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Evaluation of heavy metal pollution risk associated with road sediment

Kazi Kader Newaz[1], Sudip Kumar Pal[2†], Shahadat Hossain[3], Ahsanul Kabir[4]

[1]*Department of Disaster & Environmental Engineering at Chittagong University of Engineering & Technology, Chittagong-4349 and Executive Engineer, Chittagong Development Authority, Bangladesh*
[2]*Department of Civil Engineering at Chittagong University of Engineering & Technology, Raozan, Pahartali, Chittagong-4349, Bangladesh*
[3]*Atomic Energy Center, Chittagong, Bangladesh Atomic Energy Commission, Bangladesh.*
[4]*Department of Renewable Energy and Environment, Faculty of Engineering Technology, University Malaysia Pahang, 26300 Gambang, Pahang, Malaysia*

Abstract

A detailed investigation has been conducted to assess the heavy metal pollution risk associated with the road deposited sediment collected from the 32 major road sites in Chittagong city. The acid digestion of road sediments for metals extraction was carried out prior to determine total concentrations of Zn, Pb, Cr, Cu, Ni, Cd by using Polarized Zeeman Atomic Absorption Spectrophotometer (Z-2000) following standard analytical protocol. The contamination and pollution risk level were assessed using degree of contamination, potential ecological risk index and integrated pollution index. The study revealed that the mean heavy metal concentrations of Zn, Pb, Cr, Cu, Ni, Cd were found as 975, 84, 77, 74, 32, 1.6 mg/kg, respectively, across the road sites in Chittagong city. The mean concentrations are found 1.1 to 44 times higher in comparison to soil background, signifying relatively greater enrichment for Zn, Cd and Pb across the sites, suggesting vehicular emission on roads with site-specific characteristics. Based on pollution indices, Ruby Cement, City Gate and Enayeth Bazar road sites pose high risk, while eight other sites are found with moderate to considerable risk potential, and remaining 21 sites pose low to moderate risk potential.

Keywords: Chittagong, Heavy metal, Pollution index, Risk index, Road dust Spectrophotometry

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† Corresponding Author
E-mail: sudip@cuet.ac.bd
Tel: +88 031-714948
Orchid: 0000-0002-1511-6984

1. Introduction

Environmental pollution caused by heavy metals is a major problem for the developing counties due to the rapid urbanization and industrialization, population growth, land use, and food production practices [1, 2]. Generally, urban areas/cities have been strongly influenced by anthropogenic activities, such as vehicles and industrial activities, since they have high population densities. Large volume of waste has been producing every day due to the consumption of substantial amounts of resources by the large population in city area. Persistent anthropogenic activities produce large amounts of various pollutants which treating the urban environment in many aspects. Consequently, the concentration of pollutants tends to be exceed its background values in many cities that causing varying degrees of contamination [3].

Roads are the major hub of urban communication and amenities which are frequently used by people of the cities for their daily activities. Roads play a major role in stimulating social and economic progress. However, the road surface was found as a major sink of urban diffusion pollution, although it comprises a small percentage of urban land uses [4]. Generally, an accumulation of solid particles in the form of organic and inorganic pollutants on the outdoor ground surfaces called road deposited sediment (RDS) was considered as a valuable medium to characterize urban environmental quality [5]. The road dust may act as a temporary sink of contaminants from a variety of mobile and stationary sources in urbanized areas, including anthropogenic activities, traffic emissions, industrial discharge, long range transport, domestic fossil fuel burning, construction and demolition activities, weathering of building and pavement, municipal activities, atmospheric deposition and natural geochemical processes [4, 6]. Particularly, road dust pollution was found to be significantly higher in the developing countries due to the unplanned urbanization; road surface pattern and poor maintenance practice; vehicle fitness; road-traffic management; and surrounding land uses. Road dust may act as a source of materials which could enter the atmosphere through re-suspension of particles, contributing to atmospheric pollution [7]. Moreover, they could also enter to the water body through surface runoff during rainy season, resulting in sediment contamination and eventually entering to the food chain [4, 6, 7]. Additionally, they could also enter the human body through direct ingestion of dust, inhalation of dust particles through the mouth and nose, and dermal absorption, threatening people's health [1]. However, the fine dust derived from the road traffic environment was seen to be contaminated by different constituents, mainly heavy metals, organics, other inorganic, animal dander, pollen fragments, mound spores, etc. [4, 6]. Among them, heavy metals in road dust can remain in urban environments for a long time or be re-suspended into the atmosphere, and thus pose a potential threat to local ecosystems and public health [8]. Moreover, heavy metals are priority environmental pollutants which are obviously cyto-toxic, concealed, persistent, and biological accumulated [9, 10]. They may cause permanent harm to the ecosystem and the human [11]. Thus, the heavy metals released from road dust could accumulate in different media such as water, soil, and the atmosphere, have been reported to cause environmental pollution in many cities [10]. It was realized from recent knowledge that the heavy metals could be a significant contributor of the urban diffuse pollution which directly affects the urban dwellers and pedestrian of the road and others [12]. Therefore, it is necessary to distinguish the contamination level and risk associated with heavy metals in road dust [13].

