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Health Risk Assessment of Heavy Metal Contaminated Sites in India

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Abstract: *Due to various health risks associated with contaminated sites, health risk assessment has gained a lot of attention among the researchers worldwide. Health risk analysis is also one of the elementary steps involved in the selection of a cleanup program for a site. In this paper, the non carcinogenic (as Hazard Index) and carcinogenic health risks are evaluated for the three contaminated sites located in different parts of India i.e. Balanagar industrial area (Hyderabad), Pali industrial area (Rajasthan) and Surat industrial area situated in south Gujarat, to identify the potential health risks to human involved with the exposure to the site. Analysis was made for three receptors (i.e., child, adult and industrial worker) by considering three types of exposure pathways (ingestion, inhalation and dermal contact). Results demonstrated site 1 to be highly contaminated as the induced risks were much higher than safe level. Site 2 was mainly polluted by Cr and Pb only. High carcinogenic risk was induced with the exposure to site 3 due to accumulation of high concentration of Cr.*

Keywords: *Carcinogenic Risk, Hazard Index, Hazard Quotient, Non-Carcinogenic Risk.*

I. Introduction

In the last few decades, millions of contaminated sites have been discovered all over the world. Most of the developed and developing countries are facing the problem of land scarcity, especially in urban areas, due to contamination. India is also one of them. Till date, there are a total of 557 sites identified as contaminated in India, with total area of about 175 million hectares. Also, huge number remains unidentified. Most of these sites reported are found in Uttar Pradesh (75), Punjab (61), Gujarat (54), Andhra Pradesh (46), Madhya Pradesh (38), National Capital Territory (32) and Rajasthan (21) [1]. As per the report of MoEF [1], most of the sites in India are contaminated with Chromium (160), Lead (104), Cadmium (50), Mercury (35) and Arsenic (20). Other heavy metals such as Ba,, Co, Cu, Sr, V, Y, Zn etc. are also found in most of the sites. Some heavy metals like Ca, Mg, Cu, Zn etc) are found important for human upto a regulatory limit. However excess will result in poisoning or toxicity, which is evident by certain reported medical symptoms that are clinically diagnosable [2, 3, 4 and 5]. Chromium generally occurs in two oxidation states, Cr(III) and Cr(VI). Cr(III) is an essential nutrient for human in amounts of 50-200 µg/day. But even a small concentration of Cr(VI) is harmful for human. Exposure to Cr(III) and Cr(VI) compounds can be associated with allergic responses in sensitive individuals. Effects also include irritating respiratory effects, effects on stomach and blood, liver and kidney effects and increased risk of death from lung cancer [5, 6 and 7]. Unlike other heavy metals, Lead (Pb), Cadmium (Cd) and Mercury (Hg) have no bio-importance in human biochemistry and physiology and consumption of even a small amount of concentration may be toxic. Adverse health effects of Cd exposure include primarily in the form of kidney damage but possibly also bone effects and fracture [5]. The symptoms of acute lead poisoning are headache, irritability, abdominal pain and various symptoms related to the nervous system. Children may be affected by behavioral disturbances, learning and concentration difficulties. In severe cases of lead encephalopathy, the affected person may suffer from acute psychosis, confusion and reduced consciousness. People who have been exposed to Pb for a long time may suffer from memory deterioration, prolonged reaction time and reduced ability to understand [8]. Long term exposure to Arsenic (As) is mainly related to increased risks of skin cancer, but also some other cancers, as well as other skin lesions such as hyperkeratosis and pigmentation changes. Occupational exposure to arsenic, primarily by inhalation, is sometimes associated with lung cancer [9]. Health risks associated with contaminated sites may be harmful enough to cause cancer, known as carcinogenic health risks otherwise they may be less harmful but still problematic, known as non-carcinogenic health risks. Due to all these associated health risks, health risk assessment of a contaminated site has gained a lot of attention among the researchers. A large number of researchers have worked to determine the concentration of various contaminants at different sites in India like Chhattisgarh [10], Hyderabad [11

