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RISK-BASED ASSESSMENT OF HEAVY METAL CONTAMINATED SITE AT KHULNA REGION OF BANGLADESH

Pangkaj, K. M.[1] and Rafizul, I.M.[2]

[1] *Post graduate student, Khulna University of Engineering & Technology, Bangladesh,*
E-mail: pangkaj1001058@gmail.com
[2] *Associate Professor, Khulna University of Engineering & Technology, Bangladesh,*
E-mail: imrafizul@yahoo.com

ABSTRACT

Waste disposal site produces leachate which contaminates underlying soil and possesses public health and environmental risk. The present study aimed to evaluate health and environmental risk associated with heavy metals release from soil and leachate of waste disposal site. To these attempts, fifteen soil and leachate samples were collected from distinct locations in and around the waste disposal site at Rajbandh, Khulna, Bangladesh. In the laboratory, concentration of heavy metals of As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb and Zn in soil and leachate samples were measured according to standard test methods. To evaluate health risk from soil exposure pathways of ingestion, dermal and inhalation while ingestion and dermal for leachate were considered according to US.EPA guideline (1989). The chronic daily index (CDI), hazard quotient (HQ) and hazard index (HI) were evaluated. Result reveals that the dermal and ingestion were more effective for contributing health risk for inhabitants for soil and leachate, respectively. Results also indicated that child's were more vulnerable than that of adults. Reasonable Maximum Exposure (RME) showed comparatively more risk values than that of Central Tendency Exposure (CTE). Results of Enrichment Factor (EF) for Pb, Zn, Cd, As and Hg indicated that soil was extremely severe enriched. In addition, Potential Ecological Risk Index (PERI) for entire soil samples indicated that the soil was extremely strong ecological risk of the disposal site. In this study, to check the distribution of CDI, HQ and HI in risk model, ArcGIS was performed. For uncertainty analysis of parameters in risk models and risk values, Monte Carlo Simulation (MCS) was performed. Finally, it can be concluded that this study will help in making precise management strategies to avoid or decline of heavy-metal contamination as well as finally environmental and health risk of inhabitants in and around of disposal site.

Keywords: *Disposal site, hazard quotient, hazard index, health risk, enrichment factor, potential ecological risk index, Monte Carlo simulation, spatial distribution.*

1. INTRODUCTION

Contamination problem have been started in the 19th century with the production of dyes and other organic chemicals developed from coal tar industry in Germany. During the 20th century the contamination problem increased drastically with production of steel and iron, lead batteries, petroleum refining and other industrial practices. The period of World War II leads in massive production of wartime products which needed a use of chlorinated solvents, polymers, plastics, paints, metal finishing and wood preservatives. Very little was known about the environmental impact of many of these chemicals wastes until much later (Bedient, 1997). Nowadays around 100000 of chemicals are registered at EU market and more than 1000 of new chemicals are introduced annually. Municipals solid waste (MSW) generation in Khulna city, Bangladesh is estimated to roughly 450 t/d in 2016 (Alam and Hassan, 2013). These MSW are dumped in waste disposals site as the cheapest means of MSW management system. The waste dumped in this process causes various aesthetic and public health problems and also attracts insects, rodents and various disease vectors (Aderemi et al., 2011; Sizirici and Tansel, 2010). The MSW in dumping process, undergoes slow, anaerobic decomposition over a period of 30-50 years and generate substantial amount of leachate with decomposition products, heavy metals and a variety of carcinogens and non-carcinogens chemicals which may seep from the disposal site into underground aquifers and thus polluting water resources (Shenbagarani, 2013). There are also possibilities of surface runoff and/or overflow of leachate to the surrounding lands, ponds, canals and rivers causing surface water quality deterioration (Lee and Jones-Lee, 1994). However, due to the generating huge amount of MSW, most of the developing countries have dumped MSW in the open disposal sites which possess serious impacts to the surrounding area. In addition, contamination of underlying groundwater is one of the major problems regarding open dumping sites (Butt and Oduyemi, 2003; Butt et al., 2008). Evaluating the environmental impact of contaminants in soils must start with a robust determination of their concentration and spatial distribution. GIS based spatial distribution map is generally used to display the distribution of metal contamination has been widely used to assist the interpretation of environmental data and to distinguish between natural and anthropogenic inputs (Manta, 2002).

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 the groundwater which is the most important concern of the human being. To these attempts, it is essential to examine the contamination level of waste disposal site via (soil, leachate, surface and groundwater). The main focused of this study, to evaluate human health and environmental risk from soil and leachate from a selected waste disposal site. For the fulfilment of desired objectives, fifteen soil and leachate samples were collected from distinct locations within a waste disposal site at Rajbandh, Khulna, Bangladesh. The latitude and departure of all the sampling locations was recorded using GPS device. To evaluate health risk assessment from contaminated soil; ingestion, dermal and inhalation pathway, while, for leachate, ingestion and dermal contact were considered according to US.EPA guideline (1989). Then chronic daily index (CDI), Hazard Quotient (HQ) and Hazard Index (HI) via ingestion, dermal contact and inhalation route were evaluated. Health risk assessment procedure provides a clear and systematic form of quantitative (or semi-quantitative) description of health and environmental risk. It is well known that this approach is burdened with various types of uncertainties of different origin and nature. Therefore, the results of risk assessments should always contain both the "number" and the "measure of uncertainty". The problem is that even if one does attempt to take account of the uncertainty, one does not know a priori what is the probability of getting a given risk value within the specified range of uncertainty. A promising tool for the assessment of risk which provides a means of describing the sensitivity with respect to different exposure factors and evaluating different intervention scenarios is the technique of Monte Carlo simulation (MCS). In this study, to check uncertainty of exposure parameters and risk values, MCS was used. In addition, ordinary kriging (OK) through ArcGIS was performed to distribute CDI, HQ and HI spatially. Here, it can be noted that this study will help in making precise management strategies to avoid or decline of heavy-metal contamination as well as finally environmental and health risk of inhabitants in and around of the selected waste disposal site.

