HEAVY METAL CONTAMINATION MODELLING INDICES EQUATIONS AND INTERPRETATION - A CRITICAL REVIEW

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Abstract:

Environmental contamination of heavy metals has become a serious global issue. Studies on heavy metals source in soils were said to be either natural source or anthropogenic activities. Anthropogenic sources include mining operations, metal processing and smelting operation, chemical production, factory emissions, farming operations, rapid industrialization and urbanization. While the natural sources include factors such as volcanic eruptions and continental dusts, as well as soil parent materials and pedogenetic processes; causing worries over their possible impacts on human health and the environment. Factors influencing the toxicity of heavy metals include the chemical specie, dosage and exposure pathway. This paper review the sources of heavy metal, it toxicity and give detail interpretation of 19 soil contamination modeling indices equations such as the Geo-accumulation Index (I_{geo}), Contamination Factor (CF), Pollution Load Index (PLI), Metal Pollution Index (MPI), Enrichment Factor (EF), Degree of Contamination (DC), Ecological Risk Index (ERI), Potential Ecological Risk Index (PERI), Percentage Bioavailable and Non-bioavailable Fractions, Transfer Factor, carcinogenic and non-carcinogenic risks, Hazard Quotient, Hazard Index, Cancer Risk (CR), Lifetime cancer risk (LCR), Daily Intake of Heavy Metal (DIM) and Health Risk Index (HRI). In addition, this review addresses the basis of their applications and aid in decision making.

Key Words: Geo-accumulation Index (I_{geo}), Contamination Factor (CF), Pollution Load Index (PLI), Ecological Risk Index (ERI) and Health Risk Index (HRI).

Introduction

Metals and metalloids with densities greater than 5 g/cm^3 are referred to as Heavy metals (Li *et al.*, 2014). Sources of heavy metals are either anthropogenic activities or natural origin (Shifaw, 2018; Chukwu and Oji, 2018; Alam *et al.*, 2020). Anthropogenic sources include mining operations, metal processing and smelting operation, chemical production, factory emissions, farming operations, rapid industrialization and urbanization (Sheng *et al.*, 2012; Krishna and Mohan, 2016; Shifaw, 2018; Shen *et al.*, 2018; Zhang *et al.*, 2018 and Wang *et al.*, 2019). These have been proven to be primary sources of heavy metal pollution. The natural source of heavy metal pollution includes factors such as volcanic eruptions and continental dusts, as well as soil's parent materials and pedogenetic processes (Shifaw, 2018). However, the natural level of metals in soil is generally low and does not pose a threat.

Environmental pollution by havy metals has become a serious issue, drawing global attention (Jarup, 2003; Hou *et al.*, 2014; O'Connor *et al.*, 2018; Zhao *et al.*, 2018). Soil is the first host of heavy metals released into the environment through natural and anthropogenic sources. Unlike organic contaminants which are biodegraded, most metals do not undergo microbial or chemical degradation. Yerima *et al.*, (2018) conducted a soil quality survey in a sack production and packaging company around an industrial layout in Akwanga, Nasarawa state, Nigeria, and revealed heavy metal contamination of the soil. In response to this environmental pollution, the study recommended an action plan which requires the state and local governments to control anthropogenic activity.

A separate study by Ogah *et al.*, (2020), in an auto-mechanic dumpsites in Makurdi Metropolis, North Central Nigeria, gave the concentration of different heavy metals as; Cd (4.65 mg/kg), Cu (137.12 mg/kg), Zn (294.75 mg/kg) and Pb (257.77 mg/kg), which exceeded the USEPA and WHO standard. .