The evaluation of contamination level and risk associated with heavy metals in road dust have attracted much attention in recent years due to their concerning impacts. Likewise, the impact of heavy metals contamination on residents and environments of Chittagong city, Bangladesh is of a great concern. Chittagong, the port city and the 2nd largest city of Bangladesh, is considered as one of the most prominent commercial cities of South Asia. At present, the total population of Chittagong city was estimated around 4 million in 2019 and around 0.2 million adding to the total population every year (World population review/countries/Bangladesh). This population and current growth have accelerated the demand for services in all sectors of society. Huge amount of development works such as road construction, flyover or elevated road constructions, building construction, industrial infrastructure, etc. has been developed in public sector as well as in private sector to meet their demand and amenities. Moreover, traffic and transportation system of this city is squeezing day by day for its rapid urbanization and commercial activities. It accelerates the vehicle exhausts, industrial discharges, oil lubricants, automobile parts and particulate emission. As a result, the road dust of the Chittagong city is increasing enormously and its contamination by heavy metal assumed to be increased simultaneously, which could directly affect the city dwellers, pedestrian, tourists, and others. In this context, the evaluation of environmental pollution regarding heavy metal hazard in the road dust of this city could not be avoided. However, no such detail study about RDS considering the road network of Chittagong city was found in present literatures. Although, some studies have been conducted in different cities of developed countries [14-23], a very few studies were conducted in the developing countries [24-27]. Particularly, only one study was conducted for Dhaka City in Bangladesh [28]. It is worth noting that, a significant variability in the heavy metal concentrations among the available studies, as mentioned, demands local knowledge of this pollution aspect prior to taking any effective preventive measures. It is essential to identify the level and sources of heavy metals to control directly and effectively. Therefore, a detail study of heavy metal concentrations considering the road network of Chittagong city and its pollution risk associated with RDS would be conductive to assess the contamination level and to forecast environmental pollution risk of this city.

The objective of this study was to determine heavy metal concentrations in RDS of urban road network in order to assess their contamination level in Chittagong city. Furthermore, the environmental pollution risk was evaluated by calculating degree of contamination, potential ecological risk index and integrated pollution index. The results of this study would provide an important insight into heavy metal contamination level in the city of Chittagong and will be beneficial to the scientific society, the local authorities and policy makers of the municipality. To the best of our knowledge, no study was found to address this issue in the past; hence, this study would be a pioneer in this area to plug the data and information.

2. Material and Methods

2.1. Study Area

Chittagong, the commercial city of Bangladesh, is the financial and cultural center of Bangladesh (Fig. 1). Chittagong is situated at the southeastern border of the Bangladesh (91°46'-91°53' E, 22°14'-22°24' N) (Banglapedia, National encyclopedia of Bangladesh). The city is located on the banks of the Karnaphuli river between the Chittagong Hill Tracts and the Bay of Bengal. It is one of the most crowded cities in the Bangladesh. According to the World population review, it has a population of 3,920,222 making it the second largest city in the country. In 2020, its permanent population may exceed 4 million, with most of the population centered in urbanized areas.