2. METHODOLOGY

The materials and adopted methods of this study are described in the following articles.

2.1 Sampling of Soil and Leachate

Before collecting leachate samples the bottle was washed by distilled water several times. Then the bottles were air or sun dried. Then 2-3 mL a solution was used as preservative. The preservative was prepared by mixing concentrated nitric acid and distilled water at a ratio of 1:1. Then the bottle was kept for 24 hours at room temperature. After that the bottles were prepared for collecting water sample. In this study, fifteen soil and fifteen leachate samples were collected from distinct sampling locations in and around waste disposal site shown in Figure 1. The latitude and departure of each sampling point was recorded GPS device.

2.2 Laboratory Investigations

The collected soil and leachate samples were brought to the laboratory to measure the concentration of heavy metals of Al, Fe, Mn, Cr, Cu, Pb, Zn, Ni, Cd, As, Co and Hg. In order to measure concentration in soil samples it was digested with the help of HNO_3 and H_2O_2. After performing the digestion procedure for soil samples, heavy metals of soil and leachate samples were determined using atomic absorption spectrophotometer (AAS) and the amount of each heavy metal was deduced from calibration graph.

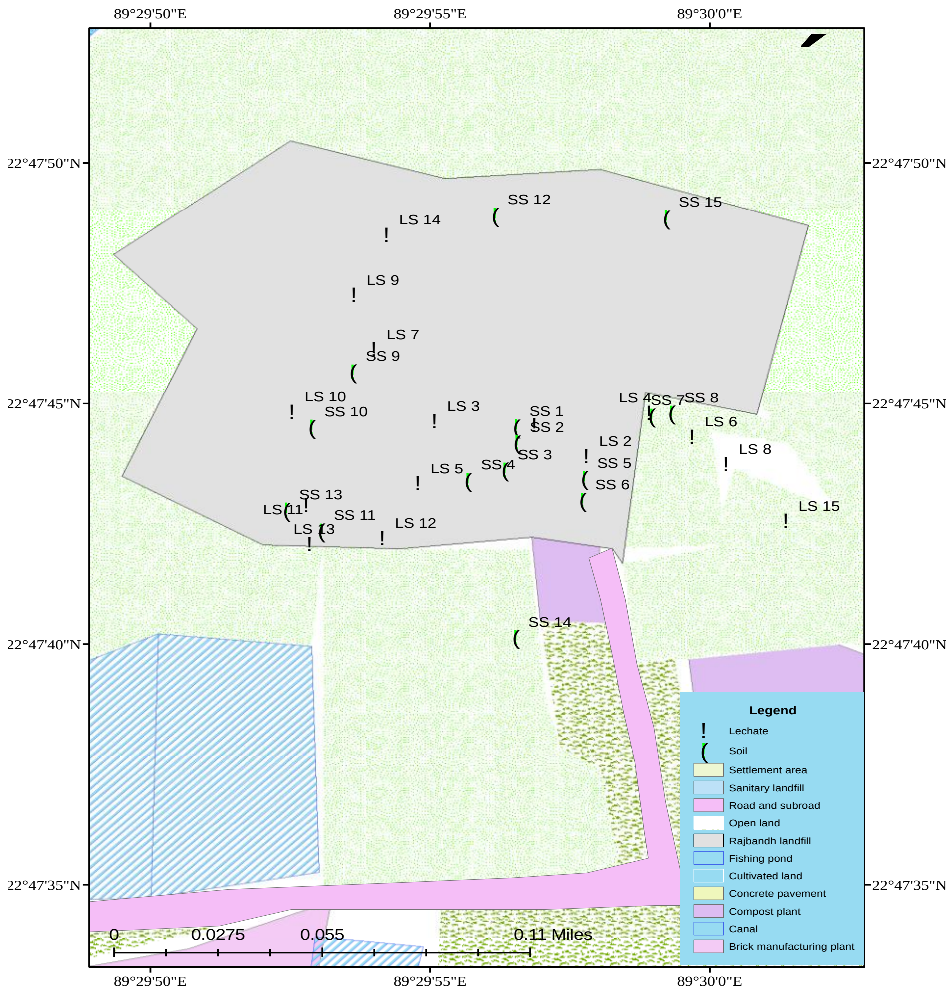

Figure 1: Soil and leachate sampling locations of waste disposal site at Rajbandh, Khulna.

3. RISK ASSESSMENT METHODOLOGY

The health and environmental risks associated from heavy metal contaminated site are presented and hence discussed in the following articles.

3.1 Health Risk Assessment

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

3.1.1 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 and leachate. According to US.EPA (1989) guidelines human can be contaminated through three pathways including direct ingestion, dermal contact and inhalation through nose. Among them dermal contact and ingestion are vital in health risk for leachate (US.EPA, 1989; US.EPA, 2004; Wu et al., 2009). In this study, all three pathways were considered for soil samples and ingestion and dermal contact were considered for leachate. In addition, chronic daily intake (CDI) (mg/kg/day) in case of non-carcinogen risk for ingestion, dermal and inhalation for 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 tendanct exposure (CTE) and resonable maximum exposure (RME) were followed from RAGS (US.EPA, 1989).

$$CDI_{ing} = \frac{C_s * IR * CF * FI * ABS * EF * ED}{BW * AT} \quad (1)$$

$$CDI_{der} = \frac{C_S * SA * CF * AF * ABS * SM * EF * ED}{BW * AT} \quad (2)$$

$$CDI_{inh} = \frac{C_S * IR * ET * EF * ED}{PEF * BW * AT} \quad (3)$$

Where, CDIing/der/inh = chronic dialy intake through ingestion/dermal contact/inhalation with heavy metals in soil, Cs = heavy metal concentration in soil.

