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Human Health Risk Assessment for Inhabitants of Four Towns of Rajshahi, Bangladesh due to Arsenic, Cadmium and Lead Exposure

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Abstract

We performed a risk assessment for inhabitants of four towns of Rajshahi, Bangladesh beside the silt (toxic metal enriched) carrying river Padma due to arsenic, cadmium and lead exposures from consumption of rice, vegetables, fish, drinking water and dust. As, Cd and Pb concentrations in the samples (n=300) ranged 0.002-3.441, 0.001-0.017 and 0.001-0.398 μg/g (w/w) respectively. Since $P<0.05$, Levene and Kruskal-Wallis tests revealed that there were statistically significant differences amongst both standard deviations and medians of the data at 95% confidence level respectively. Generally concentrations of the concerned metals in the samples followed the order: Dust>Rice>Fish>Vegetables>Drinking water. Bangladesh consumption rate showed that rice alone imposed most of As and Pb load, whereas drinking water most of Cd load. We utilized USEPA risk assessment model and considered potential exposure pathways (diet and non-diet ingestion, and dust inhalation). Ingestion accounted for 95.0-99.9% exposure, whereas inhalation only 0.1-5.0% exposure. Risk, defined as 'Hazard Index' (HI), was mapped for three population sub-groups: *Highly Exposed Child, Average Person and Senior*. The results showed that all children (0-6 years) were at health risk, whereas 70% of seniors and 60% of average persons (i.e., adults) were safe in consuming the foods. The contribution of the metals in total exposure was As(69%)>Cd(21%)>

Pb(10%). This study highlights the importance of sight-specific human health risk assessment considering more pollutant parameters.

Keywords: human health; risk assessment; arsenic; lead; cadmium; exposure

1. Introduction

British Geological Survey (BGS) in 2001 showed that the groundwater (n=3,540) of shallow aquifer, used for both drinking and irrigation purposes, in 60 out of 64 districts of Bangladesh was contaminated with arsenic (BGS/ DPHE, 2001). In Chapai Nawabganj district the highest concentration of arsenic in tube-well water was found as 2,400 µg/L (BGS/ DPHE, 2001), whereas WHO guideline value for drinking water was 50 µg/L for Bangladesh and 10 µg/L for many other countries (WHO, 2017). An estimated 24 million people are directly exposed to this contamination and another 75 million are at risk (Engconsult Limited, 2017; WHO, 2016a).Nearly 10,000 arsenicosis patients had been identified and a few deaths due to arsenic related diseases had also been reported (Engconsult Limited, 2017; Fazal et al., 2001; SOES/DCH, 2000). Clearly Bangladesh is facing the probably the largest mass poisoning in history. According to BGS (2001) and, Saha and Ali (2007), the groundwater of Bangladesh was moderately contaminated with lead and least contaminated with cadmium.

The area under irrigation has been increased significantly over the last fifteen years in Bangladesh to raise food production mainly through installation of shallow tube-wells (BBS, 2017). Islam and his co-authors (2012) found that vegetables were good accumulators of arsenic and arsenic accumulated in vegetables exponentially due to successive harvesting. Das et al. (2004) investigated arsenic concentrations in rice, vegetables and fishes in Bangladesh and found that some of these exceeded some food safety legislation limit (Table 4). Saha and Zaman (2011) investigated the cereals such as rice, wheat and urid beans of Shibganj, Chapai Nawabganj, Bangladesh and found high lead contents ranging 7.31-12.33 µg/g (dw). All samples exceeded FAO/WHO CODEX recommended maximum permissible limit of Pb in foodstuff which was 0.2 µg g-1 (FAO/ WHO, 2009b). Obviously, increased use of arsenic and other metal contaminated groundwater for irrigation purpose suggests that consumption of the irrigated crops and vegetables could be another major exposure route of arsenic and heavy metals in humans in Bangladesh.

