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HUMAN HEALTH RISK ASSESSMENT DUE TO THE PRESENCE OF HEAVY METALSIN SOIL OF WASTE DISPOSAL SITE AT KHULNA IN BANGLADESH

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ABSTRACT

Waste disposal site produces leachate which contains extensive range of heavy metals that contaminate underlying soil and possess a potential human health risk. The present study aims to evaluate human health risk associated with heavy metals which contaminating the soil of a waste disposal site. To this attempts an open dumping site at old Rajbandh, Khulna, Bangladesh was selected. In this study, soil samples were collected from fifteen distinct locations of the selected waste disposal site. The values of hazard quotient (HQ) and hazard index (HI) exceed the allowable limit (=1) for Hg for child in both the CTE and RME condition indicating non-carcinogenic risks of child from heavy metal. In this study, the main contributing exposure pathway to non-carcinogenic risk for inhabitants was found as dermal contact pathway. The values of non-carcinogenic and carcinogenic risk were found higher for child than that of adult in both the CTE and RME condition meaning that child are facing higher harmful health risks than that of adult for all the exposure pathways. In this study, the variability and uncertainty of risk values was analysed using Monte Carlo Simulation (MCS). The MCS helps in reducing the range of uncertainties associated with the decision making for risk assessment.

1. INTRODUCTION

The term “landfill” is a unit, designed and operated for the disposal of municipal solid waste (MSW) to protect the environmental receptors such as human, water, air, soil, etc. from the contaminant presences in MSW stream (Rafizul *et al.,* 2012; Sanjida and Rafizul, 2018a). The generation of MSW in Khulna city, Bangladesh is estimated about 450 t/d in 2017 (Sanjida and Rafizul, 2017). In Asian countries, about 90% of MSW are dumped in open dumping condition. The dumping of MSW in open dump condition causes aesthetic and health problems (Pangkaj and Rafizul, 2018). The deposited MSW is decomposed slowly and generated huge amount of contaminated leachate with a variety of carcinogenic and non-carcinogenic chemicals which may spread into the surrounding water bodies and underlying soil layer (Adamcová *et al.,* 2016). The propagated leachate from landfill contaminates the underlying soil layer as well as surrounding water bodies (Lee and Jones-Lee, 1994). However, due to the generation of huge amount of MSW, most of the developing countries have dumped MSW into the open dumping sites which possess serious impacts to the surrounding environment (Fahmida and Rafizul, 2017).

The main emissions from waste disposal site are landfill gases (LFG) and contaminated leachate. The LFG not only spread mainly through the atmosphere, but also through soil, while the leachate spreads through surrounding water bodies (Fahmida and Rafizul, 2017; Pangkaj and Rafizul, 2017). In addition, to date, in the developing countries due to lack of proper design of waste disposal site, leachate is runoff into the surface bodies as well as infiltrated easily through the underlying soil layer and hence pollutant groundwater which is the most important concern of the human being (Sanjida and Rafizul, 2018b). In the literature, there are many studies on heavy metal in soil all over the world (Canbay, 2010). Moreover, numerous studies have focused only on the concentration, distribution and source identification of heavy metals in soil (Visvanathan *et al.,* 1999). To these attempts, it is essential to assess the value of potential human health risk of waste disposal site via soil, leachate, air, biota, sediments, surface water, groundwater etc.

This study mainly emphasized to assess the potential health risk of inhabitants in and around of the study site associated from soil from a selected waste disposal site. To assess the human health risk from contaminated soil; ingestion through mouth, dermal contact via skin and inhalation through nose were considered as exposure pathways according to USEPA (1989) guideline. Then chronic daily intake (CDI), hazard quotient (HQ) and hazard index (HI) via ingestion, dermal contact and inhalation pathway were calculated. To assess the potential human health risk, the inhabitants in the vicinity of the selected disposal site were separated as child and adult. The CDI were computed based on exposure models, exposure parameters for central tendency exposure (CTE) and reasonable maximum exposure (RME), toxicity parameters and risk models following USEPA (1989) guidelines. The various exposure parameters like average soil ingestion rate (IR), fraction ingested from contaminated source (FI), absorption factor (ABSs), skin surface area avialable for contact (SA), conversion factor (CF), solid material to skin adherance factor (AF), factor for solid materials matrix (SM), inhalation rate for receptor (IR_h), particales emition factor (PEF), Exposure time (ET), exposure frequency (EF), exposure

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duration (ED), body weight (BW), average time (AT) were considered in exposure models to evaluate the potential health risk of the inhabitants in the vicinity of the selected disposal site.

The assessment of health risk provides a strong and logical formula of quantitative (or semi-quantitative) sketches of health risk. It's very clear that this assessment technique is burdened with various uncertainties from origin. Therefore, in this analysis the results may contain both the number and the measurement of uncertainty. The innovative technique of Monte Carlo simulation (MCS) provides an idea about the analysis of sensitivity of results in compare to its original values. In this study, to check variability and uncertainty of exposure parameters and risk values, MCS through @RISK was used. Therefore, the findings of this study will may help to other researchers about the type, degree, scope and sources of heavy metal pollution from waste disposal site and providing a systematic basis for further risk management.

2. MATERIALS AND METHOD

2.1 Study Area

Khulna is the third largest metropolitan city of Bangladesh, stands on the banks of the Rupsha and the Bhairab rivers. Geographically, Khulna lies between 22°47′16′′to 22°52′0′′north latitude and 89°31′36′′ to 89°34′35′′ east longitude. At present, Khulna city has a population of about 1.5 million with an area of 47 square kilometres and 31 Wards. The MSW of Khulna city is dumped in the disposal site at Rajbandh, Khulna. Therefore, the open dumping site at old Rajbandh was selected as a case study to assess soil quality and human health risk and hence discussed in the following articles.