and 12], Kanpur [13, 14, 15, 16 and 17], Mumbai [18], Mysore [19 and 20], Patancheru [21], Pondicherry [22], Rajasthan [23], Ranga Reddy [24], Surat [25], Sivasagar and Dibrugarh [26], Tamil Nadu [27] and Thane [28]. Only few researchers have discussed the health risk associated to the contaminated sites in India. Singh et. al. [29] discussed the risk assessment of heavy metals associated with contaminated vegetables in Varanasi. The reclamation of contaminated sites with perspective of future reuse of land requires assessment of land post cleanup with two perspectives, one its restoration with respect to possible land use and second with respect to reduced health risks to acceptable limits. Therefore, choice of remediation technology has to be primarily compatible with both these requirements apart from other criteria. It is in this context that health risk assessment has become of prime importance for any land reclamation and reuse project. In this study, three sites were selected out of pre-identified 557 contaminated sites, each from Andhra Pradesh, Rajasthan and Gujarat. Work has been already done at Balanagar Industrial Area, Hyderabad [12]; Pali Industrial Area, Rajasthan [23] and Surat Industrial Area, Gujarat [25] to determine the extent and concentration of heavy metals. Results presented by these authors were used in this study for the assessment of carcinogenic and non-carcinogenic health risks to human. Aims of this study are to: (1) determine the potential health risks to human induced due to contamination by heavy metals (2) provide a basis for the selection of remediation process, (3) define an acceptable level of contaminant concentration on the site.

II. Site Description

Three contaminated sites were selected from different parts of India. Concentrations of heavy metals presented by various researchers were used for the study. Site 1 is Balanagar industrial area situated in the north-western part of Hyderabad City, India [12]. Main industries causing the contamination in this site are: steel, chemical, automobiles, refineries and battery manufacturing. Site 2 is Pali industrial area, Pali district, Rajasthan, India which is also identified as polluted by Central Pollution Control Board (CPCB), New Delhi [23]. Around 300 industries exist in this area which includes chemical, dye, textile, paint and marble based industries. Site 3 is Surat industrial area situated in south Gujarat, India [25]. This site is also identified as polluted by Central Pollution Control Board (CPCB), New Delhi. There are large number of small scale and also several large and medium scale textile industries. Other industries that have come up in and around Surat include petrochemical, refinery, natural gas, cement, steel plant etc. Table 1 shows the heavy metal concentration present on each site.

Table 1: Heavy metal concentrations in soil

Site	Conc.	Ba	Co	Cr	Cu	Ni	Pb	Rb	Sr	V	Y	Zn	Zr
Site 1	Min.	536.5	8.6	84.2	31.3	34.3	57.4	54	66.5	66.6	10.3	67.5	144.5
	Max.	2732.4	54.8	2264.4	1040.4	127.9	12748.2	211.5	242.7	156.1	45.7	5819.5	710.2
	Avg.	859.8	17.6	371.98	214.76	55.86	900.89	143.15	112.01	87.08	27.28	811.75	404.41
Site 2	Min.	-	-	40	10	-	10	-	222	43	-	48	-
	Max.	-	-	240	298	-	293	-	2694	377	-	1364	-
	Avg.	-	-	154.8	93.7	-	57.05	-	952.7	102.7	-	357.5	-
Site 3	Min.	266.3	24.4	100.4	77.1	33.7	-	-	91.4	141.9	-	91.0	-
	Max.	471.7	51.3	305.2	137.5	79	-	-	317.9	380.6	-	139	-
	Avg.	386.2	45.7	196.8	111	48	-	-	188.5	284.8	-	109.4	-

Table 2: Chronic Average Daily Demand (CADD) can be calculated by using the following formulas

Chronic Average Daily Dose (CADD)			Reference
Ingestion	Inhalation	Dermal Contact	
$\frac{C \times IingR \times EF \times ED \times CF}{BW \times AT}$	$\frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT}$	$\frac{C \times SA \times ABS \times AF \times EF \times ED \times CF}{BW \times AT}$	[30]