There are two major processes by which a chemical can cross the boundary from outside to inside the human body (USEPA, 2016, 1992). The first process is intake that involves physically moving the chemical through an opening in the outer boundary (usually the mouth or nose), typically via inhalation, eating, or drinking

(Figure 1). The second process is uptake that involves absorption of the chemical through skin (Figure 1), where mass transfer occurs by diffusion. Irrespective of exposure pathways, arsenic, cadmium and lead are cumulative poisons that do not metabolized in other intermediate compounds easily and do not easily break down in environment (Adal, 2017). Arsenic, defined as Group 1 carcinogen by International Agency for Research on Cancer (IARC, 2012a), causes acute lethality to chronic effects. Chronic arsenic exposure leads to vascular diseases, hypertension, cancer, hyperpigmentation, genotoxicity, diabetes mellitus, repeated abortions, stillbirth, preeclampsia, etc. (USEPA, 2001; ATSDR, 2013; WHO, 2016). Cadmium is a possible human carcinogen of class B1 (IARC, 2012b). Long-term cadmium exposure leads to cancer, kidney dysfunction, bone fracture, genotoxicity, etc. (IARC, 2012b; WHO, 2010). Lead exposure also causes anaemia, hypertension, renal impairment, immunotoxicity, dysfunction of central nervous system and brain, etc. (ATSDR, 2007; IARC, 2006; WHO, 2016b).

2. Materials and Methods

2.1 Study Area

The study area is situated at the northwestern part of Bangladesh, namely, Rajshahi Sadar Upazilla of Rajshahi district, which is under 12 number Ward of Rajshahi City Corporation (RCC) authority. It is located between 24°19´N to 24°22´N and 88°35´E to 88°36´E that covers an area of about 10.5 sq. kilometer (Figure 2). The studied four urban Towns were Rani Bazar, Shaheb Bazar, Futhkipara and Kumarpara. The reason for selecting the towns is that the river

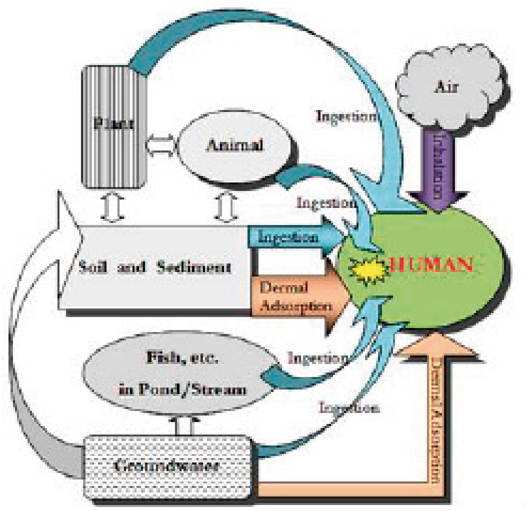

Figure 1. Exposure pathways of heavy metals to human beings in nature.

Padma (also called Ganges) flows adjacent to these Towns that carries a huge amount of silt from India every year as Himalayan drain, a fraction of which contains toxic heavy metals such as Cr, Pb, etc. (Zereen et al., 2000).

2.2 *Sampling of Diets and Non-diet*

For sampling five houses were selected in random from each town, comprising a total of 20 houses. The five samples that were collected from each house included rice, vegetables, fish, drinking water and dust. The owners of the houses used to collect rice, vegetables and fishes (of the river Padma) from their near-by market Shaheb Bazar, but they fetched drinking water from their adjacent tube-wells. The collected vegetables were fresh and the fishes were kept refrigerated at -20°C until frozen. In order to get aquifer water the tube-wells were flushed with 2-3 tube-well volumes of groundwater. The water was collected in polyethylene bottles and acidified with conc. HNO3 to keep pH below 2 (APHA, 2017). The dust samples were collected mainly by sweeping the shelves and floor where they stayed most of the time. At laboratory, the vegetables and fish samples were washed with distilled deionized water (DDW), cut into pieces and dried in an oven at 80-100°C for 24 h. Rice was dried in a similar manner without washing. The dried materials were subjected to grinding with ceramic mortar and pestle followed by sieving with 0.5 mm screen. The dust sample after drying at 105°C for 48 h was ground and sieved as before.