2.2 Sample Collection

In this study, fifteen soil samples were collected from different selected locations of waste disposal site as shown in Figure 1**.** In this study, GPS device has been used to record the latitude and departure of each sampling points. The soil samples were collected at a depth of around 0-30 cm from the existing ground surface within the disposal site.

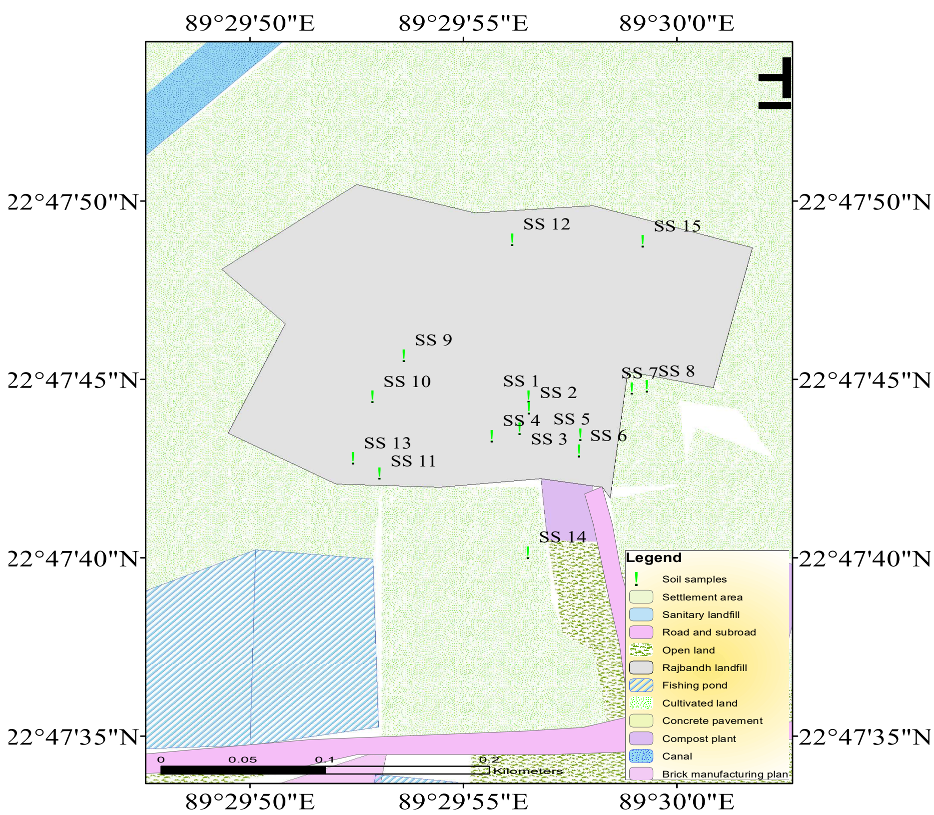

Figure 1: Map showing the soil sampling locations of waste disposal site.

2.3 Laboratory Investigations

In this study, acid digestion procedure has been performed on soil samples to convert into liquid for measuring the concentrations of heavy metals in soil. To these attempts, at first 10 g of each soil sample was taken into a 100 mL conical flask washed by deionized water. Then 6 mL of solution prepared with $HNO_3/HClO_4$ acid and deionized water at a ratio of 2:1 was added and left it for overnight. Each sample was heated at a temperature of 150°C for about 90 minutes. Later on, the samples were heated at a temperature of 230°C for 30 minutes. Subsequently, HCl solution prepared with HCl and deionized water at a ratio of 1:1 was also added to the digested sample and re-digested again for another 30 minutes. Then the digested sample was washed into 100 mL volumetric flask and obtained mixture was cooled down to room temperature. Then the concentration of heavy metals such as Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb) and Zinc (Zn) of digested soil samples were measured in the laboratory with the help of Atomic Adsorption Spectrophotometer (AAS).

2.4 Risk Assessment Methods

The human health risk assessment comprises of problem identification (contaminated site), exposure assessment (exposure pathways) toxicity assessment (reference doses, slope factor) and risk assessment (cancer and non-cancer risks) and hence discussed in the following articles.

Table 1: Values of exposure parameters for exposure assessment used in this study

Exposure pathway	Variable	Ault		Child		Unit	References
		CTE value	RME value	CTE value	RME value		
Incidental soil ingestion	IR	50	100	100	200	mg soil/day	USEPA Handbook 2001
	ABSs	1	1	1	1	unit-less	
	CF	1.00E-6	1.00E-6	1.00E-6	1.00E-6	kg/mg	USEPA Handbook 1998
	FI	0.5	1	0.5	1	unit-less	USEPA Handbook 1997
	EF	200	225	200	225	days/year	USEPA Handbook 1993a
	ED	25	25	5	5	years	
	BW	70	70	13.2	13.2	kg	
	AT	365*ED (non-carcinogenic), 365*70 (carcinogenic)				days	
Soil-dermal contact	SA	3300	3300	2000	2000	cm^2/event	USEPA Handbook 2001
	AF	0.1	0.2	0.1	0.2	mg/cm^2	USEPA Handbook 1998
	ABSs	1	1	1	1	unit-less	
	SM	0.15	0.15	0.15	0.15	unit-less	USEPA Handbook 2011
	EF	200	225	77	100	days/year	USEPA Handbook 2001
	CF	1.00E-6	1.00E-6	1.00E-6	1.00E-6	kg/mg	
	ED	25	25	5	5	years	USEPA Handbook 1993a
	BW	70	70	13.2	13.2	kg	USEPA Handbook 2001
Inhalation of dust particulates	IR_A	1.3	3.3	1.9	3.3	m^3/hr	USEPA Handbook 1997
	ET	8	8	8	8	hours/day	USEPA Handbook 2001
	EF	200	225	200	225	days/day	USEPA Handbook 1997
	ED	25	25	5	5	years	USEPA Handbook 2001
	PEF	1.36E+9	1.36E+9	1.36E+9	1.36E+9	m^3/kg	
	BW	70	70	70	70	kg	USEPA Handbook 1993b
	AT	365*ED (non-carcinogenic), 365*70 (carcinogenic)				days	USEPA Handbook 2001