Table 3: Factors used for estimation of CADD for cancer and non-cancer risk

Factors	Symbol	Unit	Value				Reference
			Adult	Child	Worker		
					Outdoor	Indoor	
Soil Ingestion rate	IngR	mg/day	100	200	100	50	[31]
Exposure Duration	ED	Year	24	6	25	25	[31]
Exposure Frequency	EF	day/year	350	350	305	305	[31], [32]
Average body weight	BW	Kg	63	14	63	63	[33], [34]
Average time for non-cancer risk	AT*	Days	8760	2190	25550	25550	[31]
Average time for cancer risk	AT*	Days	24258	24258	24258	24258	[31]
Conversion Factor	CF	Kg/mg	$1x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$	$1x10^{-6}$	[31]
Surface area of the skin that contact the soil	SA	cm^2/event	5700	2800	3300	3300	[31]
Skin adherence factor	AF_{soil}	mg/cm^2	0.07	0.2	0.2	NA	[31]
Dermal absorption factor for NCR	ABS	mg/cm^2	0.001	0.001	0.001	0.001	[35]

Dermal absorption factor for CR	ABS	mg/cm^2	0.03	0.03	0.03	0.03	[35]
Inhalation factor	InhR	m^3/day	20	20	20	20	[31]
Particle emission factor	PEF	m^3/day	$1.36x10^9$	$1.36x10^9$	$1.36x10^9$	$1.36x10^9$	[31]
Life Time (ED for cancer risk)	LT	Year	66.46				[36]

III. Risk Assessment

Main Components of risk assessment are hazard identification, dose response assessment and exposure assessment. Hazard identification is referred to the potential harm caused by contaminant to the human and/or environmental health. A dose-response relationship describes how the likelihood and severity of adverse health effects are related to the amount and condition of exposure to a receptor [31]. Exposure assessment is the determination or estimation of the magnitude, frequency, duration and route of exposure [30]. Human health risk is calculated in the term of non-carcinogenic risk (as Hazard Index) and carcinogenic risk.

Health risk analysis was done on the basis of minimum, maximum and mean concentration of contaminants for the each of the receptors (adult, child and industrial worker). Exposure of contaminant to the human can occur by any one or more of the following pathways: (a) soil ingestion (b) inhalation of dust particles (c) dermal absorption. In this study, risk assessment of heavy metals on all the receptors by all these three pathways is discussed. Analysis was made for the chronic exposure duration. In case of humans, chronic exposure duration varies from 7 years to lifetime.

Non Carcinogenic health risk is measured in terms of chronic Hazard Quotient (HQ), which is calculated as (equation 1):

$$HQ = \frac{CADD}{RfD} \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where, CADD- Chronic Average Daily Demand and RfD- Reference Dose.

Formulas used for calculating CADD are give in table 2 and the factors used for the estimation of CADD are illustrated in table 3.

Reference Dose indicates that below that concentration, there will be no harm to even most sensitive receptor. If the HQ exceeds the unity, then site is considered to be associated with non-cancer health risk. For more than one contaminant, HQs are added to get Hazard Index (HI). (Eqn. 2)

$$HI = \sum_{i=1}^{n}\sum_{j=1}^{n} HQ \dots\dots\dots\dots\dots\dots\dots (2)$$

Carcinogenic Risk is estimated for the lifetime exposure and calculated by multiplying Lifetime Average Daily Dose (LADD) to Cancer Slope Factor (CSF). (Eqn. 3)

$Risk = LADD\ x\ CSF \dots\dots\dots\dots\dots\dots\dots$ (3)

This linear equation of carcinogenic risk estimation is valid only at risk level below 0.01. For the risk more than 0.01, the one hit equation is used (Eqn. 4):

$$Risk = 1 - e^{-LADD\ x\ CSF} \dots\dots\dots\dots\dots\dots\dots (4)$$

Total carcinogenic Risk is estimated as (Eqn. 5)-

$$Cancer\ Risk = \sum_{i=1}^{n}\sum_{i=1}^{n} Risk \dots\dots\dots\dots\dots\dots\dots (5)$$

If the cancer risk value exceeds the 1 x 10^{-6} than it may cause potential cancer risk to human.