2.3 *Extraction and Estimation of the Metals*

For extraction of As, Cd and Pb, the water samples were subjected to mild digestion with HNO3 (APHA, 2017), dust samples were digested by modified method of Small and McCants with H_2SO_4-$HClO_4$ (volume ratio of

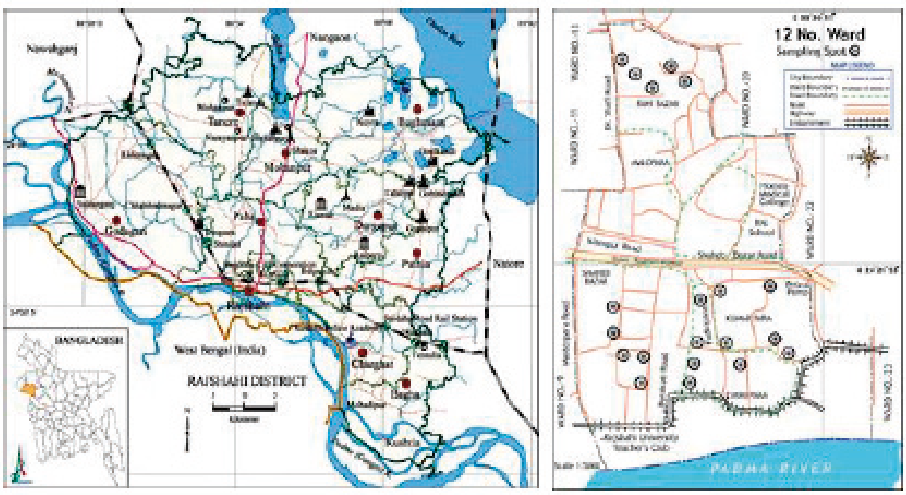

Figure 2. Study area for risk assessment. [Sampling spots are marked by]

2 : 3) (Sakamoto et al, 2001; Hesse, 1994; Shimadzu Cookbook) and, vegetables, rice and fish samples were digested through Wet Oxidation by HNO_3-H_2SO_4- $HClO_4$ (volume ratio of 10: 1: 4) (Hesse, 1994; Jackson, 1958; Shimadzu Cookbook) . Prior to wet oxidation the samples were predigested with 69% (v/v) HNO3. The digestates, after dilution with 6M HCl and then DDW, were analyzed for total concentrations of As, Cd and Pb by GF-AAS using a Shimadzu AA-6800 (Shimadzu Corporation, Kyoto, Japan) atomic absorption spectrophotometer. It was equipped with an auto-sampler (ASC-6100, Shimadzu) and a graphite furnace (GFA-EX7, Shimadzu), and operated through 'WizAArd' software. Certified reference materials (CRM) of As, Cd and Pb standard solutions for AAS (TraceCERT®) (Fluka, Switzerland) were used for calibration purposes. The minimum detection limits of As, Cd and Pb were 0.3, 0.02 and 0.15 μg/L respectively.

2.4 Model Development

For estimating total exposure of As, Cd and Pb for the consumers of the studied samples, we first estimate Average Daily Dose (ADD, mg/kg/d). Individual ADDs of arsenic contributed by each of rice, vegetables, fish, drinking water and soil were estimated utilizing the following equation as suggested by U. S. EPA Guidelines for Human Exposure Assessment (USEPA, 2016; USEPA, 1992):

$$^{AS}\,ADD_{Diet\,/Non\,diet} = \frac{^{As}\,C_{Diet\,/Non\,diet}\,.\,IR.ED}{BW.AT}$$

where $^{As}C_{Diet/Non\text{-}diet}$ is the concentration (mg/kg, ww) of arsenic in a particular dietary item or soil, IR is ingestion rate (kg/day, ww) for the diet/non-diet, *ED* is exposure duration (yr), *BW* is the body weight (kg) and *AT* is averaging time (yr) (Table 1). We considered bio-accumulation by multiplying equation (1) by relative bio-availability factor, *RBAF*. $^{As}ADD_{Ingestion}$ was then estimated as follows:

$$^{As}ADD_{Ingestion} = \Sigma^{As}ADD_{Diet} + {}^{As}ADD_{Non\text{-}diet} \quad (2)$$

$$^{As}ADD_{Ingestion} = ({}^{As}ADD_{Rice} + {}^{As}ADD_{Veg} + {}^{As}ADD_{Fish} + {}^{As}ADD_{Water}) + {}^{As}ADD_{Soil} \quad (3)$$

The term $^{As}ADD_{Soil}$ is included as we passively eat some soil adhered to foods, e.g., vegetables (Hough, 2004; USEPA, 2011). Similarly, $^{Pb}ADD_{Ingestion}$ and $^{Cd}ADD_{Ingestion}$ were calculated.