2.4.1 Exposure Assessment

Exposure assessment for human health risk of waste disposal sites has become progressively more important due to the emission of toxicological heavy metals from contaminated soil. According to US.EPA (1989) guidelines human can be contaminated through three pathways including direct ingestion, dermal contact and inhalation through nose from contaminated soil. In this study, all three pathways were considered for soil samples. In addition, chronic daily intake (CDI) (mg/kg/day) in case of non-carcinogen risk for ingestion, dermal and inhalation of soil were computed using Equation 1, 2 and 3, respectively, was taken from exhibit 6-18 in the Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A): Interim Final (RAGS) (US.EPA, 1989).

In this study, the values of individual factors (ingestion rate, body weight, body surface area, etc.), or parameters (time weighted factors such as contact frequency, contact duration or lifetime exposure) for different groups of inhabitants with various exposure pathways for central tendency exposure (CTE) and resonable maximum exposure (RME) were followed from RAGS (US.EPA, 1989).

$$CDI_{ing} = \frac{(C_S \times IR \times CF \times FI \times ABS_S \times EF \times ED)}{(BW \times AT)} \quad (1)$$

$$CDI_{derm} = \frac{(C_S \times SA \times CF \times AF \times ABS_S \times SM \times EF \times ED)}{(BW \times AT)} \quad (2)$$

$$CDI_{inha} = \frac{(C_S \times IR_h \times ET \times EF \times ED)}{(PEF \times BW \times AT)} \quad (3)$$

Where, $CDI_{ing/der/inh}$ = chronic dialy intake through ingestion/dermal contact/inhalation with heavy metals in soil (mg/kg-day), Cs = heavy metal concentration in soil (mg/kg). In the above exposure models, the exposure parameters stands the meaning of CF = conversion factor (10^{-6} kg/mg), FI= fraction ingested from contaminated source(unitless), ABSs = absorption factor (%), SA= skin surface area avialable for contact (cm^2), CF= conversion factor (10^{-6} kg/mg), AF= solid material to skin adherance factor (mg/cm^2), SM = factor for solid materials matrix (%), IR_h = inhalation rate for receptor (m^3/hrs), PEF = particales emition factor (m^3/kg), ET= Exposure time (hours/event), EF = exposure frequency (days/year), ED = exposure duration (years), BW= body weight (kg) and AT = averaging time (period over which exposure is averaged-days). AT = ED×365 days/year, for non-carcinogens effects of human exposure and LT×365 days/year for carcinogens effects of human exposure, considering an average lifetime, LT of 70 years.

2.4.2 Toxicity Assessment

The risk is divided into two parts from toxicity point of view: non-cancer risk and cancer risk. The chemical with high enough doses can cause non-cancer health effects. However, when the dose is sufficiently low, typically no adverse effect is observed. The reference dose (RfD) and carcinogenic slope factor (CSF) are considered for non-carcinogenic and carcinogenic risks, respectively, and were followed from RAGS (US.EPA, 1989). Therefore, the carcinogen and non-carcinogen thresholds are assigned from the historical database and numerous experiments. According to RAGS (USEPA, 1989), risk models (Eq. 4) for evaluating non-cancer risk of soil was considered.Potential non-carcinogenic risks were assessed from each exposure pathway with the reference dose (RfD) (Table 2) in order to produce the hazard quotient (HQ), defined as follows:

$$\mathrm{HQ}_{\mathrm{ing/derm/inh}} = \frac{\mathrm{CDI}_{\mathrm{ing/derm/inh}}}{\mathrm{RfD}_{\mathrm{ing/derm/inh}}} \quad (4)$$

Where $HQ_{ing/derm/inh}$ is hazard quotient via ingestion, dermal contact and inhalation (unitless) and $RfD_{ing/derm/inh}$ is oral/dermal/inhalation reference dose (mg/kg-day). The RfD_{ing}, RfD_{derm} and RfD_{inh} values were obtained from the literature elsewhere (Li and Zhang, 2010; USEPA, 1989).

Table 2: Dermal permeability constant and RfD values for non-carcinogenic risk of different heavy metals

Chemical Name	RfD_{ing} (mg/kg-day)	RfD_{derm} (mg/kg-day)	RfD_{inh} (mg/kg-day)	References
Cr	3.00E-03	6.00E-05	2.86E-05	Li and Zhang, 2010; USEPA, 1989;
Zn	3.00E-01	6.00E-02	3.00E-01	
Cd	1.00E-03	1.00E-05	5.70E-05	
Ni	2.00E-02	5.40E-03	2.06E-02	
Cu	4.00E-02	1.20E-02	4.02E-02	
Pb	1.40E-03	5.25E-05	3.52E-03	
As	3.00E-04	1.23E-04	3.00E-04	
Hg	3.00E-04	3.00E-05	8.57E-05	
Co	2.00E-02	1.60E-02	5.71E-06	
Mn	4.60E-02	1.84E-03	1.43E-05	
Fe	9.00E-03	7.00E-01	----	

2.4.3 Health Risk Assessment

In the study, the potential health risk of inhabitants in the vicinity of the selected waste disposal site were assessed based on non-carcinogenic and carcinogenic risk and hence discussed in the following articles.