Toxicity of Heavy Metals

The toxicity of heavy metals contamination of the soil has been widely reported (Xiao *et al.*, 2013; Krishna and Mohan 2016). Heavy metals toxicity depends on their chemical form and the species of the elements (Emmanuel *et al.*, 2018). The most toxic form of metal is that possessing the alkyl groups attached to the metal. The accumulated heavy metals in soil enter into human body by ingestion, dermal contact, and inhalation of soil dust (US EPA, 2001; Quan *et al.*, 2015; Qing *et al.*, 2015; Diami *et al.*, 2016; Ciarkowska, 2018; Alshahri and El-Taher 2018). Soils contaminated by heavy metals could pose very hazardous effects on human health as well as environment. Diami *et al.*, (2016) pointed out that the contamination of heavy metals not only pose some human health risk but also deteriorates the surface water, groundwater and air quality. Heavy metals in soils could pose long-term environmental and health implications because of their non-biodegradability and persistence (Xiao *et al.*, 2013; Zeng *et al.*, 2015; Krishna and Mohan 2016; Chen *et al.*, 2017). Jarup, (2003) reported that excessive intake of heavy metals causes diseases related to kidney, blood, cardiovascular, and bone disease. For instance, chronic exposure to Pb can damage the nervous, enzymatic, immune system, kidney dysfunction, and hypertension (Zhuang *et al.*, 2009; Diami *et al.*, 2016; Ciarkowska, 2018). Arsenic causes dermal lesions, neurotoxicity and skin cancer (Quan *et al.*, 2015). High exposures to Cadmium Cd result in renal tubular damage, bone deformities, and heart related diseases (Emmanuel *et al.*, 2018). Ingestion and inhalation of high levels of nickel (Ni) induce lung damage in man (Krishna and Mohan 2016). The toxicity of Mercury (Hg) depends on its chemical form and route of exposure (Qing *et al.,* 2015; Emmanuel *et al.,* 2018). It affects the immune system, alters genetic and enzyme systems, and damages the nervous system, including incoordination and the textile, and visual hallucinations (Emmanuel *et al.,* 2018). Some other metals, such as chromium (Cr), and copper (Cu) causes fever, vomiting, diarrhea, stomach cramps, and nausea, nephritis, and extensive lesions in the kidney (Qing *et al.,* 2015: Emmanuel *et al.,* 2018). Due to their potential toxic, persistent, and irreversible characteristic, the heavy metals, such as Cd, Cr, As, Hg, Pb, Cu, Zn, and Ni, have been listed as priority control pollutants by the United States Environmental Protection Agency (USEPA) (USEPA, 2001; Rodrigues *et al.,* 2013; Chen *et al.,* 2015). Globally, researcher's attention has been drawn to heavy metal contamination and its impact on the human health.

Heavy Metals Pollution Assessment Indices

To quantitatively assess the impact level of heavy metals contamination in soil and on human health, various types of pollution load indices have been used in different regions of the world. These are; Geo-accumulation index (Igeo), Geo-accumulation Index (I_{geo}), Contamination Factor (CF), Pollution Load Index (PLI), Metal Pollution Index (MPI), Enrichment Factor (EF), Degree of Contamination (DC), Ecological Risk Index (ERI), Potential Ecological Risk Index (PERI), Percentage Bioavailable and Non-bioavailable Fractions, Transfer Factor, carcinogenic and non-carcinogenic risks, Hazard Quotient, Hazard Index, Cancer Risk (CR), Lifetime cancer risk (LCR), Daily Intake of Heavy Metal (DIM), Health Risk Index (HRI) and their results compared with world referenced standards upon which decisions are made (Salah *et al.,* 2012; Li *et al.,* 2014; Hassaan *et al.,* 2016; Emmanuel *et al.,* 2018; Yerima *et al.,* 2018; Adimalla and Wang, 2018; Okereke *et al.,* 2019; Alam *et al.,* 2020; Han *et al.,* 2020).