For dust inhalation, first concentration of inhaled arsenic, for example, in indoor air was estimated from existing indoor dust using the following equation (USEPA, 2011):

$$[As]_{air} = D \times M_{PM} \times F_{PM} \times F_{count} \quad (4)$$

where, *D* is the concentration of dust in the air [assumed the standard value of 70.0 μg/m^3 (USEPA, 2011)] . M_{PM} is the arsenic concentration on airborne particulate matter (assumed equal to $[As]_{dust}$ where dust is derived from the soil),

F_{PM} is the proportion of particulate matter that is respirable [assumed PM_{10} ~ 73% as 27% of airborne particles are generally found to be > 10 μm in equivalent diameter] and F_{cont} is the fraction of dust that is derived from the contaminated source. For indoors, $F_{cont} = 0.445[M_{soil}]$ because 44.5% of indoor dust is considered to be derived from outdoor soil. This yielded

$$[As]_{air} = (70.0\ \mu g/m^3) \times [As]_{dust}\ (mg/kg)\ 0.27 \times 0.445\ \mu g/m^3$$

$$Or,\ [As]_{air} = (0.070\ mg/m^3) \times [As]_{dust} \times 0.27 \times 0.445\ \mu g/m^3$$

Dust inhalation model was the same as equation (1) from where $^{As}ADD_{Inhalation}$ was obtained (USEPA, 2011). Similar calculations were made for Cd and Pb.

Considering the potential routes of entry of the metal into human body, the term $^{As}ADD_{Total}$ was defined as: $^{As}ADD_{Total} = {}^{As}ADD_{Ingestion} + {}^{As}ADD_{Inhalation}$. Similarly $^{Cd}ADD_{Total}$ and $^{Pb}ADD_{Total}$ were calculated. We ignored dermal adsorption as its contribution to total ADD is extremely small (USEPA, 2001). The parameters involved in ADD estimation are summarized in Table 1. These were adapted from the data of Exposure Factor Handbook (USEPA, 2011), US EPA standard values (USEPA, 2002) and Bangladesh surveys and standards (BBS, 2010). ADD were estimated for three population subgroups: *'Highly Exposed Child'*, *'Average Person'* and *'Senior'*. The children of 0-6 years age are often referred to as 'High Exposed Individuals (HEIs)'.

Table 1. Parameters involved in the risk assessment model.

Factors	Unit	Population sub-group		
		Children (0-6 yr)	Average Person	Senior
Age	yr	6	39.5	60.3
Body weight (BW)	kg	18.6	80.8	82.6
Rice ingestion rate	g (ww.)/d	100	344	300
Vegetable ingestion rate	g (ww.)/d	60	155	120
Fish ingestion rate	g (ww.)/d	40	60	60
Water ingestion rate	L/d	1.4	2.5	2
Soil and dust ingestion rate	mg (ww.)/d	100	50	50
Dust inhalation rate	m^3/d	10.1	16	15.7
Exposure frequency (EF)	d/yr	350	350	350
Year	d	365.25	365.25	365.25
Averaging time (AT)	yr	6	30	50
Exposure duration (ED)	yr	6	30	50
Relative Bio-availability Factor (RBAF)	(unit less)	As: 0.4, Cd: 0.6, Pb: 0.6		

Table 2. Metal reference dose (RfD), experimental dose and provisional tolerable weekly intake (PTWI).