2.4.3.1 Non-carcinogenic Risk

The HQ is a numeric estimation of the toxicity potential of a single heavy metal within a single route of exposure pathway. When HQ ≤ 1it indicates no adverse health effects and HQ >1 indicates likely adverse health effects. To evaluate overall potential for non-carcinogenic effects from more than one heavy metal, the calculated HQs for each heavy metal are integrated and expressed as a hazard index (HI) by the following Equation 5 (USEPA, 1989)

$$HI = \sum_{i=1}^{n} HQ_i = HQ_{ingestion} + HQ_{dermal} + HQ_{inhalation} \quad (5)$$

Where HI is hazard index via ingestion, dermal or inhalation (unitless). If the value of HI < 1, it is believed that there is no significant risk of non-carcinogenic effects. If HI > 1, it means there is a great chance of non-carcinogenic effects, and the probability increasing with the increasing value of HI (Song *et al.,* 2012). In this study, HI is used to assess human health risk of heavy metal exposure to selected disposal site.

2.4.3.2 Carcinogenic Risk

In case of carcinogenic risk, the values are computed as the incremental probability of an individual over a lifetime. Risk is a function of consequence and likelihood. To calculate carcinogenic risk the following equation 6 was used.

$$Carcinogenic\ Risk\ Model = CDI \times CSF \quad (6)$$

Where, CDI is chronic daily intake and CSF is the carcinogenic slope factor. In addition, Risk is a unit less probability of an individual developing carcinogenic over a lifetime.

Table 3: CSF for carcigones risk of different heavy metals

Chemical Name	CSF_{ing} (mg/kg-day)$^{-1}$	CSF_{der} (mg/kg-day)$^{-1}$	CSF_{inha} (mg/kg-day)$^{-1}$	References
Cr	5.00E-01	--	4.10E+01	Li and Zhang, 2010; USEPA, 1989
Zn	--	--	--	
Cd	--	--	6.30E+00	
Ni	--	--	--	
Cu	--	--	--	
Pb	8.50E-03		4.20E-02	
As	1.50E+00	1.50E+00	1.50E+01	
Hg	--	--	--	
Co	--	--	9.80E+00	
Mn	--	--	--	

The total excess lifetime carcinogenic risk or total cancer risk (TCR) is computed from the averagecontribution of each heavy metals for all the selected exposure pathways using following equation 7.

$$\text{Total carcinogenic risk} = Risk_{ingestion} + Risk_{dermal} + Risk_{inhalation} \quad (7)$$

In this study for estimating carcinogenic risk, the heavy metals of Pb, Cd, As, Hg and Co with CSF were considered. According to USEPA (1989) guideline the safe limit for carcinogenic risk is $1x10^{-6}$ and unacceptable limit for carcinogenic risk is $1x10^{-4}$.

2.5 Uncertainty Analysis

For assessing human health risk using exposure and risk models considering of variability and uncertainty is very important parameters (Kilic and Aral, 2008; US.EPA, 1989).The basic aim of a MCS is to characterize, quantitatively the uncertainty and variability in estimates of exposure or risk model. A MCS analyses the model through hundreds or thousands of times and each time the values were selected randomly. For exposure and risk models, distinguishing of variability and uncertainty is very important because it is directed affected the final outputs of risk values (Morgan and Henrion, 1990). In this study, the variability and uncertainty of risk values was analyzed using MCS through @RISK 7.5.× software with 10000 iterations.

3. RESULTS AND DISCUSSION

In this study, the exposure and health risks associated from waste disposal site were assessed according to US.EPA (1989) guideline and hence discussed in the following articles.

3.1 Concentration of Heavy Metals

The concentration of heavy metals in soil were measured in the laboratory and provided in Table 4. Table 4 shows that the mean concentration of the heavy metals in soil from the waste disposal site varies significantly and decreased in the order of Fe >Pb> Zn >Mn> Cu > Hg > Co > Ni > Cr > Cd > As. According to a study of Adamcova´ et al. (2016) the sequence of concentration of heavy metal was found in the order of Mn> Cr > Ni > Cu > Zn > Co >Pb> Cd > Hg. The mean concentration of Pb was found comparatively higher than the recommended maximum allowable values of different countries such as U.K., U.S.A. The value of SD for the heavy metal of Fe were found to be higher than that of other heavy metals, thus, indicating the highest dispersion range of Fe within the waste disposal site.

Table 4: Heavy metal concentration in soil of waste disposal site (mg/kg)

	Fe	Mn	Cr	Cu	Pb	Zn	Ni	Cd	As	Hg	Co
SS1	1731.06	85.51	5.84	43.11	226.76	131.46	3.55	4.62	3.18	104.72	5.58
SS2	1632.71	82.86	5.03	57.94	241.27	125.22	3.39	3.16	4.29	31.88	6.04
SS3	1655.37	89.01	5.24	63.95	246.66	134.85	5.05	3.49	4.62	22.52	6.50
SS4	1654.70	85.70	7.79	70.25	282.26	164.71	6.68	5.38	3.42	29.39	4.13
SS5	1714.69	92.68	7.56	82.33	282.15	179.89	5.73	4.29	4.18	6.51	3.66
SS6	1921.02	107.81	10.46	95.85	297.89	192.03	6.72	3.32	2.66	6.47	5.90
SS7	1857.64	106.89	7.21	7.21	354.53	191.54	6.54	3.20	4.23	9.82	8.79
SS8	1827.61	114.94	7.71	106.18	397.02	207.83	5.97	4.27	3.45	27.89	8.99
SS9	1469.80	113.10	5.49	100.41	356.18	192.56	6.13	5.27	3.53	15.01	7.52
SS10	1634.90	128.07	3.84	83.51	321.58	145.60	5.69	3.49	4.93	4.33	8.50
SS11	1370.56	107.55	4.28	75.22	278.11	136.95	8.25	5.41	4.01	2.87	10.02
SS12	1132.66	91.98	2.79	67.58	237.32	122.65	4.51	2.45	2.71	2.06	6.93
SS13	1097.87	75.80	2.34	59.39	225.60	112.03	5.34	2.61	3.09	3.16	7.75
SS14	1054.16	68.23	2.64	46.47	194.17	81.93	4.72	2.09	3.16	3.41	7.12
SS15	1059.43	61.48	2.11	36.21	173.91	75.63	5.84	2.03	2.94	4.76	7.06
Minimum	1054.16	61.48	2.11	7.21	173.91	75.63	3.39	2.03	2.66	2.06	3.66
Maximum	1921.02	128.07	10.46	106.18	397.02	207.83	8.25	5.41	4.93	104.72	10.02
Mean	1520.94	94.11	5.36	66.37	274.36	146.33	5.61	3.67	3.63	18.32	6.97
Median	1634.90	91.98	5.24	67.58	278.11	136.95	5.73	3.49	3.45	6.51	7.06
SD	293.99	17.99	2.36	25.47	60.82	39.40	1.22	1.11	0.68	25.27	1.70
SE	19.60	1.20	0.16	1.70	4.05	2.63	0.08	0.07	0.05	1.68	0.11
U.K.	--	--	50	100	100	300	50	3	--	--	--
U.S.A.	--	--	1000	100	200	300	500	0.7	--	--	40