Geo-accumulation Index (I_{geo})

The index of geo-accumulation has been studied extensively by (Li *et al.,* 2014; Adimalla and Wang, 2018; Chukwu and Oji, 2018; Yerima *et al.,* 2018; Alam *et al.,* 2020; Ogah *et al.,* 2020). The geo – accumulation index (Igeo) was originally developed by Muller in 1969, in order to evaluate the degree of heavy metal pollution in sediments, by comparing current concentration with pre- industrial levels (Müller, 1969; Adimalla and Wang, 2018; Ogah *et al.,* 2020). However, a number of researchers have used it to evaluate the heavy metal contamination in soils. The index of geo-accumulation (I_{geo}) was initially meant to assess contamination by comparing the current status and pre-industrial concentrations originally bottom sediments (Yerima *et al.,* 2018). The method assesses the degree of metal pollution in terms of seven enrichment classes based on the increasing numerical values of the index (Table 1). The index of geo accumulation was calculated using the Equation (1) adopted from Ogah *et al.,* (2020),

$$\boldsymbol{I_{geo} = log_2(\frac{C_n}{1.5\times Bn})} \qquad (1)$$

Where, C_n (mg/kg) is the measured concentration of the metal in soil or sediment and Bn is the geochemical background value. The constant value, 1.5 is the back-ground matrix correction factor due to the lithological variations in the content of a given substance in the environment (Adimalla and Wang, 2018). The geo-accumulation index (I_{geo}) values are shown on Table 1.

Table 1. Classification for geo-accumulation index (I_{geo}) as adopted by Yerima *et al.,* (2018)

I_{geo} Value	Class	Sediment Quality
≤ 0	0	Unpolluted
0 - 1	1	From unpolluted to moderately polluted
1 - 2	2	Moderately polluted
2 - 3	3	From moderately to strongly polluted
3 - 4	4	Strongly polluted
4 - 5	5	From strongly to extremely polluted
>6	6	Extremely polluted

Contamination Factor (CF)

The contamination factor (CF) gives an indication of the degree of contamination in the soil. It has been extensively studied by (Salah *et al.,* 2012; Hassan *et al.,* 2016; Omran, 2016; Otene and Alfred- Ockiya, 2019; Okereke *et al.,* 2019; Alam *et al.,* 2020). Contamination factor (CF) was evaluated as the ratio of metals concentration in soil to its background concentration (Emmanuel *et al.,* 2018). Many authors prefer to express the metal contamination with respect to average shale to represent the degree of quantification of pollution (Omran, 2016). Others used the background value of the study area to be the geometric mean concentration of the different sample sites, which is the antilog of the arithmetic average of log10 of the concentration values and the world surface rock average of individual metal to the background (Emmanuel *et al.,* 2018). The average shale, however, varies from place to place. The contamination factor of sediment by metal is expressed by Equation (2).

$$\mathbf{CF} = \frac{C_{metal}}{C_{Background\ value}} \qquad (2)$$

Where C_{metal} is the concentration of the given metal in shore sediment; $C_{Background}$ is the background value of the metal concentration, also known as their world surface rock average (WSRA) (Alam *et al.,* 2020). CF < 1 indicates low contamination; CF values between 1-3 indicate moderate contamination; CF values between 3-6 indicate considerable contamination and CF > 6 indicates very high contamination (Otene and Alfred-Ockiya, 2019). The background values of some heavy metals in soil are shown on Table 2.

Table 2: Some Heavy Metals and their Reference Values (Emmanuel *et al.*, 2018).

Metal	World surface rock average $mgkg^{-1}$	WHO
Cd	0.2	6
Cu	32	25
Pb	16	-
Zn	127	123
As	10	20
Cr	16	100
Mn	750	2000
Fe	300	5000

Pollution Load Index (PLI)

The generally pollution load index (PLI) was developed by Tomlinson *et al.*, (1980). It has been extensively studied by (Salah *et al.*, 2012; Hassan *et al.*, 2016; Olatunde *et al.*, 2015; Chukwu and Oji, 2018; Otene and Alfred- Ockiya, 2019; Okereke *et al.*, 2019). The Pollution Load Index (PLI) is used to evaluate level of pollution in an environment (Emmanuel *et al.*, 2018). It is usually evaluated using the proposed method by Tomlinson *et al.*, (1980). It is obtained as degree of overall contamination factors (CF). This is as shown in equation (3):

$$\mathbf{PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{1/n}} \quad (3)$$

Where, CF is the contamination factor and n the number of metals investigated. If PLI >1 it indicates pollution, while PLI < 1 indicates no pollution and PLI =1 indicates perfect soil (Emmanuel *et al.*, 2018).