Metal	Experimental dose (mg/kg/d)	RfD (mg/kg/d)			FAO/WHO PTWI (µg/kg BW)
		Children	Adults	Senior	
As	NOAEL: 8.0×10^{-4} LOAEL: 0.014	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	15
Cd	NOAEL (food): 0.01 LOAEL: N/A	5.0×10^{-4}	3.0×10^{-2}	1.0×10^{-3}	7
Pb	NOAEL: 25 µg/dL LOAEL: 0.02	5.0×10^{-4}	5.0×10^{-4}	5.0×10^{-4}	25

2.5 Risk Characterization

Risk may be characterized using a hazard quotient (HQ). This is the ratio of ADD of a chemical to a reference dose (RfD) defined as the maximum tolerable daily intake of a specific metal that does not result in any deleterious health effects. The RfDs, may be derived from a NOAEL (No Observed Adverse Effect Level) or a LOAEL (Low Observed Adverse Effect Level), were adapted from US EPA's Health Effects Notebook and Exposure Factors Handbook (USEPA, 2011) and California EPA's reference dose values (CalEPA, 2009) (Table 2). For arsenic,

$$^{AS}HQ_{Total} = \frac{^{As}ADD_{Total}}{RfD} \quad (5)$$

Similarly $^{Cd}HQ_{Total}$ and $^{Pb}HQ_{Total}$ were calculated. Then HI were estimated using the equation

$$HI = \Sigma^{M}HQ_{Total}$$

$$= {}^{As}HQ_{Total} + {}^{Cd}HQ_{Total} + {}^{Pb}HQ_{Total} \quad (6)$$

where M = As, Cd or Pb. Finally maps of HI were constructed for the three population sub-groups.

2.6 Quality Assurance

We followed USEPA approved QA/QC plan with a reagent blank, a duplicate and a spike for every 20 samples. All glassware was kept in 10% (v/v) HNO_3 for 48 h and rinsed with DDW several times before use. Certified reference materials (CRM) of As, Cd and Pb standard solutions for AAS (TraceCERT®) (Fluka, Switzerland) were used for calibration purposes. After analyzing every 10 samples, readings of standard solutions were recorded to check the instrument. Two certified reference materials [Tomato Leaves (SRM 1573a) and Lake Sediment (NIES CRM No. 31)] were digested and analyzed in five replicates for total As, Cd and Pb concentrations under the identical experimental conditions. The overall agreement between the certified and the observed results were in the range of 91-104% (Table 3).

2.7 Statistical Analyses

In our investigation each concentration value corresponds to an average of triplicate measurements. The datasets were treated separately for analyzing basic statistical parameters and for making cross-tabulations and cross-plots. The SPSS (version 20.0) and STATGRAPHICS Centurion (version 18.1.01) statistical software package, and Microsoft Excel (version 12.0.4518.1014) were employed for the purpose. ANOVA and Levene's Variance test were employed for analyses of variance of the data (Table 5). Kruskal-Wallis and Mood's median tests were also employed for analyses of median of the data.

3. Results and Discussion

3.1 Distribution of the Metals in Studied Diets and Non-diet

The statistical analyses of the observed concentrations of arsenic, cadmium and lead in the studied five types of samples, namely, rice, vegetables, fish, drinking water and dust (n=300) are presented in Table 4 The arsenic, cadmium and lead concentrations in the studied dietary samples ranged 0.002-0.527, 0.0003-0.0170 and 0.0002-0.0631 μg/g (ww) respectively. Our observed concentrations of arsenic, cadmium and lead in the dietary samples are in accordance with many authors (Williams et al, 2006; Alam et al, 2003). It was found that the tube-well water used for drinking purpose were all safe from arsenic and lead contamination, but all were unsafe of cadmium contamination with respect to WHO guideline values (0.010, 0.003 and 0.010 mg/L respectively for As, Cd and Pb (WHO, 2017). This is probably due to the fact that the studied urban area does not fall into 'hot-spots' of arsenic, where the concentrations of As and other metals are very high (Charlet et al, 2007; BGS/DPHE, 2001). Generally the concentrations of the concerned metals in the studied samples follow the order: Dust > Rice > Fish > Vegetables > Drinking water. The ANOVA table (Table 5) decomposes the variance of the data (n=100 for each of As, Cd and Pb) into two components: a between-group. component and a within a within-group component. Since P values of the F-tests were less than 0.05, there was a statistically significant difference between the means of the variables. Levene's test showed a statistically significant difference amongst the standard deviations at 95% confidence level. Kruskal-Wallis test revealed that there was a statistically significant difference amongst the medians at 95% confidence level, as P values were less than 0.05. The same observations were found in Mood's median test, as P values for the chi-square test were less than 0.05.