In addition, according to RAGS (US.EPA, 1989), the following exposure models (Equation 4 for ingestion and Equation 5 for dermal) for leachate for the evaluation of non-carcinogen risk were considered.

$$CDI_{ing} = \frac{C_W * CR * ABS_S * ET * EF * ED}{BW * AT} \quad (4)$$

$$CDI_{derm} = \frac{C_W * SA * CF * PC * ABS_S * ET * EF * ED}{BW * AT} \quad (5)$$

Where CDIing/der = chronic dialy intake through ingestion/dermal contact with heavy metal concentration (Cw) in leachate.

In the above exposure models, the exposure paramers stands the meaning of IR= average soil ingestion rate (mg soil/day), 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), AF= solid material to skin adherance factor (mg/cm^2), SM= factor for solid materials matrix (%), PEF=particales emition factor (m3/kg), ET= exposure time (hrs/event), EF=exposure frequency (days/year), ED=exposure duration (years), BW=body weight (kg), AT=averaging time (period over which exposure is averaged-days). AT=EDx365 days/year, for non-carcinogens effects of human exposure and LTx365 days/year for carcinogens effects of human exposure, considring an average lifetime, LT of 70 years.

3.1.2 Toxicity Assessment

The risk is divided into two parts from toxicity point of view: cancer risk and non-cancer risk. Essentially all chemicals can cause non-cancer adverse health effects if given at a high enough doses. However, when the dose is sufficiently low, typically no adverse effect is observed. The reference dose (RfD) and potency factor (PF) are considered for non-cancer and cancer risks, respectively and were followed from RAGS (US.EPA, 1989). The first is a qualitative evaluation of the weight of evidence that chemical does or does not cause cancer in humans. Therefore the carcinogen and non-carcinogen thresholds are assigned from the historical database and numerous experiments.

3.1.3 Health Risk Assessment

According to RAGS (US.EPA, 1989), risk models (Equation 6) for evaluating non-cancer risk of soil and leachate were considered. Potential non-carcinogenic risks for exposure to contaminants were assessed by comparison of the calculated contaminant exposures from each exposure route with the reference dose (RfD) (Table 6) in order to produce the hazard quotient (HQ), defined as follows

$$HQ_{ing/derm/inh} = \frac{CDI_{ing/derm/inh}}{RfD_{ing/derm/inh}} \tag{6}$$

Where HQing/derm/inh is hazard quotient via ingestion, dermal contact and inhalation (unitless) and RfDing/derm/inh is oral/dermal/inhalation reference dose (mg/kg-day). The RfDing, RfDderm and RfDinh values were obtained from the literature elsewhere (Li and Zhang, 2010; US.EPA, 1989; Wu et al., 2009; Liang et al., 2011).

The HQ is a numeric estimate of the systemic toxicity potential posed by a single heavy metal within a single route of exposure. To evaluate the overall potential for non-carcinogenic effects posed by more than one heavy metal, the computed HQs for each heavy metal are integrated and expressed as a hazard index (HI) by Equation 7 (US.EPA, 1989)

$$HI_{ing/derm/inh} = \sum_{i=1}^{n} HQ_{ing/derm/inh} \tag{7}$$

Where HIing/derm/inh is hazard index via ingestion, dermal or inhalation (unitless).

3.2 Environmental Risk

3.2.1 Enrichment Factor

Enrichment factor (EF) is used to determine the level of contamination by anthropogenic actions based on heavy metal accumulation by soil (Sakan et al., 2009). The EF is calculated consuming the following Equation 8.

$$EF = \left(\frac{C_x}{C_{ref}}\right)_{sediment} \Big/ \left(\frac{C_x}{C_{ref}}\right)_{background} \tag{8}$$

Where, Cx is the concentration of element x, and Cref is the concentration of reference element in soil and the earth's crust, respectively (Kalender and Ucar, 2013). In the assessment of EF, Al was used as the reference heavy metal because this normalizing element assumed less contamination with respect to the other study heavy metals in soil of the selected disposal site. The interest of using Al content is its relationship to the abundance of clay and other aluminium silicates in the sediment. Al contents are influenced by natural sedimentation and the effects of enhanced erosion, but not by pollution (Li and Schoonmaker, 2003; Luoma and Rainbow, 2008). As, Al was selected as reference element hence EF of Al was found to be 1.

3.2.2 Potential Ecological Risk Index

The potential ecological risk factor (PERI) was used as an indicator to check the ecological risk in soil (Hakanson, 1980). This strategy for assessing natural hazard extensively considers the cooperative energy, concentration of heavy metals and biological affectability of those heavy metals (Nabholz, 1991; Singh et al., 2010; Douay et al., 2013). PERI is formed by three basic parts: contamination factor (CF), toxic-response factor (TR) and potential ecological risk factor (ER). In this study, the ER and PERI were calculated using the following Equation 9 and Equation 10, respectively.

$$\mathrm{ER} = \mathrm{TR} \times \mathrm{CF} \tag{9}$$

$$PERI = \sum ER \tag{10}$$

Where, CF of a particular heavy metal is the ratio of heavy metal concentration in soil and the background value of same metal, computed by Equation 11.

$$\mathrm{CF} = \frac{C_{\mathrm{Metal}}}{C_{\mathrm{Background}}} \tag{11}$$

4. RESULT AND DISCUSSION

In this study, the risk-based assessment were performed in terms of health and environmental risks for exposure media of soil and leachate and discussed in followings.