3.2 Human Health Risk

In this study, the assessment of non-carcinogenic and carcinogenic risk of inhabitants (child and adult) in the vicinity of the selected waste disposal site was performed and hence discussed in the following articles.

3.2.1 Chronic Daily Intake

In the study, exposure assessment was carried out by measuring the chronic daily intake (CDI) of heavy metals through ingestion, dermal contact and inhalation by child and adult in the vicinity of the selected disposal site. The mean value of CDI through selected exposure pathways in this study for both the child and adult in CTE condition are presented in Table 5. Table 5 reveals the highest value of CDI for Pb among heavy metals considered in this study for child and adult. Moreover, the CDI of the investigated heavy metals for child in various pathways appeared to be higher than that of the adult, meaning that child have comparatively higher doses of these heavy metals in soil than that of adult. Based on the results of this study, the CDI for both the child and adult was found in the order of Pb> Zn >Mn> Cu > Hg > Co > Ni > Cr > Cd >As in soil for ingestion pathway in CTE condition. However, a study conducted by Ogunkunle *et al.* (2013) and stated that the order of CDI of Pb> Cu > Cd > Zn > Cr and Cu > Cd >Pb> Cr > Zn for child and adult, respectively, in case of ingestion pathway. The findings of this study are almost same with the results postulated by Ogunkunle *et al.* (2013). In addition, in this study, the same sequence of CDI was found for heavy metals in soil for all inhabitants in case of dermal and inhalation exposure pathways.

Table 5: Mean value (n=15) of CDI from heavy metals in soil of various exposure pathways in CTE condition

Heavy metals	Ingestion		Dermal		Inhalation	
	Child	Adult	Child	Adult	Child	Adult
Mn	1.95E-04	1.84E-05	3.01E-04	1.01E-04	2.30E-08	4.33E-09
Cr	1.11E-05	1.05E-06	1.71E-05	5.72E-06	1.31E-09	2.47E-10
Cu	1.38E-04	1.30E-05	2.12E-04	7.09E-05	1.62E-08	3.06E-09
Pb	5.69E-04	5.37E-05	8.78E-04	2.93E-04	6.70E-08	1.26E-08
Zn	3.04E-04	2.86E-05	4.68E-04	1.56E-04	3.57E-08	6.74E-09
Ni	1.16E-05	1.10E-06	1.79E-05	5.99E-06	1.37E-09	2.58E-10
Cd	7.62E-06	7.18E-07	1.17E-05	3.92E-06	8.96E-10	1.69E-10
As	7.53E-06	7.10E-07	1.16E-05	3.88E-06	8.86E-10	1.67E-10
Hg	3.80E-05	3.58E-06	5.86E-05	1.96E-05	4.47E-09	8.44E-10
Co	1.45E-05	1.10E-06	2.23E-05	7.44E-06	1.70E-09	3.21E-10

In addition, Figure 2 illustrates the value of CDI from heavy metals in soil evaluated under different exposure pathways such as ingestion, dermal contact and inhalation in CTE condition. The highest value of CDI (2.67×10^{-3}) was found for dermal exposure pathway, while, the values of CDIs for various exposure pathways were found in the order of dermal contact (1.42×10^{-3}) > ingestion (1.42×10^{-3}) > inhalation (1.81×10^{-7}) in soil samples (Figure 2). However, in a research of Bifeng *et al.* (2017) CDI was found in the order of dermal contact > ingestion > inhalation. The result of present study revealed that dermal contact was the main pathway for contributing human health risk in the study area.

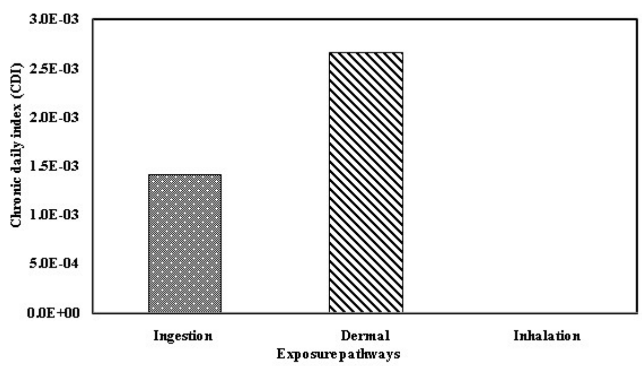

Figure 2: CDI of inhabitants through different pathways for soil in CTE condition.

In addition, from Table 5 the value of CDI for child was found comparatively higher than that of adult for every heavy metal considered in this study. This pointed out that child's of the studied disposal site were more exposed to heavy metals in comparison with the adult.