Moreover, the city generates 40% of Bangladesh's industrial output, 80% of its international trade, and 50% of its governmental revenue (BBS, 2010). The Port of Chittagong handled USD 60 billion of annual trade in 2011, ranking 3rd position in the South Asia following the Port of Mumbai and the Port of Colombo. A wide variety of road network exists in the city since it is the financial hub of the country, and people of different categories are using these road networks for day to day uses (i.e., schooling, offices, amenities, business reason etc.). Moreover, a large number of cement industries, oil refineries, steel industries and brick kilns significantly causing atmospheric pollution. Subsequently, a large number of trips associated with heavy vehicles e.g. trucks, lorries, vans etc. are also causing traffic jam and emissions on roads. As seen in Fig. 1, the city is divided into 41 wards and each of which has different site and surrounding land uses pattern. After careful inspection of different characteristics associated with road traffic pollution, 32 major road sites scattered around the city were selected for road sediment sampling in order to assess heavy metal pollution from the road traffic environment. Based on the characteristics of urban road network, road sites were selected to collect road deposited sediment samples covering diverse features of road, such as straight portion, controlled and uncontrolled junctions, parking for different traffic maneuverings along with different land uses pattern that may have some inputs directly or indirectly to the metals emission patterns.

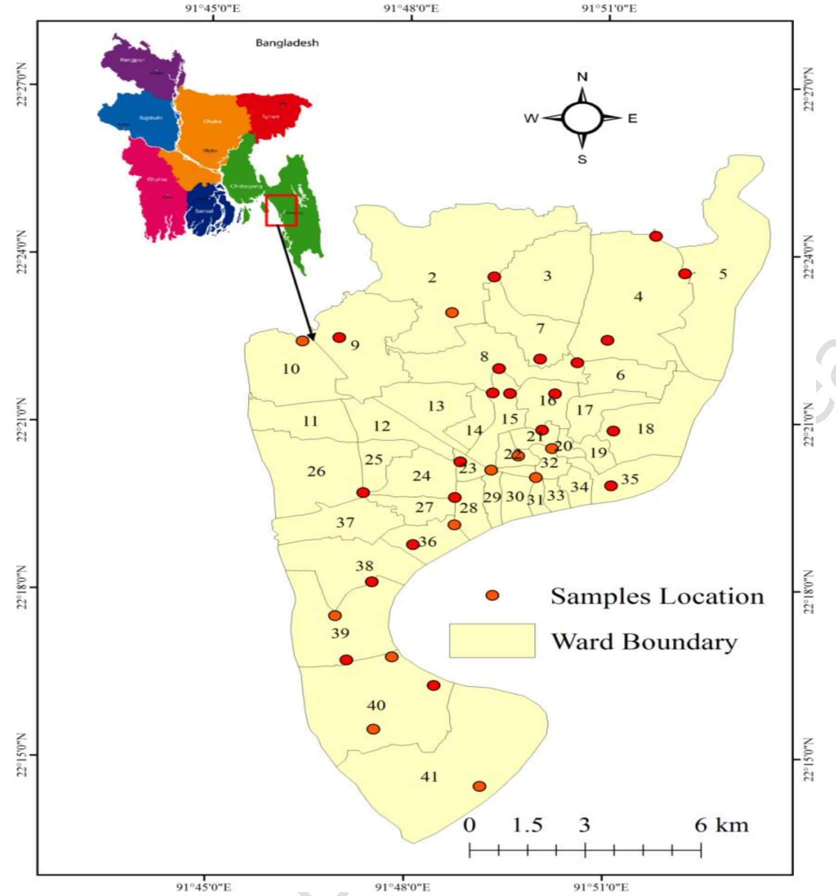

Fig. 1. Chittagong city ward boundary map showing road sediment sampling sites.