3.2 Arsenic, Cadmium and Lead Load

The Joint Food and Agriculture Organization (FAO) / World Health Organization (WHO) Expert Committee on Food Additives (JECFA) (FAO/WHO, 2011, 2009) has set Provisional TolerableWeekly Intake (PTWI) values for various metals/contaminants, below the dose would not cause any deleterious health

Table 3. Analysis of certified reference materials for total arsenic, cadmium and lead.

Sample	Metal	Certified values (µg/g)	Measured valuesa (µg/g)	% of recovery	n[b]
Tomato Leaves (SRM 1573a)	As	0.112 ± 0.004	0.117 ± 0.009	104	5
	Cd	1.52 ± 0.04	1.44 ± 0.12	95	5
	Pb	/	/	/	/
Lake Sediment (NIES CRM No. 31)	As	13.9 ± 1.5	13.5 ± 1.3	97	5
	Cd	0.342 ± 0.043	0.341 ± 0.045	100	5
	Pb	22.0 ± 3.0	20.0 ± 2.6	91	5

[a] the samples were analyzed by GF-AAS; [b] No. of measurements.

effect. The PTWI values for arsenic, cadmium and lead are 15, 7 and 25 µg/kg body weight respectively. The weekly total load of As, Cd and Pb due to ingestion of the dietary foods at Bangladeshi rate for the three population sub-groups is represented in Figure 3. Obviously rice alone imposes most of the arsenic and lead load, whereas drinking water imposes most of the cadmium load. This suggests that rice (staple food in Bangladesh and many countries of Asia) intake should be reduced that might be compensated by foodstuffs containing more gluten, e.g. wheat. Because it was reported (Bulka et al., 2007) that the diets containing less gluten might be exposed to higher levels of arsenic and mercury.

3.3 Exposure Pathways

Among the ingestion and inhalation processes, dust driven air was included in inhalation and the others were in ingestion processes. It was found that almost all (99.9%) of cadmium and lead, and 96.6% of arsenic exposure came from ingestion processes (Table 6). On an average, 98.84% exposure is contributed from ingestion processes, while the rest (1.16%) from inhalation process.

3.4 Metalwise Exposure

The hazard index (HI), which is the sum of hazard quotients, is a screening risk assessment technique commonly used to judge whether there is concern for additive effects between chemicals. If the hazard index is less than unity (1.00), it indicates that even if all the metals acted on the same organ or interacted in some other way to cause health effects, the risk of these effects would be low. Since different pollutants may cause similar adverse health effects, USEPA suggests combining hazard quotients associated with different substances. In the investigation we summed up total HQ for all the metals concerned (i.e., $HI = \Sum {}^{M}HQ_{Total} = {}^{As}HQ_{Total} + {}^{Cd}HQ_{Total} + {}^{Pb}HQ_{Total}$).

Table 4. Statistical analyses of arsenic, cadmium and lead data sets of the studied samples.