3.2.2 Non-carcinogenic Risk

The non-carcinogenic health risk is expressed in terms of hazard quotient (HQ) computed by dividing CDI of heavy metals by corresponding RfD's. The HI can be defined as the sum of more than one HQ for numerouselements and/or multiple exposure pathways. The results of non-carcinogenic risks of health in terms of HQ and HI are presented and hence discussed in the following articles.

3.2.2.1 Toxicity assessment

The non-carcinogenic health risk is expressed in terms of hazard quotient (HQ) and hazard index (HI). When the values of HQ and HI are found to be less than unity, there is no noticeable risk to the inhabitants, but if it exceeds unity, there may be concern of non-carcinogenic risks (USEPA, 1989). Table 6 represents the descriptive statistics of HQ in entire soil samples through exposure pathways considered in this study for both the child and adult in CTE condition. Characterization of the non-carcinogenic risk of child from individual heavy metals of Hg and Pb in soil portend higher toxic hazard of 1.95, 1.67, respectively, for dermal exposure (Table 6). A study of Bifeng *et al.* (2017) postulated that As with highest contribution of health risk for different age groups and ingestion was the main pathway for health risk, while, the other heavy metals and exposure pathways initiated no non-carcinogenic risks. Furthermore, in the present study, the mean values of HQs from heavy metals were almost all lower than the threshold value of unity for adult, indicating no risks from these heavy metals in soil for adult. However, the HQ for child was found higher in comparison to the corresponding results obtained for adult for the exposure pathways selected in this study. A study of Bifeng *et al.* (2017) showed that the decreasing order of HQ is child > adult. In the present study, the peak value of HQ was found for Pb in soil, while, minimal for Ni for child and adult in ingestion pathway. However, the sequence of HQ for child and adult was found in the order of Pb> Hg > As > Cd >Mn> Cr > Cu > Zn > Co > Ni for ingestion pathway; Hg >Pb> Cr > Cd >Mn> As > Cu > Zn > Ni > Co for dermal pathway as well as Mn> Co > Hg > Cr >Pb> As > Cd > Cu > Zn > Ni for inhalation pathway. A study conducted by Ogunkunle *et al.,* (2013) stated that the heavy metal Cd was main contributor to non-carcinogenic risk. In this study, the main contributing heavy metal was found Hg followed by Pb in soil for the dermal exposure pathway.

Table 6: Mean value (n=15) of HQ of heavy metals in entire soil for various exposure pathways in CTE condition

Heavy metals	Ingestion		Dermal		Inhalation	
	Child	Adult	Child	Adult	Child	Adult
Mn	4.25E-03	4.00E-04	1.64E-01	5.46E-02	1.61E-03	3.03E-04
Cr	3.70E-03	3.49E-04	2.86E-01	9.54E-02	4.57E-05	8.62E-06
Cu	3.44E-03	3.25E-04	1.77E-02	5.91E-03	4.03E-07	7.60E-08
Pb	1.63E-01	1.53E-02	1.67E+00	5.58E-01	1.90E-05	3.59E-06
Zn	1.01E-03	9.55E-05	7.81E-03	2.61E-03	1.19E-07	2.25E-08
Ni	5.82E-04	5.49E-05	3.32E-03	1.11E-03	6.65E-08	1.25E-08
Cd	7.62E-03	7.18E-04	2.35E-01	7.85E-02	8.96E-07	1.69E-07
As	2.51E-02	2.37E-03	9.44E-02	3.15E-02	2.95E-06	5.57E-07
Hg	1.27E-01	1.19E-02	1.95E+00	6.52E-01	5.22E-05	9.84E-06
Co	7.23E-04	6.82E-05	1.39E-03	4.65E-04	2.98E-04	5.62E-05

3.2.2.2 Hazard indices of heavy metals

The hazard index (HI) of heavy metals in soil of child and adult in CTE condition for exposure pathways are represented in Table 7. Result reveals that the value of HI in soil were found to be 4.44 and 1.48 for child and adult, respectively, which exceeds threshold value (=1), for the exposure pathway of dermal indicating that child are particularly more sensitive to the exposure to toxic metals in soil than that of adult in the vicinity of the selected disposal site. The values of Hg and Pb implied the more values of HI for child. A study of Bifeng *et al.* (2017) postulated that more value of HI was found due to highest value of as for all age groups. In addition, the heavy metals of Pb and Hg also had comparatively the large contributions to HI.

According to the study of Kamunda *et al.* (2016) in the inhabitants of both child and adult, the exposure pathway of dermal contributing the highest non-carcinogenic risk followed by the pathway of ingestion. In addition, inhalation was contributing the least non-carcinogenic risk. In the present study, dermal pathway was found to be main dominant pathway to pose non-carcinogenic health risk from soil to the inhabitants in the vicinity of waste disposal site. The present study is well agreed to the results published by Kamunda *et al.* (2016). Figure 3 represents the Hazard index value of selected heavy metals for child and adult in CTE condition. Figure 3 reveals that for both child and adult the heavy metal, Hg shows comparatively higher values of HI followed by the heavy metal, Pb than that of other heavy metals. It is a clear indication that for soil sample, Hg is main contributing heavy metal to non-carcinogenic health effect in the vicinity of selected waste disposal site. Figure 3 also reveals the value of HI for child than that of HI values of adult. According to Figure 5 it can be said that the child suffers more from non-carcinogenic health effect than the adult in the vicinity of selected waste disposal site.

The values of HI for the exposure pathway of dermal for entire soil samples of waste disposal site of Child at CTE and RME condition are shown in Figure 4. The soil of soil sampling point 1 (SS1) shows higher value of HI than that of other soil sampling points for both the CTE and RME condition. Figure 4 depicts RME showed comparatively higher values of HI than that of CTE in case of Child for soil exposure. Moreover, the same results of HI were also found for Adult.