2.2. Sample Collection and Analysis

A total of sixty-five (65) road deposited and suspended sediment samples were collected from thirty-two (32) major road sites of Chittagong City. With a few exceptions, as seen in Fig. 1, the sampling road sites are well scattered around the city that is representatives of city's road network falls in 41 wards. The road sites not covered in few wards are due to very rural in nature compared to other sites. The samples were collected, from the 32 major road sites with urban road network characteristics, in late winter months of 2017. The winter period usually spanning from October to February when the weather is mostly dry, and this period receives rainfall very occasionally. As mentioned in the previous studies elsewhere [19, 23, 25], it is seen that heavy metal concentration is significantly higher with longer antecedent dry days. Hence, winter period was chosen to collect the sediment samples for this study. Road deposited sediment, especially very fine dust fraction size 75 µm or lower is subjected to re-suspension from deposition on roads, were collected from 32 major road intersections based on high vehicular density and distinguished urban characteristics around the major road networks in the city.

About 50 g of road dust sample was collected from each sampling site by street sweeping using a brush and dustpan. This is the most commonly used technique for the sampling which was frequently found to be used in other studies [17, 23, 29, 30]. The different sets of brushes and dust pans were used to avoid cross contamination among the collected samples. The collected samples were packed into self-sealing plastic bags and transported back to the Environmental Engineering Laboratory at Analytical Laboratory at Bangladesh Atomic Energy Commission, Chittagong center (BAEC) for extraction and determination using standard analytical laboratory protocol. The detail sampling procedure described by Pal [4] has been followed in the present study. In brief, all dust samples were air dried at room temperature (25 ± 2℃) and sieved though ASTM 200 mesh nylon sieve to remove coarse particle larger than 75 µm. The sieved dust samples were analyzed for metal contents according to standard methods (US-EPA, 1999). The acid mix of 70% nitric acid and HCl in 3:1 proportion by volume was used for digestion in road sediments for metals extraction following the procedure found in Pal [4]. Thereafter, total concentrations of Zn, Pb, Cr, Cu, Ni, Cd were determined by using Polarized Zeeman Atomic Absorption Spectrophotometer (Z-2000) following standard analytical protocol

[4, 12]. Calibration standards were prepared through serial dilution of standard stock solution of multi-elements having concentrations of 1,000 mg/L (Merck, Cat. No.111355). Standard solutions were used to validate the analytical method for quality control and assurance. All extractions and analyses were made with replicate samples (n = 3) and the mean values were reported. Blank samples were used time to time to avoid cross contamination.

2.3. Heavy Metal Pollution Assessment

Heavy metals associated pollution in relation to road deposited sediment or in any sediment are well documented in the literature [31, 32]. In this study, assessment of contamination of suspended/re-suspended road dust collected from road side plants, road barriers, road islands were performed taking several indicators, such as contamination factor (C_f), degree of contamination (C_{deg}), potential ecological risk index (RI), pollution index (PI) and integrated pollution index (IPI) in a hierarchy level. In line with Hakanson [33], Pal [4] and Suryawanshi et al. [31], the degree of contamination (C_{deg}) is the sum of contamination factors for all the elements being considered, as presented in Eq. (1).

$$C_{deg} = \sum C_f \quad (1)$$

While, C_f the contamination factor was defined in Eq. (2) as shown below:

$$C_f = C_i / C_n \quad (2)$$

Where, C_i is the mean concentration of individual metal, and C_n is the concentration of a reference value for individual metal. In this study, C_n for soil was adopted from the Indian natural soil background values referred by Kuhad et al. [42] and Gowd et al. [43]. The classifications of degree of contamination associated with six heavy metals in road sediment studied here were adjusted and revised accordingly as suggested by Suryawanshi et al. [31], as appropriate based on the concept derived by Hakanson [33]. The classifications based on degree of contamination used for this study are presented in Table S1.

The assessment of degree of heavy metal pollution risk on ecology was carried out using the index called potential ecological risk, based on the toxicity of metals and the response of the environment once it is washed off by manual sweeping/cleaning or natural rainfall-runoff events to the nearby water bodies, as proposed by Hakanson [33] according to the following equations Eq. (3) and Eq. (4):

$$RI = \sum E_r \quad (3)$$

$$E_r = T_r.C_f \quad (4)$$

Where, E_r is the monomial potential ecological risk factor, T_r is the metal toxic factor, C_f is the metal contamination factor, as defined previously. The RI classification suggested by Hakanson [33] was based on eight pollutants. In this study, a modified RI classification suggested by Zhang et al. [32], is being considered in order to evaluate the RI, as presented in Table S2.