4.1 Health Risk

The health risk were assessed for different exposure pathways of dermal contact, ingestion and inhalation and discussed in followings.

4.1.1 Risk Assessment Observations for Soil

Non-carcinogenic health risk assessment for the selected heavy metals in soil of sampling point 1 (SS1) for children's and adults via the exposure routes of ingestion, dermal and inhalation is summarized in Table 3. Table 3 shows that the CDI for non-cancer risk for child via ingestion was maximum for Pb and sequence of CDI through ingestion was found to be Pb> Zn> Mn> Cu> Co> Cr> As> Ni> Cd. Moreover, for child via exposure route ingestion the HQ were found in the sequence of Pb > Hg > As > Cd > Mn > Cr > Cu >Zn> Co > Ni shown in Figure 2. Figure 2 indicated that Pb, Hg, As and Cd was the main contributor to non-carcinogenic risk for child, whereas, Zn, Ni and Co in soil was the least contributed for non-carcinogenic risk. Result reveals that exposure pathway of dermal for SS1 showed comparatively the higher values of HQ in soil for child in CTE condition than that of other exposure pathways (Figure 2). In addition, result reveals that Pb possess adverse health effect on child in both the CTE and RME condition for entire soil samples. In all soil samples, HI for Pb was found to be greater than 1 where the acceptable limit of HI is 1 for non-carcinogenic health effect. In addition, the HI for the exposure pathway of dermal for soil of child and at CTE and RME condition is shown in Figure 3. Figure 3 depicts RME showed comparatively the higher values of HI than that of CTE in case of child for soil exposures. Moreover, the same results were also found for adult.

The values of non-cancer risk with various exposure pathways for different environmental media are shown in Figure 4. Figure 4 reveals that the exposure pathway of dermal for entire soil (SS1 to SS15) contributed most of the non-cancer risk for child, In addition, the pathway of ingestion for entire leachate (LS1 to LS15) showed comparatively the higher contribution for non-cancer risk of child than that of dermal contact pathway (Figure 4).

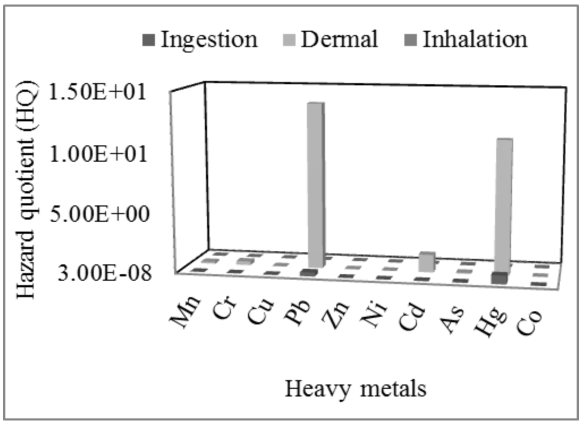

Figure 2: Hazard quotient (HQ) of child for soil of SS1 of CTE condition.

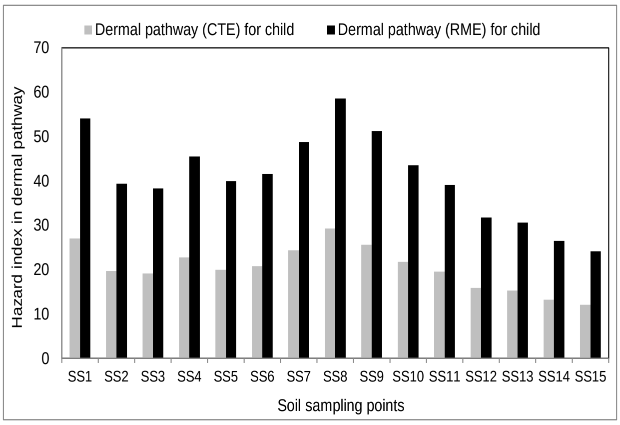

Figure 3: HI for dermal pathway in soil of child in CTE and RME condition.

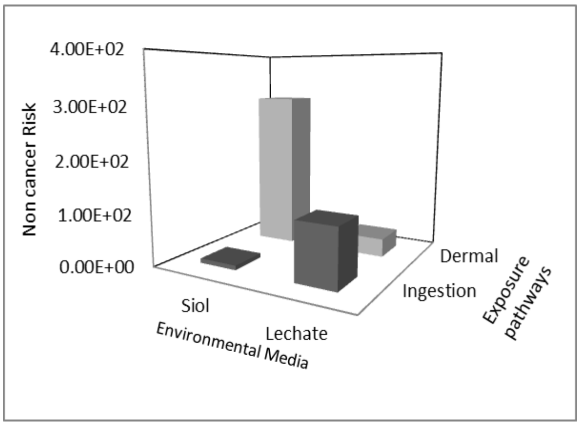

Figure 4: Vertical bar chart illustration of risk summary results for child at CTE condition.