Table 7: HI in CTE condition of selected exposure pathways of soil

Descriptive statistics		Minimum value		Maximum value		Mean value	
Inhabitants		Child	Adult	Child	Adult	Child	Adult
Hazard Index (HI)	Ingestion	1.46E-01	1.38E-02	1.03E+00	9.68E-02	3.36E-01	3.17E-02
	Dermal	1.71E+00	5.70E-01	1.49E+01	4.97E+00	4.44E+00	1.48E+00
	Inhalation	1.25E-03	2.35E-04	3.04E-03	5.73E-04	2.03E-03	3.82E-04

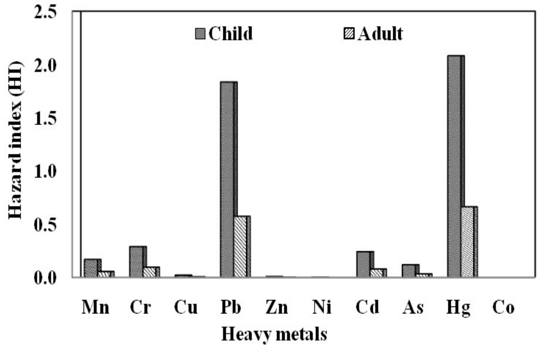

Figure 3: Hazard index (HI) of inhabitants for soil sample in CTE condition

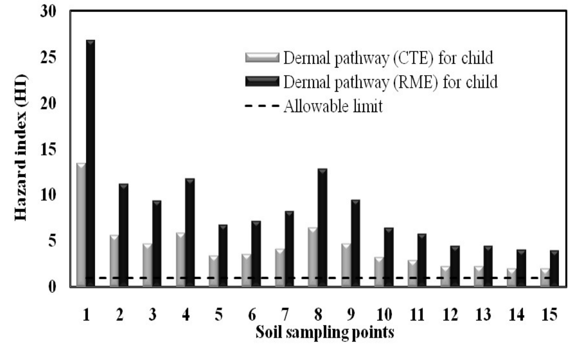

Figure 4: HI for dermal pathway in soil of Child in CTE and RME condition

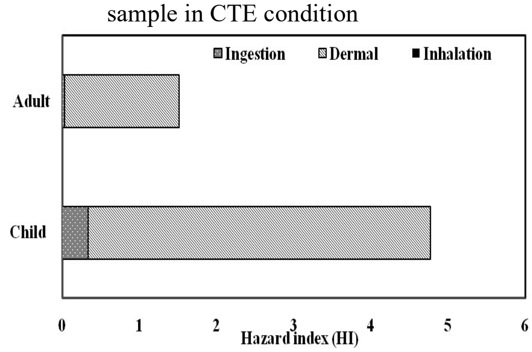

Figure 5: Risk summary results of inhabitants for soil in CTE condition

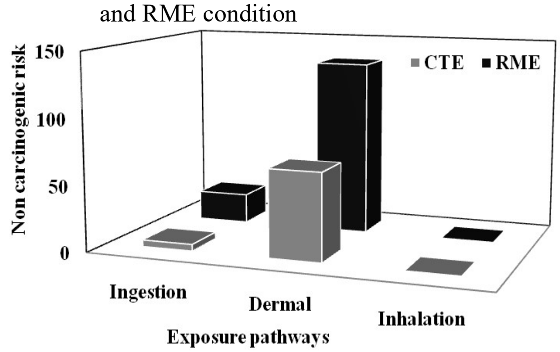

Figure 6: Vertical bar chart illustration of risk summary results for child in CTE and RME condition

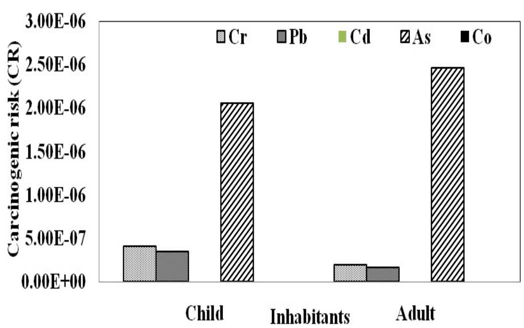

Figure 7: Carcinogenic risk from heavy metals in soil for inhabitants from different exposure pathways in CTE condition.

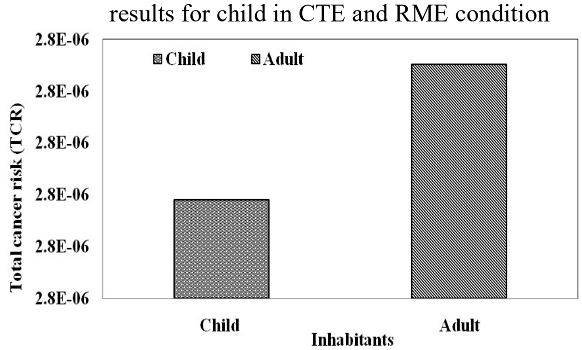

Figure 8: Total carcinogenic risks (TCRs) for different inhabitants under different exposure in CTE condition

The variation of HI for child and adult for entire soil in CTE condition for various exposure pathways is shown in Figure 5. Figure 5 depicts that the exposure pathway of dermal was the main dominant pathway for contributing non-carcinogenic risk for both the child and adult. Moreover, from Figure 5 it was clear that the HI value for child was comparatively higher than that of adult for all exposure pathways considered in this study. It indicated that the child was more vulnerable to health risk than that of adult. The HI caused by the dermal of heavy metals for child was significantly higher than those for adult. The risk from dermal was found to be 13 times higher than those of the pathway of ingestion (Figure 5).