To assess the degree of metal contamination, a revised PI for each metal and an IPI of the six metals were estimated for each sampling site using the equations Eqs. (5)-(8) suggested by Huang [34] in a similar nature.

$$PI = C/X_a \qquad \text{where, } C \leq X_a \quad (5)$$

$$PI = 1 + (C - X_a)/ (X_b - X_a) \qquad \text{where, } X_a < C \leq X_b \quad (6)$$

$$PI = 2 + (C - X_b)/(X_c - X_b) \qquad \text{where, } X_b < C \leq X_c \quad (7)$$

$$PI = 3 + (C - X_c)/(X_c - X_b) \qquad \text{where, } C > X_c \quad (8)$$

Where, C is the measured concentration of specific metal, X_a is the threshold concentration of the metal enrichment, X_b is the threshold concentration of the low level of pollution, and X_c is the threshold concentration of the high level of pollution. The values of X_a, X_b, and X_c, were adopted from Huang [34] and Bai et al. [35]. Following PI, the IPI of all measured elements for each sample is defined using Eq. (9) and then classified the pollution status based on PI and IPI according to the classification suggested by Bai et al. [35] in Table S3.

$$\mathrm{IPI} = \sum (\mathrm{PI} - 1) \tag{9}$$

3. Results and Discussion

3.1. Heavy Metal Concentrations

The concentration of the heavy metals (Cu, Pb, Zn, Cr, Cd, Ni) in road deposited sediment collected from 32 junctions of Chittagong City were determined and analyzed spatially as shown in Fig. 2. The range of heavy metal concentrations of Zn, Pb, Cr, Cu, Ni and Cd in road sediment were found as 296 to 4,220, 20 to 993, 21 to 413, 24 to 326, 3 to 227, 0.3 to 19 mg/kg, respectively, while the mean of these were 974, 84, 77, 74, 32, 1.6 mg/kg, respectively, across the sites in the city. The heavy metal concentrations observed in the present study were in good agreement with those found in the study of capital city Dhaka by Ahmed and Ishiga [28] and elsewhere in other cities [4, 12-27].