IV. Results And Discussion

By using the concentrations given in table 3 non-carcinogenic risk (HI) and carcinogenic risk are evaluated for all the three sites. Table 4 shows HI values for all the receptors based on mean and maximum concentrations for site 1. It shows that site is associated with high potential non-carcinogenic health risks. Table 5 shows HI values through different pathways based on mean concentrations for site 1. It shows that risk is associated mainly due to ingestion pathway. Table 6 shows carcinogenic health risks for all the receptors based on mean and maximum concentrations for site 1. It shows that site 1 is associated with the high carcinogenic risk to each of the receptors as the risk value exceeds the safe value of $1x10^{-6}$. Table 7 shows cancer risk through different pathways based on mean concentrations for site 1. It also shows that risk is highest through ingestion and minimum through inhalation. HI values of Cr were observed 10.869 and 1.389 for child and adult, respectively based on maximum concentration and 1.7855 for child as per mean value. HI values of Pb for child were 3.5496 and 50.229 based on mean and maximum concentrations, respectively and 5.86 for industrial worker based on maximum concentration. HI of Zr for child,

adult and industrial worker were 110.81, 12.3 and 12.86 based on mean concentration and 194.59, 21.6 and 29.935 based on maximum concentration. Hence more attention must be paid to Cr, Pb and Zr. Table 8 shows HI values for all the receptors based on mean and maximum concentrations for site 2. It shows HI for Child as 1.32 and 3.56 based on mean and maximum concentrations respectively, hence it is stated that site may cause potential non-carcinogenic health risk to child. Table 9 shows HI values through different pathways based on mean concentrations for site 2. It shows that risk is associated mainly due to ingestion pathway. Table 10 shows carcinogenic health risks for all the receptors based on mean and maximum concentrations for site 2. It shows that site 2 is associated with significant carcinogenic risk to each of the receptors as the risk value exceeds the safe value of $1x10^{-6}$. Table 11 shows cancer risk through different pathways based on mean concentrations for site 2. It also shows that risk is highest through ingestion and minimum through inhalation. HI of Cr, Pb and V for child were found to be 1.52, 1.154 and 1.024, respectively based on maximum concentration.

Table 4: Non- Carcinogenic risk to different receptors for site 1

Receptors	HI	
	Based on mean concentration	Based on maximum concentration
Adult	12.63	23.86
Child	116.61	257.096
Industrial Worker	13.546	29.935

Table 5: Non-Carcinogenic risk through different pathways for site 1

Receptors	HI (Based on mean concentration)		
	Ingestion	Inhalation	Dermal contact
Child	116.4983809	0.00402636	0.108514116
Adult	12.58979226	0.00089297	0.049155275
Industrial Worker	13.52061501	0.000777	0.02478

Table 6: Total carcinogenic risk to different receptors for site 1

Receptors	Cancer Risk	
	Based on mean concentration	Based on maximum concentration
Adult	295.9×10^{-6}	1896×10^{-6}
Child	$2655x\ 10^{-6}$	16893×10^{-6}
Industrial Worker	$308.5x\ 10^{-6}$	1976×10^{-6}

Table 7: Carcinogenic risk through different pathways for site 1

Receptors	Cancer Risk (Based on mean concentration)		
	Ingestion	Inhalation	Dermal contact
Child	2652.9×10^{-6}	0.19×10^{-6}	2.59×10^{-6}
Adult	$294.7x\ 10^{-6}$	0.043×10^{-6}	$1.17x\ 10^{-6}$
Industrial Worker	$307.9x\ 10^{-6}$	0.0377×10^{-6}	$0.59x\ 10^{-6}$

Table 8: Non- carcinogenic risk to different receptors for site 2

Receptors	HI	
	Based on mean concentration	Based on maximum concentration
Adult	0.159	0.418
Child	1.32	3.56
Industrial Worker	0.0835	0.3067

Table 9: Non-carcinogenic risk through different pathways for site 2

Receptors	HI (Based on mean concentration)		
	Ingestion	Inhalation	Dermal contact
Child	1.282074641	0.001583407	0.036768807
Adult	0.142431942	0.000351171	0.016655721
Industrial Worker	0.0749559	0.00018656	0.008396

Table 10: Total carcinogenic risk to different receptors for site 2

Receptors	Cancer Risk	
	Based on mean concentration	Based on max concentration
Adult	119×10^{-6}	187×10^{-6}
Child	1068×10^{-6}	1679×10^{-6}
Industrial Worker	124×10^{-6}	1068×10^{-6}