3.2.2.3 Summary of non-carcinogenic risk

Figure 6 represents the values of non-carcinogenic risk in terms of HI of child with CTE and RME condition for different exposure pathways in soil. Figure 6 reveals that the exposure pathway, dermal contact in both the case of CTE and RME condition showed comparatively higher contribution for non-carcinogenic risk of inhabitants than that of other exposure pathways. A study conducted by Hung *et al.* (2010) and postulated the dermal pathway has contributed the highest non-carcinogenic risk of heavy metals in soil followed by ingestion pathway. In the present study, the exposure pathway, dermal for entire soil samples was found as main contributing pathway for non-carcinogenic risk. The findings of this study are well agreed with the results published by Hung *et al.* (2010).

3.2.3 Carcinogenic risk

According to USEPA (1989) guidelines some heavy metals contributed carcinogenic risk (CR) for inhabitants of nearby a contaminated site. In this study, the heavy metals of Pb, Cd, As, Hg and Co were considered for carcinogenic risk according to USEPA (1989) guidelines for the inhabitants in the vicinity of the selected waste disposal site.

Figure 7 illustrates the carcinogenic risk (CR) from heavy metals in soil for child and adult from different exposure pathways in CTE condition. Figure 7 reveals that As (2.05×10^{-6}) was the main contributor to carcinogenic risk followed by Cr (4.01×10^{-7}), Pb (3.36×10^{-7}), Co (1.19×10^{-9}) and Cd (4.03×10^{-10}) in soil for CR of child in CTE condition. In addition, the CR of As (2.46×10^{-6}) was the main contributor followed by Cr (1.91×10^{-7}), Pb (1.63×10^{-7}), Co (1.12×10^{-9}) and Cd (3.08×10^{-10}) in soil of adult in CTE condition in the vicinity of the selected disposal site. Here, it was observed that the CR was higher for child than that of adult from heavy metal in soil. A study conducted by Bifeng *et al.* (2017) and stated CR was comparatively maximum for As in soil, followed by those of Cd and Pb. Based on the findings of the present study, it can be said that the carcinogenic risk was higher for child than that of adult from heavy metal in soil of the selected disposal site.

The total carcinogenic risks (TCRs) in entire soil samples in CTE condition for different inhabitants are presented in Figure 8. The TCR was higher (2.80×10^{-6}) for child than that of adult (5.63×10^{-7}) from soil. A study conducted by Bifeng et al. (2017) and postulated that TCR for child was the highest (5.24×10^{-5}) followed by those of adult (2.65×10^{-5}). Based on the results of different exposure pathways, the order of different exposure pathways were ingestion > dermal contact > inhalation. Here, it can be concluded that the results of the present study is agreed well with the findings published by Bifeng *et al.* (2017).

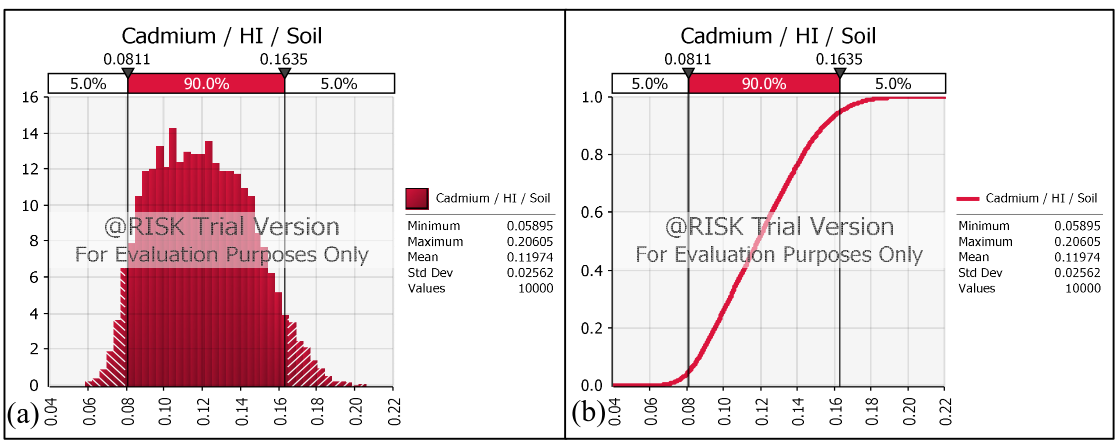

Figure 9: Normal distribution of HI of Cadmium in soil for Adult as (a) Bell-shaped curve represents the PDF and (b) S-shaped curve represents the CDF.

3.3 Uncertainty Analysis

The results of HI for Cd in soil in CTE condition is provided in Figure 10 in a form of probability distribution for a given risk. This is more useful technique for presenting results of uncertainty and variability analysis through MCS. From Figure 9(a) and Figure 9(b) it was observed that about 90% value of HI lies between the ranges of 0.0811 to 0.1635. It is indicating that on account the uncertainties of HI values, the true HI value will lies between the given ranges of 0.0811 to 0.1635.

4. CONCLUSIONS

Result reveals that the values of hazard quotient and hazard index exceed the threshold value (=1) for Hg in soil for both the central tendency and reasonable maximum exposure condition. Moreover, Hg was contributing more non-carcinogenic risk of the inhabitants than that of other heavy metals in soil. In addition, the carcinogenic risk of child and adult were found less than the unacceptable limit of 1×10^{-4} but higher than the safe limit of $1x10^{-6}$ from soil of waste disposal site. The exposure pathway of dermal contact was mainly contributing non-carcinogenic risk from heavy metals in soil for inhabitants in the vicinity of the selected waste disposal site in both the central tendency and reasonable maximum exposure condition. Moreover, the non-carcinogenic and carcinogenic risks were found higher for reasonable maximum exposure condition than that of central tendency exposure condition. The values of non-carcinogenic and carcinogenic risk were found higher for child than that of adult for all the exposure pathways and exposure media indicating child's suffered more health risk than that of adult in central tendency and reasonable maximum exposure condition. The MCS reduces the ranges of uncertainties of risk values and exposure parameters.

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