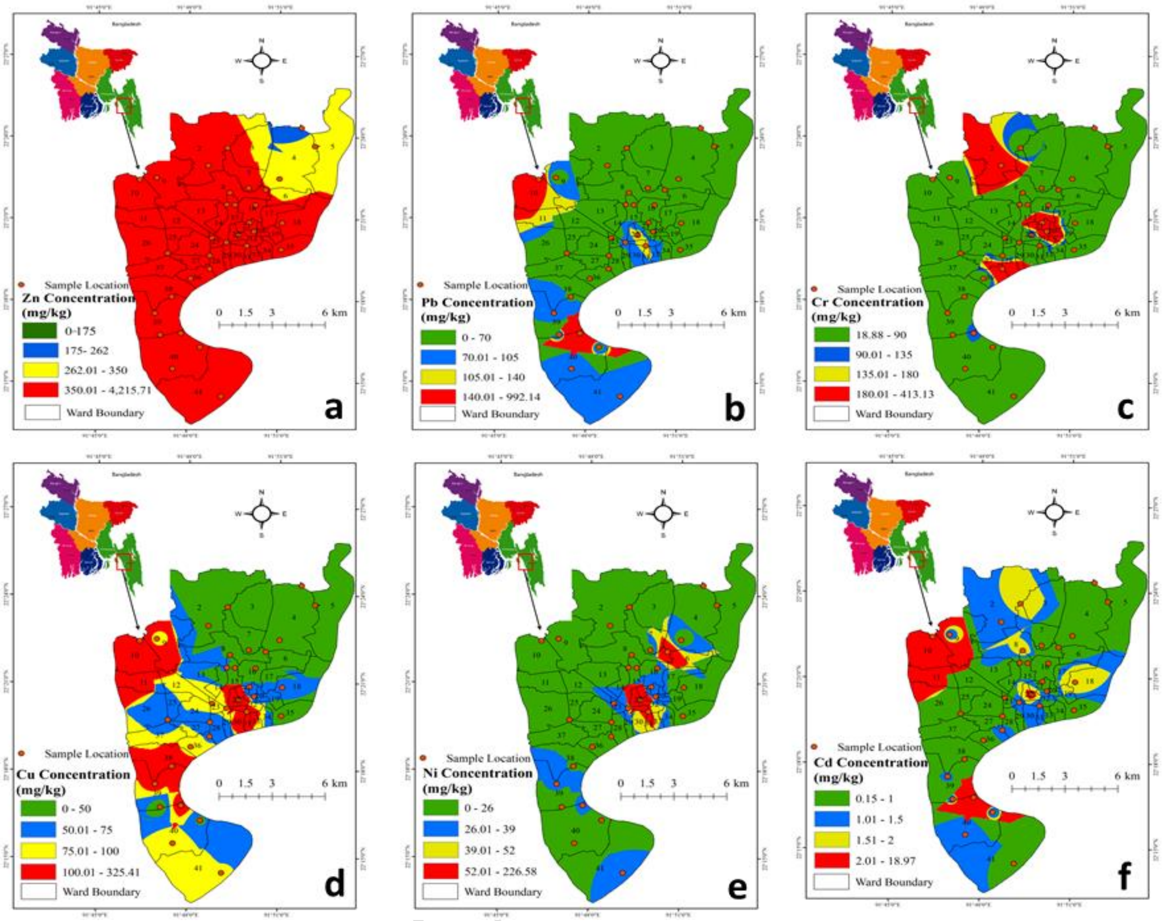

Fig. 2. Distribution of heavy metals in Chittagong city. (a) Zn (b) Pb (c) Cr (d) Cu (e) Ni (f) Cd.

In context of spatial variability among the sites, as seen in Fig. 2, Zn showed significantly higher concentration at most of the sites in the city compared to city's mean and to Indian soil background value. Following Zn, the mean Cu concentrations of the 13 among 32 sites were found greater than the city mean, while in comparison to Indian soil background, 17 sites located in major road junctions were seen higher concentrations. Accordingly, the mean concentrations of Pb, Zn, Cd, Cr, and Ni concentration were higher than average value for the 8, 10, 6, 7, 6 junctions respectively. Moreover, the contamination of Cd, Cr, Ni were higher than Indian soil background value in 15, 4, 7 junctions, respectively.

It is important to mention that the concentration of five metals i.e., Pb, Zn, Cd, Cr, Cu (except, Ni) were relatively higher in City Gate, Ruby Cement Factory, and Enayeth Bazar junction. Higher concentrations of metals in these junctions are linked to the presence of heavy industries, major road sites activities along with road bends and road with intersections influencing traffic movement pattern of stop and start in those areas [4, 12, 13, 36]. Likewise to the present study, Wang and Qin [36] reported that the concentration of heavy metals was higher in the industrial zone of urban areas compared to the commercial and residential areas in China. Furthermore, the concentration of Pb was found to be very high in the Ruby Cement Factory Junction that might be attributed to the fact that the cement dust has been mixing with the road dust sediment during the cement manufacturing and transportation [36, 37]. Another reason of the high Pb concentration could be burning of the higher fossil fuels in industries in these junctions [37]. On the other hand, the concentrations of the Cd and Cr were found to be high in the City Gate and Enayeth Bazar junction. This is recognized to the large number of metal welding and electroplating shops, chemical and metallurgical activities by the metal related workshops, car parks in those areas than other parts of the city [38]. Moreover, City Gate, Ruby Cement, A K Khan circles are the busiest road sites carry large lorries, trucks, van, motor vehicles among others for transport goods and freights, as these sites are connected with national highway towards different destinations from Chittagong. The elevated concentration of Zn and Cu in these junctions can be accreted to the road traffic environment such as heavy vehicular traffic with the sloped road condition [39]. For example, the Enayeth bazar junction was found to have heavy vehicular traffic due to the greater number of market activities and sloped road pattern with congestions at road sites. In contrast, the low concentrations of heavy metals at