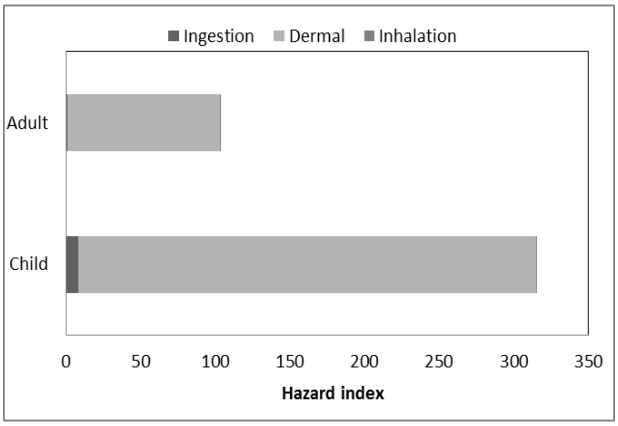

Figure 5: Risk summary results of inhabitants for soil in CTE condition.

The variation of HI for child and adult for entire soil in CTE condition for various pathways is shown in Figure 5. Figure 5 depicts that for both the child and adult, the exposure pathway of dermal was the main dominant pathway for contributing non-cancer risk for inhabitants. Moreover, it was clear from Figure 5 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 Childs were more vulnerable to health risk than that of adults of the selected disposal site.

4.1.2 Risk Assessment Observations for Leachate Samples

The health risk for heavy metals in LS1 for inhabitants for various pathways is summarized in Table 4. The CDI for child via dermal was maximum for Fe (Table 4). In addition, HQ via dermal indicated that Mn, Pb, As, Cd and Cr in leachate was the main contributor to risk for child. Result reveals that Fe has a major contribution in possessing adverse health risk for child alongside with other contributor of As, Ad and Mn. Figure 6 depicts variation of HI of child and adult of LS2 at CTE condition. Figure 6 displays the greater value of Fe than other heavy metals. Figure 6 showed higher values of HI for child than that of adult in all heavy metals indicated child was suffered more than adult due to the adverse effect of heavy metals in leachate.

Table 3: Summary of health risk assessment for selected heavy metals in soil of BH2 for CTE condition during dry season

Heavy metals	Child(CDI)			Adult(CDI)			HQ Child			Total (HI)	HQ Adult			Total (HI)
	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation	Ingestion	Dermal	Inhalation		Ingestion	Dermal	Inhalation	
Mn	1.72E-04	2.65E-04	2.02E-08	1.62E-05	8.85E-05	3.82E-09	3.74E-03	1.44E-01	1.41E-03	1.49E-01	3.53E-04	4.81E-02	2.67E-04	4.87E-02
Cr	1.04E-05	1.61E-05	1.23E-09	9.85E-07	5.38E-06	2.32E-10	3.48E-03	2.68E-01	4.30E-05	2.72E-01	3.28E-04	8.96E-02	8.10E-06	9.00E-02
Cu	1.20E-04	1.85E-04	1.41E-08	1.13E-05	6.19E-05	2.67E-09	3.01E-03	1.55E-02	3.52E-07	1.85E-02	2.83E-04	5.16E-03	6.64E-08	5.44E-03
Pb	5.01E-04	7.72E-04	5.89E-08	4.72E-05	2.58E-04	1.11E-08	3.58E-01	1.47E+01	1.67E-05	1.51E+01	3.37E-02	4.91E+00	3.16E-06	4.94E+00
Zn	2.60E-04	4.01E-04	3.06E-08	2.45E-05	1.34E-04	5.77E-09	8.66E-04	6.68E-03	1.02E-07	7.55E-03	8.17E-05	2.23E-03	1.92E-08	2.31E-03
Ni	7.03E-06	1.08E-05	8.27E-10	6.63E-07	3.62E-06	1.56E-10	3.51E-04	2.01E-03	4.01E-08	2.36E-03	3.31E-05	6.70E-04	7.57E-09	7.03E-04
Cd	6.56E-06	1.01E-05	7.72E-10	6.18E-07	3.38E-06	1.46E-10	6.56E-03	1.01E+00	1.35E-05	1.02E+00	6.18E-04	3.38E-01	2.55E-06	3.38E-01
As	8.90E-06	1.37E-05	1.05E-09	8.40E-07	4.58E-06	1.98E-10	2.97E-02	1.12E-01	3.49E-06	1.41E-01	2.80E-03	3.73E-02	6.58E-07	4.01E-02
Hg	6.62E-05	1.02E-04	7.79E-09	6.24E-06	3.41E-05	1.47E-09	2.21E-01	3.40E+00	9.08E-05	3.62E+00	2.08E-02	1.14E+00	1.71E-05	1.16E+00
Co	1.25E-05	1.93E-05	1.47E-09	1.18E-06	6.45E-06	2.78E-10	6.27E-04	1.21E-03	2.58E-04	2.09E-03	5.91E-05	4.03E-04	4.87E-05	5.11E-04

Table 4: Summary of health risk assessment for selected heavy metals in LS2 for CTE condition during dry season