Concentration of metal (mg/kg, ww)								
Sample	**Metal**	**Range (Min -Max)**	**Mean ± SE**	**95% CI for mean**	**Median**	**Standard Deviation**	**Variance**	**Skewness**
Rice	As	0.045 - 0.276	0.077±0.011	0.054-0.099	0.065	0.049	0.002	4.009
	Cd	0.0003-0.0170	0.007±0.001	0.004-0.010	0.008	0.006	0.000	0.128
	Pb	0.0183-0.0631	0.040±0.003	0.033-0.047	0.045	0.015	0.000	-0.203
Vegetables	As	0.007 - 0.119	0.034±0.006	0.022-0.046	0.033	0.025	0.001	2.103
Fish	As	0.044 - 0.527	0.144±0.022	0.097-0.190	0.125	0.100	0.010	3.194
	Cd	0.0012-0.0066	0.003±0.000	0.003-0.004	0.003	0.002	0.000	1.013
	Pb	0.0017-0.0407	0.015±0.002	0.011-0.019	0.014	0.009	0.000	1.892
D. water	As	0.002 - 0.004	0.003±0.000	0.002-0.003	0.003	0.001	0.000	0.241
	Cd	0.0003-0.0132	0.003±0.001	0.001-0.004	0.001	0.003	0.000	1.768
	Pb	0.0065-0.3983	0.044±0.019	0.004-0.083	0.027	0.084	0.007	4.353

[a] the guideline values (GV) were according to WHO, FAO/WHO, Chinese and EC regulations;

[b] inorganic As; [c] 0.05 in Bangladesh.

Table 5. ANOVA Table for the distribution of the metals in studied samples.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Arsenic: Between groups	33.7121	4	8.42803	69.82	0.0000
Arsenic: Within groups	11.4674	95	0.12071		
Cadmium: Between groups	0.000382826	4	0.0000957064	10.28	0.0000
Cadmium: Within groups	0.000884508	95	0.0000093106		
Lead: Between groups	0.029872	4	0.00746793	5.05	0.0010
Lead: Within groups	0.140587	95	0.00147986		

The estimated average total HQ values ($^{M}HQ_{Total}$) of arsenic, cadmium and lead for the three population sub-groups are represented in Table 7. It is evident that in total exposure the contribution of the metals for all population subgroups follow the order: As (69%) > Cd (21) > Pb (10). Obviously arsenic alone averagely contributes roughly one-third of total HI. The HQ contributions for specific diets towards HI are in accordance with Figure 3.

3.5 *Risk Assessment*

Risk assessment strategies are often aimed at population sub-groups. It is common practice to identify vulnerable people in society, such young children or elderly, and assess potential risk to the health of these population sub-groups (GRCIRAT, 1999). Hough et al (2004) consid ered young children to be 'Highly Exposed Individuals (HEIs)'. Thus risk assessment can usually focus on highly exposed subpopulations on the basis that if the risk to the HEI is acceptable then most of the population is protected.

The estimated HI values were utilized to generate HI indexed maps for three population sub-groups (Figure 4) showing clearly where the

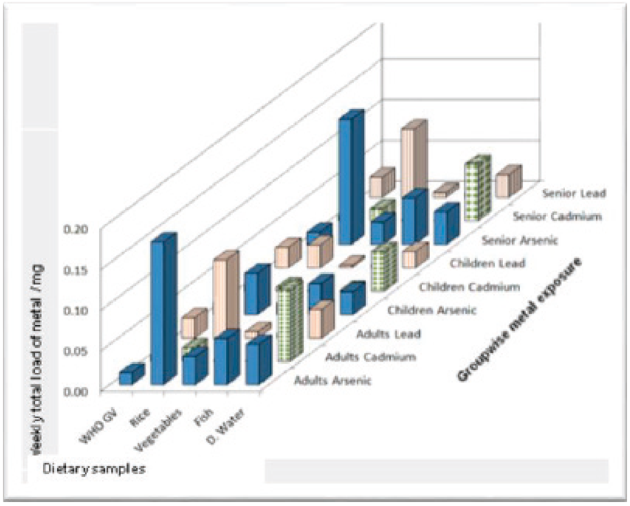

Figure 3. Groupwise weekly total load of arsenic, cadmium and lead for consuming the diets. [WHO guideline values (GV) are based on mg/kg body weight (FAO/WHO, 2011)

Table 6. Exposure pathwaywise contribution for three population sub-groups.

Population Sub-groups	Exposure Contribution (%)		
	Metal	Ingestion	Inhalation
Highly Exposed Child	As	99.28	0.72
	Cd	99.98	0.02
	Pb	99.94	0.06
Average person	As	95.55	4.45
	Cd	99.85	0.15
	Pb	99.98	0.02
Senior	As	95.03	4.97
	Cd	99.98	0.02
	Pb	99.96	0.04
Overall Average	As	96.62	3.38
	Cd	99.93	0.07
	Pb	99.96	0.04

Table 7. Metal wise average HQ contributions to HI values.