Metal Pollution Index (MPI)

The metal pollution index MPI is the summation of all metal concentrations results. This helps to overcome the difficulties with both application and understanding the demand of statistical analysis (Jorgensen and Pedersen, 1994). MPI is given as equation (4);

$$\mathbf{MPI} = \sum_{i=1}^{n5} /\mathbf{refi} \quad (4)$$

refi represents the reference value for each chosen metals in selected sites, while x represents the metal concentration mean value. According to Jorgensen and Pedersen, (1994), MPI < 1 indicates non-pollution and MPI >1 indicates pollution.

Enrichment Factor (EF)

A standard approach to evaluate the anthropogenic impact of heavy metal, is to calculate the enrichment factor (EF) for metal concentrations above uncontaminated background levels (Fagbote and Olanipekun, 2010; Huu *et al.*, 2010). EF was considered to estimate the abundance of metals in samples. It has been extensively studied by (Salah *et al.*, 2012; Okedeyi *et al.*, 2014; Olatunde *et al.*, 2015; Hassan *et al.*, 2016; Omran, 2016). EF was calculated by comparison of each tested metal concentration with that of a reference metal. The regularly used reference metals are Mn, Al and Fe. Several authors have used Fe as referenced heavy metal contaminants (Neto *et al.*, 2006; Mediolla *et al.*, 2008; Okedeyi *et al.*, 2014). According to Emmanuel *et al.*, (2018), EF is given as equation (5);

$$\mathbf{EF} = \frac{M/Fe_{sample}}{M/Fe_{Background\ value}} \quad (5)$$

Where EF is the enrichment factor, $(M/Fe)_{Sample}$ is the ratio of metal and Fe concentration of the sample and $(M/Fe)_{Background}$ is the ratio of metals and Fe concentration of the background. According to Salah *et al.*, (2012), five contamination categories are recognized on the basis of the enrichment factor;

EF < 2 is deficiency to minimal enrichment
EF = 2 - 5 is moderate enrichment
EF = 5 - 20 is significant enrichment
EF = 20 - 40 is very high enrichment
EF > 40 is extremely high enrichment

Enrichment factor can be used to distinguish between the metals which originated from anthropogenic activities, those from natural processes and to assess the degree of anthropogenic influence (Okedeyi *et al.*, 2014). As the EF values increase, the contributions of the anthropogenic origins also increase.

Degree of Contamination (DC)

The degree of contamination (DC) is used to determine the intensity of pollution. It has been studied extensively by (Aksu *et al.*, 1998; Olatunde *et al.*, 2015; Omran, 2016). The degree of contamination as adopted from Olatunde *et al.*, (2015), is as given in equation (6);

$$\mathbf{DC = \sum CF} \quad (6)$$

Where, Cf = Contamination factor, Σ = Summation of the contamination factors of the trace metals. According to Aksu *et al.*, (1998), the decision scales are;

DC < 12 - low degree of contamination
12 < DC < 24 - moderate degree of contamination
24 < DC < 48 - high degree of contamination
48 < DC < 96 - very high degree of contamination
DC > 96 - extremely high degree of contamination

Ecological Risk Index (ERI)

In order to further evaluate the level of pollution in soil Håkanson *et al.*, (1980) propose the ecological risk model. It has been studied extensively by (Omran *et al.*, 2016; Adimalla and Wang, 2018; Alam *et al.*, 2020). ERI is the nominal risk value of each metal and is calculated as equation (7).

$$\mathbf{ERI = CF \times Tr} \quad (7)$$

Where, Tr is toxic response value. The Tr values for Pb, Mn, Cr and Cd are 5, 1, 2 and 30, respectively as proposed by Hakanson, (1980). Adimalla and Wang, (2018) graded the Eri as, low ecological risk (Eri < 40), moderate ecological risk (40 < Eri < 80), considerable ecological risk (80 < Eri < 160), high ecological risk (160 < Eri < 320), very serious ecological risk (Eri > 320).