Table 11: Carcinogenic risk through different pathways for site 2

Receptors	Cancer Risk (Based on mean Concentration)		
	Ingestion	Inhalation	Dermal Contact
Child	1067.023×10^{-6}	0.0786×10^{-6}	1.043×10^{-6}
Adult	118.54×10^{-6}	0.01744×10^{-6}	0.47×10^{-6}
Industrial Worker	123.8×10^{-6}	0.01518×10^{-6}	0.238×10^{-6}

Table 12: Non- carcinogenic risk to different receptors for site 3

Receptors	HI	
	Based on mean concentration	Based on max concentration
Adult	0.253	0.358
Child	2.1429	3.0038
Industrial Worker	0.25	0.3567

T**able 13**: Non-carcinogenic risk through different pathways for site 3

Receptors	HI (Based on mean concentration)		
	Ingestion	Inhalation	Dermal contact
Child	2.095547665	0.001993191	0.045402475
Adult	0.232804638	0.000442054	0.020566643
Industrial Worker	0.243205897	0.000385	0.010368

Table 14: Carcinogenic risk to different receptors for site 3

Receptors	Cancer Risk	
	Based on mean concentration	Based on maximum concentration
Adult	150.39×10^{-6}	233.3×10^{-6}
Child	1349.48×10^{-6}	2092.8×10^{-6}
Industrial Worker	156.7×10^{-6}	243.1×10^{-6}

Table 15: Carcinogenic risk through different pathways for site 3

Receptors	Cancer Risk (Based on mean concentration)		
	Ingestion	Inhalation	Dermal Contact
Child	1348.08×10^{-6}	0.09×10^{-6}	1.31×10^{-6}
Adult	149.7×10^{-6}	0.022×10^{-6}	0.59×10^{-6}
Industrial Worker	156.45×10^{-6}	0.019×10^{-6}	0.3×10^{-6}

Table 12 shows HI values for all the receptors based on mean and maximum concentrations for site 3. It shows that site 3 is associated with non-carcinogenic health risks only for child. Table 13 shows HI values through different pathways based on mean concentrations for site 3. It shows that risk is associated mainly due to ingestion pathway. Table 14 shows carcinogenic health risks for all the receptors based on mean and maximum concentrations for site 3. It shows that site 3 is associated with the high carcinogenic risk to each of the receptors as the risk value exceeds the safe value of $1x10^{-6}$. Table 15 shows cancer risk through different pathways based on mean concentrations for site 3. It also shows that risk is highest through ingestion and minimum through inhalation. Site has only Cr causing potential carcinogenic risks to all the receptors.

V. Conclusion

Three contaminated sites from different parts of India were selected and health risk assessment was done in order to determine the associated health risks of contaminants present at these sites. Results of the previous work on the concentration of heavy metals at these sites done by various researchers were adopted for risk assessment. Results suggest that site 1 (i.e., Balanagar industrial area) has highest potential for carcinogenic and non-carcinogenic diseases in all the receptors. Site 2 (Pali Industrial Area) and site 3 (Surat Industrial Area) have non-carcinogenic risk only for children. But both sites have significant carcinogenic risk for all the receptors. Children are found to be most susceptible to carcinogenic and non carcinogenic diseases as compared to adult and industrial worker. Ingestion is found to be major pathway for both the diseases in all cases. Children are subjected to cancer risks due to dermal contact also. But inhalation does not cause any significant risk in any of the cases.

At site 1, mainly Cr, Pb and Zr are responsible for the non-carcinogenic health risks to the receptors. Cr and Pb are also carcinogens, hence causing carcinogenic health risks at site 1. Hence more attention must be given to remove Cr, Pb and Zr from the site during the remediation process. Site 2 has Cr, Pb and V which are the main cause of potential non-carcinogenic health risks to children. Cr and Pb are also responsible for carcinogenic health risks to receptors. Site 3 has mainly Cr which cannot be avoidable as it causes carcinogenic health risks to human. Hence, remediation process must be selected keeping in view future land use and health risk to remove all these heavy metals to acceptable limits. Priority should be given to site 1 as it has highest values of HI and carcinogenic risks.

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