Kuwaish site is because of the smooth vehicular movement in this junction that are found with low traffic volume of passenger cars and open surroundings around this junction. In general, substantial variability has been observed across the sites in Chittagong. While the significant concentrations are seen in southern side followed by the central east and west belt wards, the relatively lower concentrations are seen in further north side of the city. The different attributes around the road sites along with variability in road traffic environments as discussed earlier explain those and are in consistent with studies elsewhere.

Table 1. Heavy Metal Concentrations (mg/kg) in Road Dust in Chittagong with Cities Elsewhere

City	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**RDS Size (μm)**	**Reference**
Chittagong	1.6	412	74	31	84	975	< 75	This study
Delhi	2.65	148.8	191.7	36.4	120.7	284.5	< 75	[31]
Birmingham	1.62	--	466.9	41.1	48	534	< 63	[17]
Ottawa	0.37	43.3	65.84	15.2	39.05	112.5	100-250	[16]
Luanda	--	26	42	10	351	317	< 100	[40]
Oslo	--	--	123	41	180	412	< 100	[14]
Madrid	--	61	188	44	1927	467	< 100	[14]
Dhaka		104	46	26	74	154	< 1,000	[28]
Kuala Lumpur	2.9	--	35.5	--	2466	344	< 63	[41]
Indian soil background	0.9	114	56.5	27.7	13.1	22.1	--	[42, 43]
China soil guideline	0.3	200	100	50	300	250	--	[44]
Canadian soil guideline	10	64	63	50	140	200	--	[45]

The mean concentrations over the sampling sites of Cd, Cr, Cu, Ni, Pb and Zn of the present study were further compared with reported studies elsewhere [14, 16-17, 21, 24, 28, 31, 41, 42] and also with few guidelines including National Environmental Protection Agency of

China [44], Canadian Council of Ministers of the Environment [45], as presented in Table 1, in absence of guidelines on heavy metals in road dust or soil in Bangladesh at present. As presented in Table 1, the average concentrations of all six metals found in this study were significantly higher than the Indian natural soil background values, while with the Chinese soil guideline, the Cd, Cr and Zn, and with Canadian guideline, Cr, Cu and Zn were found greater. The concentration of the heavy metals in this study are seen significantly higher than the study performed in the capital city Dhaka [28]. As heavy metal concentrations in road dust of different size fractions are very different (higher with smaller fractions) as reported in studies [4, 12, 13], the comparison of cities in other countries where the size fractions of RDS comparable to size fraction used for this study (75 µm or lower) were tabulated (see Table 1). The Zn and Cr concentrations reported here are relatively higher than other cities elsewhere as seen in Table 1. Except Zn and Cr, study in Delhi [31] reported concentrations were greater than this study. With a few exceptions, significantly higher concentrations of Pb were found in studies in Kuala Lumpur [14], Madrid [41], Luanda [40] and Oslo [14], while that for Cu were found in in Birmingham [17] and Madrid [14]. The differences are expected due to significant variabilities in weather, road traffic environments, traffic management systems and further noted the needs for local studies.

3.2. Correlation Among The Heavy Metals

In order to address the sources of heavy metals in RDS, the concentrations collected from all the sites across the city were used for correlation analysis using Pearson's method. The outcomes of the correlation analysis the correlation coefficients (r) among the metals are presented Table 2. In general, the value of r towards ± 1 indicate strong positive or negative correlation while value towards 0 indicate very poor relationship. Moreover, the significance of correlation to certain acceptable confidence level is also important in statistical point of view. As seen in Table 2, the coefficients of correlations, r are found to vary between 0.035 to 0.97, explaining very poor to very strong positive correlations exist among the metals studied. The correlation coefficients obtained in this study are found in consistent with previous studies elsewhere [4, 10, 17, 27]. The relatively better association with significance to 0.01% were found for Cu with Zn (r = 0.805), Pb with Zn (r = 0.584), Pb with Cd (r = 0.970), Zn with Cd (r = 0.569), Zn with Ni (r = 0.616), while fair association were for Cu with Pb (r = 0.310) and Cu with Cd (r = 0.326). The association of Cd-Pb-Zn-Cu indicated input from single source, such as road traffic environment, whereas other interrelationship among metals indicate diverse sources inputs and are connected to the general contamination sources of industrial, commercial and surrounding land uses across the sites in the city. In this line, Cr exhibit very weak correlations with Cu, Pb, Ni and Zn varying from 0.04 to 0.111, certainly refer to sources other than road traffic emission.