Potential Ecological Risk Index (PERI)

Potential Ecological Risk Index has been studied extensively by (Omran *et al.*, 2016; Adimalla and Wang, 2018; Alam *et al.*, 2020). PERI is calculated as the sum of all risk values of individual heavy metals and is given as equation (8);

$$\mathbf{PERI = ERI_1 + ERI_2 + ERI_3 \ldots ERIn}, \quad (8)$$

Where, ERI is the ecological risk index for each heavy metal investigated.

PERI is categorized as, (Low ecological risk (PERI < 95), Moderate ecological risk (95 < PERI < 190), Considerable ecological risk (190 < PERI < 380) and Very high ecological risk (PERI > 380) (Alam *et al.*, 2020).

Percentage Bioavailable and Non-bioavailable Fractions

The term "bioavailability" denotes the amount of water-soluble heavy metals that can readily uptake and assimilate by plants and animals (Hassaan *et al.,* 2016). Heavy metal chemical fate in soil can be determined by the level of its availability, the higher the bioavailability, the higher its effect on target system (Hikon *et al.,* 2018). Research has shown that the rate of solubility and bioavailability is directly proportional to the ease of metal extraction (Hikon *et al.,* 2018). The metal fractions which are not easily extracted are regarded as non-bioavailable fractions (NBF). The percentage heavy metal bioavailability and non-bioavailable fraction (MBF) with respect to total metal concentration is given as equation 9 -10.

$$\%\ \textbf{Bioavailability} = \frac{Exchangeable + Carbonate + reducible}{Exchangeable + Carbonate + reducible + Organic + residual} X\ 100 \quad \textbf{(9)}$$

$$\%\ \textbf{Non - Bioavailability} = \frac{organic + residual}{Exchangeable + Carbonate + reducible + Organic + residual} X\ 100 \quad \textbf{(10)}$$

MBF gives information about the potential mobility of heavy metal in soils and availability to plants (Hikon *et al.,* 2018). If the MBF value is up to 10% for any element, it indicates that the element is immobile and unavailable for plants (Remon *et al.,* 2005). While MBF values greater than 50 % for a given element indicates high mobility and available to plants (Hikon *et al.,* 2018). The pH and redox potential Eh are the main factors that control the release of metals (Remon *et al.,* 2005).

Transfer Factor

Transfer factor (tf) is a special formula used to determine the level of heavy metal uptake in plant as a fraction of the soils total (Hikon *et al.,* 2018). The transfer factor is given as in Equation (11):

$$\textbf{Transfer factor (TF)} = \frac{\textbf{Concentration in plant tissue}}{\textbf{Concentration in soil sample}} \quad \textbf{(11)}$$

Hikon *et al.,* (2018), reported that the uptake of metals by plants is affected by factors such as metal specie, plant species, nature of soil, age of soil, soil pH, and climatic condition.

Health Risk Assessment of Heavy Metals in Soils

Health risk assessment is used to determine the carcinogenic and non-carcinogenic risks to human as a result of contaminant exposure. In the assessment of human risk, the carcinogenic and non-carcinogenic risk is determined (Han *et al.,* 2020). The carcinogenic and non-carcinogenic risk is calculated using the human health risk assessment model for ingestion, dermal and inhalation exposure pathways (Qing *et al.,* 2015; Han *et al.,* 2020). The health risk assessment is based on the exposure guidelines of the United States Environmental Protection Agency (USEPA) (Bwede *et al.,* 2021). The average daily dose (ADD) (mg/kg/day), via inhalation, ingestion and dermal exposure for both children and adults were determined using Equations 12-13.

$$\textbf{ADD}_{\textbf{ingestion}} = \frac{CMS \times IR \times ED \times EF}{ABW \times AET} \times CF \quad \textbf{(12)}$$

$$\textbf{ADD}_{\textbf{inhalation}} = \frac{CMS \times IHR \times EF \times ED}{ABW \times AET \times PEF} \quad \textbf{(13)}$$

$$\textbf{ADD}_{\textbf{dermal}} = \frac{C_S \times SA \times SAF \times DAF \times EF \times ED}{ABW \times AET} X\ CF \quad \textbf{(14)}$$

where CMS represents the concentration of metal in soil (mg/kg), IR and IHR represents the ingestion and inhalation of metal in soil, respectively (mg/day), ED represents the exposure duration (year), and EF represents the exposure frequency (day/year). ABW and AET represent the average body weight (kg) and average exposure time (year), respectively. CF is the conversion factor (10^{-6} kg/mg), SA is the exposed skin area (cm^2), SAF is the skin adherence factor (kg/cm^2day), DAF is the dermal absorption factor, and PEF is the particle emission factor (m^3/kg) (Adimalla and Wang, 2018).