Population Sub-groups	Metal specific contribution of HQ to HI value (%)			
	$^{As}HQ_{Total}$	$^{Cd}HQ_{Total}$	$^{Pb}HQ_{Total}$	HI
Highly Exposed Child	59.88	21.60	18.52	100.00
Average Person	76.97	22.75	0.28	100.00
Senior	69.37	18.82	11.81	100.00
Overall Average	68.74	21.06	10.20	100.00

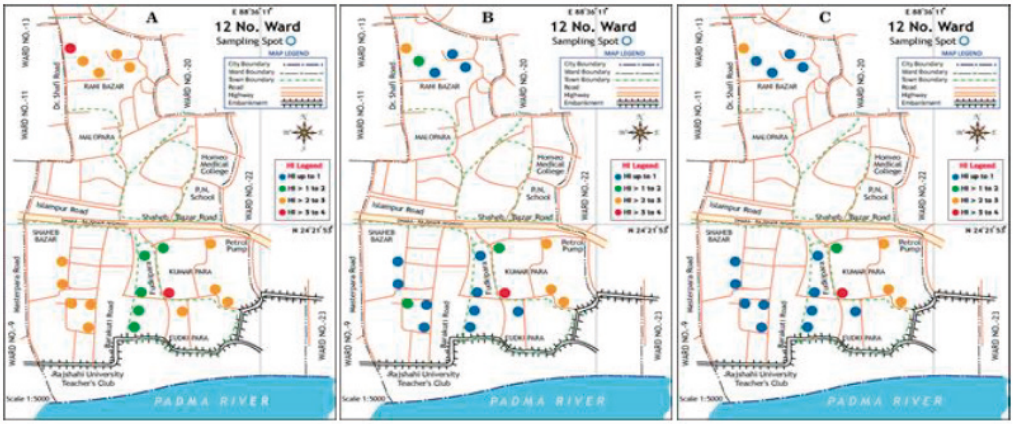

Figure 4. Map of Hazard Index (HI) values for inhabitants of four towns of RCC. [A: *Children,* B: *Average Person,* C: *Senior*]

greatest potential risks were located. The map (Figure 4 C) reveals that 70% of the Senior population sub-group was safe from consumption of the dietary foods as well as from inhalation, as HI < 1.00. The average HI for the entire Senior population sub-group was 0.96. This suggests that more than two-thirds of this population sub-group would not experience any form of deleterious health effects due to living within and consuming rice, vegetables, fish, drinking water and dust from this urban location.

Figure 4 A reflects that all the Children were in health risk due to consumption of the dietary foods and from inhalation, as HI > 1.00 for all cases. This is attributed to more consumption of foods with respect to their body weight and more intimacy with the contaminated dust/soil. The majority (65%) of the children had HI values between 2.00 and 3.00. The average HI for the Highly Exposed Child population sub-group was 2.36. The safety position of *Average Person* (i.e., Adult) population sub-group lied intermediate between child and senior. Clearly 60% of the adults were safe (Figure 4B) due to living within and consuming rice, vegetables, fish, drinking water and dust from this urban location. The average HI for the entire *Average Person* population sub-group was 1.00. Overall the human health safety order in the studied region was as follows: Senior > Average Person > Highly Exposed Child.

In UK, similar human health safety order was observed by Hough et al (2004) for consuming vegetables alone. BGS (BGS/DPHE, 2001) reported that the groundwater of Bangladesh was also contaminated with Co, Mn, Mo, Rb, Sr, U, etc. Moreover, there are some 'arsenic hot-spots' (a few kilometer across) in Chapai Nawabganj district (adjacent to Rajshahi district) and hydraulic modeling of BGS (BGS/DPHE, 2001) showed that the groundwater velocity of shallow aquifer ranged 5-20 mm/day. Thus this study highlights the importance of sight-specific human health risk assessment considering more pollutant parameters.

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