Heavy metals	Child(CDI)		Adult(CDI)		HQ Child		Total (HI)	HQ Adult		Total (HI)
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal		Ingestion	Dermal	
Mn	8.84E-03	9.08E-04	1.67E-03	3.03E-04	1.92E-01	4.94E-01	6.86E-01	3.62E-02	1.65E-01	2.01E-01
Cr	5.73E-05	1.18E-05	1.08E-05	3.93E-06	1.91E-02	1.96E-01	2.16E-01	3.60E-03	6.56E-02	6.92E-02
Cu	1.31E-03	1.35E-04	2.48E-04	4.51E-05	3.29E-02	1.13E-02	4.41E-02	6.20E-03	3.76E-03	9.96E-03
Pb	9.51E-04	9.78E-06	1.79E-04	3.26E-06	6.79E-01	1.86E-01	8.66E-01	1.28E-01	6.22E-02	1.90E-01
Zn	1.36E-03	8.36E-05	2.56E-04	2.79E-05	4.52E-03	1.39E-03	5.91E-03	8.52E-04	4.65E-04	1.32E-03
Ni	6.13E-05	1.26E-06	1.16E-05	4.21E-07	3.06E-03	2.33E-04	3.30E-03	5.78E-04	7.79E-05	6.56E-04
Cd	1.60E-04	1.64E-05	3.01E-05	5.48E-06	1.60E-01	1.64E+00	1.80E+00	3.01E-02	5.48E-01	5.78E-01
As	2.13E-04	2.19E-05	4.03E-05	7.33E-06	7.12E-01	1.78E-01	8.90E-01	1.34E-01	5.96E-02	1.94E-01
Fe	4.63E-02	4.76E-03	8.72E-03	1.59E-03	5.14E+00	6.79E-03	5.15E+00	9.69E-01	2.27E-03	9.71E-01

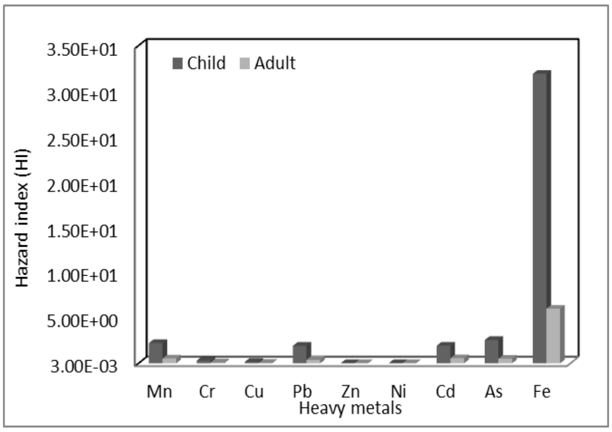

Figure 6: Hazard index of child and adult of LS7 of RME condition.

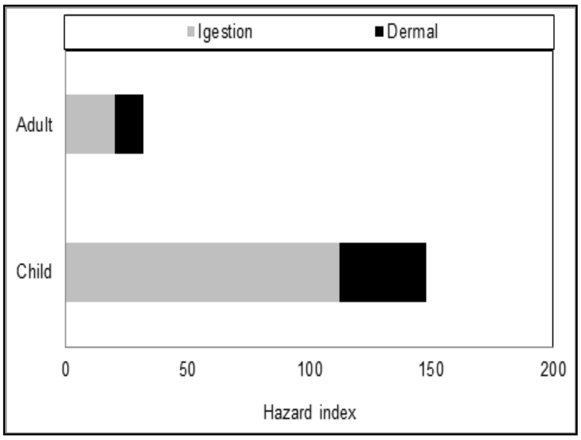

Figure 7: HI for inhabitants in different pathways for leachate in CTE condition

The variation of HI for child and adult for entire leachate samples in CTE condition for various pathways is shown in Figure 7. Figure 7 depicts that for both the child and adult, the exposure pathway of ingestion was the main dominant pathway for contributing non-cancer risk for inhabitants. Moreover, Figure 5 also depicts 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's were more vulnerable to health risk than that of adults of the selected disposal site. The health risk summary of entire soil and leachate for child at CTE condition are presented in Figure 8. Figure 8 depicts that soil was the main contributor (about 68%) for human health risk especially for child in CTE condition. In addition, for adult, soil contributed around 76 % of health risk.

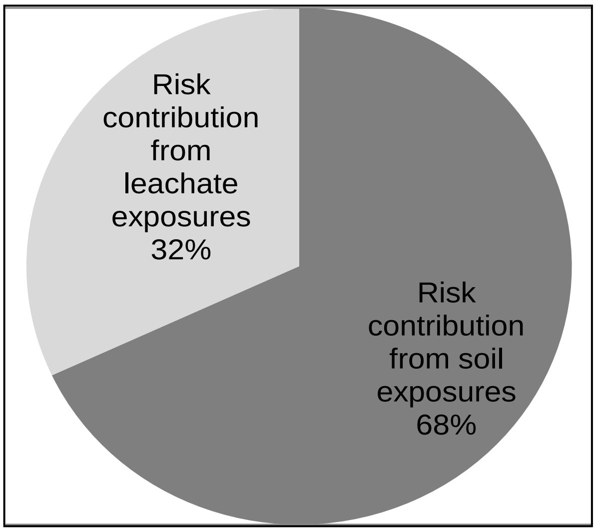

Figure 8: Pie chart illustration of risk summary results of different environmental media for child (CTE).

4.2 Environmental Risk

In this study, environmental risk was assessed interms of enrichment factor and analysis of potential ecological risk assessment and hence discussed in the following articles.

4.2.1 Enrichment Factor

The results of EF values in soil of all heavy metals considered in this study are represented in Figure 9. Figure 9 reveals that the values of EF for the heavy metals of Pb, Zn, Cd, As and Hg in soil were greater than 50 and lies in the class of extremely severe enriched. The value of Co indicates very severe enrichment where the EF value of Fe lies in the class of minor. In addition, the value of EF for Cu indicated the severe enrichment. The value of Cr and Ni indicated moderate enrichment. While the EF value Na shows no enrichment.