The reference dose is used to determine the non-carcinogenic chronic hazard level. When the exposure dose of the determined heavy metals is more than the reference dose, toxic effect occurs, which is generally computed as Hazard Quotient (HQ) and the Hazard index (HI). The estimation of chronic risk level of heavy metals in the soil is computed as HQ. The HI is the sum of all the HQ's and indicates the total risk of non-carcinogenic for a single element (Qing *et al.,* 2015). The HQ and HI are expressed as Equation (15) and (16):

$$\textbf{Hazard Quotient } (\boldsymbol{HQ}) = \frac{\textbf{ADD}}{\textbf{RfD}} \quad (15)$$

$$\textbf{Hazard Index (HI)} = \textbf{HQ}_{\textbf{ingestion}} + \textbf{HQ}_{\textbf{inhalation}} + \textbf{HQ}_{\textbf{dermal}} \quad \textbf{(16)}$$

where ADD is the average daily dose (mg/kg/day), RfD is the reference dose (mg/kg day) adopted from (Adimalla and Wang, 2018). If the value of HQ < 1 or HI < 1, no significant risk or non-carcinogenic effect is observed and the NCR is within the acceptable range (Han *et al.,* 2020). If HQ > 1 or HI > 1, then non-carcinogenic effects exist, and this possibility increases with increase HI value (Bwede *et al.,* 2021).

To determine level of risk Cancer risk and the lifetime cancer risk model are used. The cancer risk (CR) is used to determine acceptable threshold value of risk (Adimalla and Wang, 2018). It is evaluated using Equation (17):

Cancer Risk (CR) = ADD x CSF (17)

where ADD is the average daily dose (mg/kg/day) and CSF, the cancer slope factor. The CSF values for Cr, Pb, and As are 0.5, 0.0085, and 1.5 mg/kg/day (USEPA, 2001). The acceptable threshold value of the CR is 1.0E−04 (US EPA 2001). When CR < 10^{-6}, no cancer risk exists. When 10^{-6}< CR < 10^{-4}, the risk is within the acceptable range (Adimalla and Wang, 2018).

The Lifetime Cancer Risk (LCR) is the summation of all the cancer risk (CR) from each exposure pathway (ingestion, inhalation, and dermal). It is calculated using Equation (18):

Lifetime cancer risk (LCR) = ΣCR (ingestion + inhalation + dermal) (18)

The acceptable LCR value for regulatory ranged from 1.0E-06 to1.0E-04 (Adimalla and Wang, 2018). Some Reference values of some parameters for exposure health risk assessment of heavy metals in surface soils are as given in Table (3) (USEPA, 2011; Adimalla and Wang, 2018).

Table 3: Reference values of some parameters for exposure health risk assessment of heavy metals in surface soils (Adimalla and Wang, 2018)

Parameter	Unit	Adult	Children
IR	mg/day	100	200
ED	Years	24	6
EF	days/year	365	365
CF	Kg/mg	$1x10^{-6}$	$1x10^{-6}$
ABW	Kg	70	15
AET	years	8760	2190
SA	cm^2	4350	1600
SAF	Mg/cm^2	0.7	0.2
DAF	-	0.001	0.001
IHR	m^3/kg	12.8	7.62
PEF	m^3/kg	$1.36x10^9$	$1.36x10^9$
RFD	mg/kg day	**Ingestion:** As (0.0003), Cr (0.003), Pb (0.0035), Cu (0.04), Ni (0.02), Zn (0.3). **Dermal:** As (1.23E-04), Cr (6.00E-05), Pb (5.25E-04), Cu (1.20E-02), Ni (5.40E-03), Zn (6.00E-02). **Inhalation:** As (1.23E-04), Cr (2.86E-05), Pb (3.52E-03), Cu (4.00E-02), Ni (2.06E-02), Zn (3.00E-01)	
CMS	mg/kg	As: 2.4 to 5.3; Cr: 55.9 to 135.8; Pb: 5.9 to 26.8; Cu: 12.7 to 69.6; Ni: 0.5 to 27.6; Zn: 71.3 to 173	

