soil at playground, and consume more soil due to behavioral factors. Hence, the need to routinely examine the levels of the metals and to properly monitor the contaminated sites, especially with the higher tendency for cancer and non-cancer health complications reported in a farm near the dumpsite. It is further recommended that concerned authorities should educate and sensitize the local inhabitants on the possible health risks, and device a safe way for the proper disposal and management of the tannery waste.

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