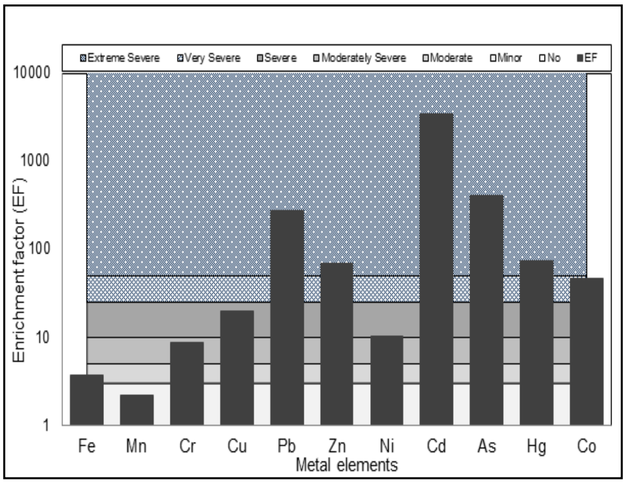

Figure 9: Classification of the level of contamination of soil based on EF in soil.

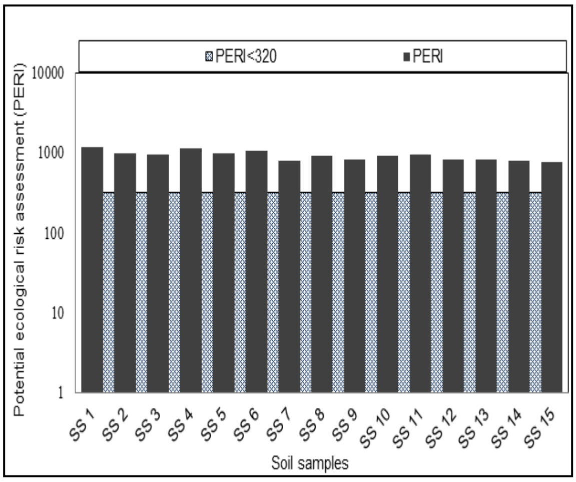

Figure 10: Variation of computed PERI in soil of boreholes of waste disposal

4.2.2 Potential Ecological Risk Index

With regard to the assessment method proposed by Hakanson (1980), ecological risk index (ER) of a single heavy metal as well as potential ecological risk index (PERI) was computed by adding ER for each heavy metal. In addition, ER is computed from contamination factor (CF) and toxic-response factor (TR) for each heavy metal. In addition, Figure 10 represents the variation of computed PERI for all soil sampling points. Hakanson (1980) stated that soil sample having the value of PERI less than 40, 40 to 80, 80 to 160, 160 to 320 and greater 320 indicated the ecological risk is slight, medium, strong, very strong and extremely strong, respectively. Figure 10 depicts that the magnitude of PERI for entire soil samples were found above 320 indicated extremely strong ecological risk by the heavy metals presence in soil for all the soil sampling points (boreholes) of the selected waste disposal site.

4.3 Uncertainty analysis (1-D Monte Carlo Simulation)

In Monte Carlo simulation (MCS), random values are selected for each of the tasks, based on the range of estimates. The model is calculated based on these random values. The result of the model is recorded, and the process is repeated. A typical MCS calculates the model hundreds or thousands of times, each time using different randomly-selected values. When the simulation is complete, we have a large number of results from the model, each based on random input values. These results are used to describe the likelihood, or probability, of reaching various results in the model. The analysis of uncertainty of exposure parameters (ED) and risk outputs (HI) were performed using 1-D MCS @RISK 7.5 with 10000 iterations. Figure 11 shows an input distribution for exposure duration (ED) for soil dermal contact (years).

In Figure 11, the height of the bars (the y-axis) represents the relative frequency of eposure durationof the eposed population and the spread of the bars (the x-axis) is the varying amounts of eposure duration (years). The y-axis for a PDF is referred to as the probability density, where the density at a point on the x-axis represents the probability that a variable will have a value within a narrow range about the point. This type of graph shows, for example, that there is a greater area under the curve (greater probability density) in the 4.5815-5.6820 years range than 3.3036-4.5815 or 5.6820-6.6839 years. That is, most inhabitants reported to be exposed near the disposal site. Graphical representation of risk parameter (HI) is shown in Figure 12. The probabilistic calculation of risk involves random sampling from each of exposure variable distributions.

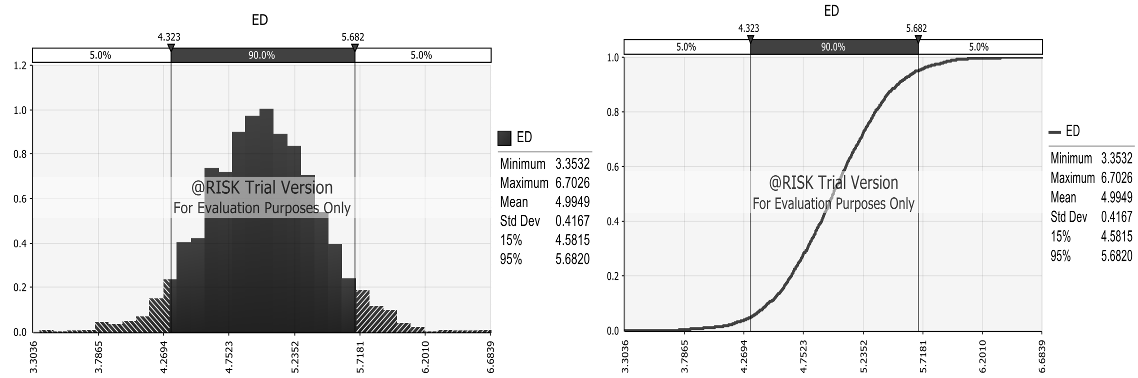

Figure 11: Normal distribution of ED of (a) Bell-shaped curve represents the PDF and (b) S-shaped curve represents the CDF.