IR: ingestion rate of soil, ED: exposure duration, EF: exposure frequency, CF: conversion factor,
ABW: average body weight, AET: average exposure time, SA: skin surface area, SAF: skin adherence factor, DAF: dermal absorption factor, IHR: inhalation rate of metal in soil, PEF: particle emission factor, RfD: reference dose, CMS: concentration of metals in soils

Daily Intake of Heavy Metal

The daily intake of metals (DIM) is used to estimate the daily accumulation of metals in the human body system (via food consumption) of an individual with specified body weight (Hassan *et al.,* 2016). The daily intake of metals (DIM) by consumption of food grown on contaminated soil was computed using Equation (19) (Alam *et al.,* 2020):

$$\mathbf{DIM} = \frac{C_{Metal} \times D_{Food\ intake} \times C_{Factor}}{B_{average}\ weight} \quad \mathbf{(19)}$$

Where C_{metal} is the metal concentration in food sample (mg kg^{-1}), $D_{Food\ intake}$ is the daily food intake ($kgday^{-1}$), $B_{average}$ body weight is the body weight (kg) of consumer, C_{factor} is the conversion factor (fresh plant into dry constant weight), as calculated using Equations (20) - 21), (Hassan *et al.,* 2016; Alam *et al.,* 2020):

$$\mathbf{C_{Factor} = IR_{ww} - IR_{dw}} \quad \mathbf{(20)}$$

$$\mathbf{IR_{ww}} = \frac{IR_{dw}(100 - W)}{100} \quad \mathbf{(21)}$$

Where IR_{ww} is the wet weight intake, IR_{dw} is the dry weight intake rate, and W is the amount in percent of water content in the fresh vegetable (Hassan *et al.,* 2016).

Health Risk Index (HRI) For Consumption of Vegetable

The health risk index (HRI) is used to determine risk associated with daily consumption vegetables in diet. The health risk index (HRI) for the consumption of contaminated vegetable can be determined using the daily intake of metals (DIM) in relation to the reference oral dose (RfD) of each metal (Alam *et al.,* 2020). This index measures the individual's heavy metals risk. HRI < 1 is acceptable and indicate no risk. The HRI is calculated using Equation (22):

$$\mathbf{HRI} = \frac{DIM}{R_F D} \quad \mathbf{(22)}$$

RfD is the oral reference dose (mg $kg^{-1}.day^{-1}$) and is a safe level of human exposure for life time (USEPA, 2011; Hassan *et al.,* 2016; Alam *et al.,* 2020).

Conclusion

This review provides insight on the sources, toxicity of heavy metals in the soil and some methods used in soil pollution modeling. Heavy metals model for pollution assessment includes; Geo-accumulation Index (Igeo), Contamination Factor (CF), Pollution Load Index (PLI), Metal Pollution Index (MPI), Enrichment Factor (EF), Degree of Contamination (DC), Ecological Risk Index (ERI), Potential Ecological Risk Index (PERI), Percentage Bioavailable and Non-bioavailable Fractions, Transfer Factor, carcinogenic and non-carcinogenic risks, Hazard Quotient, Hazard Index, Cancer Risk (CR), Lifetime cancer risk (LCR), Daily Intake of Heavy Metal (DIM) and Health Risk Index (HRI). Soil pollution modeling is a useful tool required for risk assessment of heavy metals pollution in soil. This helps to ensure the safety of the consumer population. A frequent acquisition of data on the safety of soil is essential for various stakeholders in decision making.

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