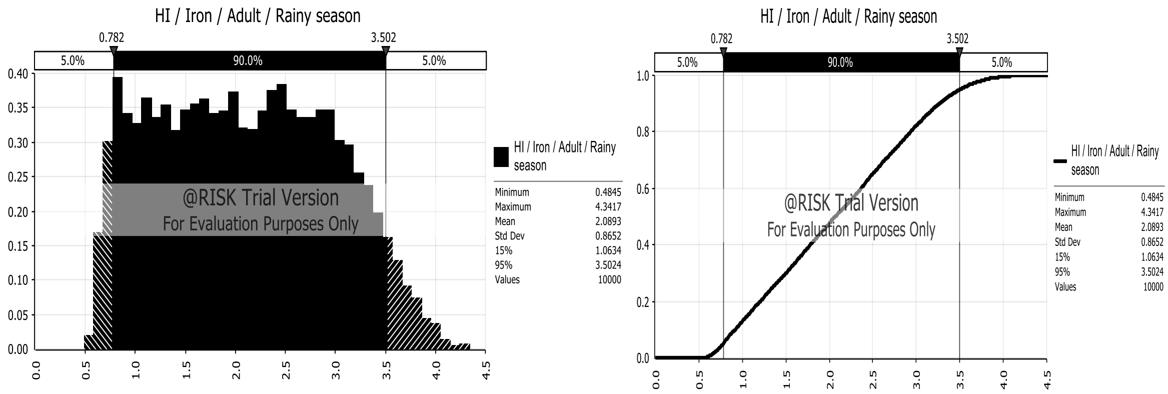

Figure 12: Normal distribution of HI of Iron in LS 2 for Adult as (a) Bell-shaped curve represents the PDF and (b) S-shaped curve represents the CDF.

4.4 Spatial Distribution of Hazard Index

Figure 13 illustrates the spatial distribution of HI of Pb for child and adult in RME condition. Figure 13 reveals that not a single collection point having HI value less than one. The deep black area indicated the possible maximum distribution of HI values for child in RME condition while the white one indicated less distribution of HI. Whatever for adult the distribution pattern was found similar to the child one but the HI value was found less than unity in all points for Pb. It can be summarised that the child near the disposal site possess to extreme health risk.

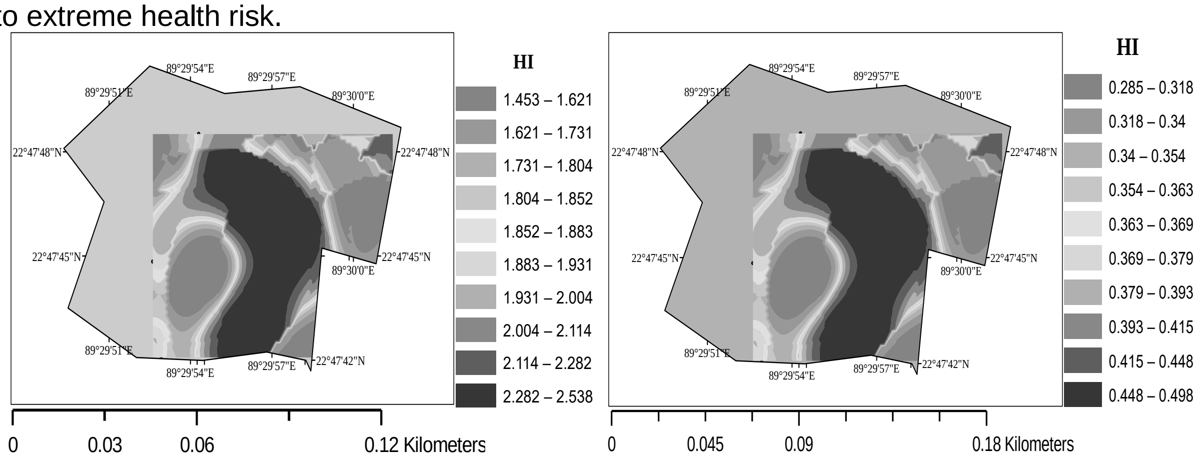

Figure 13: Spatial distribution of HI for leachate samples.

5. CONCLUSIONS

Result reveals that the heavy metals of Pb, Hg, As and Cd in soil and leachate were the mainly contributed for non- carcinogenic risk for child's and adults. In addition, result reveals that Pb possess adverse health effect on child in both the CTE and RME condition for entire soil samples. In all soil samples, HI for Pb was found to be greater than 1 where the acceptable limit of HI is 1 for non- carcinogenic health effect. In addition, the HI for exposure pathway of dermal for soil of child at CTE and RME condition showed comparatively the higher values. Result reveals that the dermal and ingestion were more effective for contributing health risk for inhabitants for soil and leachate, respectively. Results also represents that Childs were more vulnerable than that of adults. Results of EF for Pb, Zn, Cd, As and Hg indicated that soil was extremely severe enriched. In addition, PERI for entire soil samples indicated that the soil was extremely strong ecological risk of the disposal site. Based on spatial distribution, it can be summarised that the child's near the disposal site possess extreme health risk. The result of MCS was given in the form of a probability distribution of risk. The idea of MCS in health risk assessment concerning the exposure to heavy metals in soil and leachate was illustrated in the population living in the vicinity of the selected waste disposal site, taken as an example.

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