Table 2. Pearson's Correlation Coefficients Among Heavy Metals

	Cu	**Pb**	**Zn**	**Cd**	**Cr**	**Ni**
Cu	1.000					
Pb	0.310**	1.000				
Zn	0.805**	0.584**	1.000			
Cd	0.326**	0.970**	0.569**	1.000		
Cr	0.040	0.044	0.111	0.069	1.000	
Ni	0.737	0.056	0.616**	0.035	0.045	1.000

**Significance to 0.01%; blanks indicate no significant correlation

3.3. Site-Specific Heavy Metal Contamination

Based the heavy metal concentration obtained and presented in Fig. 1 and in Table S1 for this study, 11 among the 32 major road sites were found with substantially elevated pollutants concentrations These 11 sites are considered further for site-specific contamination and risk assessment associated with RDS heavy metal pollution. It has been found that these 11 sites are located at central wards and southern belt of the city. The degree of contamination, potential ecological risk and risk indices, and pollution risk index were determined to get the picture of pollution status and, hence discussed in further sections. Prior to contamination assessment, the site-specific heavy metal concentrations along with site characteristics of the selected 11 sites are presented in Table 3.

Table 3. The Mean Heavy Metal Concentrations (mg/kg) of Selected Sites in Chittagong City

SL	Location	Characteristics of site	Cu	Pb	Zn	Cd	Ni	Cr
1	Sher Shah Colony (S. S. C)	Start/Stop with high traffic	48	39	988	1.1	21	413
2	City Gate Dhaka-Ctg. Highway (C. G.)	Start/stop with very high traffic	197	213	2278	7.4	26	84
3	Katghar - Patenga Road (K. P. R)	Start/stop with high Traffic	96	90	1364	1.2	21	36
4	Airport Road Junction (Ar. J)	Start/stop with medium traffic	76	97	3045	0.9	28	41
5	Rubi Cement Junction (R. C. J.)	Start/stop with medium traffic	122	993	3266	19.0	28	106
6	Chittagong EPZ Gate (EPZ)	Start/stop with high Traffic	113	83	934	1.0	27	32

7	Barek Building Junction (B.B. J)	Start/stop with very high Traffic	72	49	934	1.2	23	362
8	Kadamtali Junction (K. J)	Start/stop with high traffic	83	75	949	1.2	34	22
9	New Market (N. M.)	Start/stop with very high traffic	123	106	915	1.0	51	42
10	Enayeth Bazar (E. B.)	Start/stop with high traffic	326	119	4220	2.2	227	96
11	Andarkillah Junction (An. J.)	Start/stop with high traffic	56	42	621	1.0	31	326

Very high traffic: traffic volume > 500 Vehicle per hour (VPH); high traffic:301-500 VPH; medium traffic: 200-300VPH

As discussed earlier, the mean heavy metal concentrations are found to be varied among the sites and among the metals studied. Point to be noted that all these sites traffic has to undergo stop and start phenomenon and probably this is the key factor apart from traffic volume and surrounding land uses [4, 12, 13]. As seen in Table 2, among 11 sites, the significantly higher heavy metal concentrations are at Enayeth Bazar, Ruby Cement, City Gate, New Market sites than other road sites. As discussed earlier in relation to Fig. 2, these sites are controlled road junctions and surrounding area houses of industries, commercial activities and gate way from the city to different locations.

3.3.1. Contamination factor (C_f) and degree of contamination (CD)

The metal contamination factor and the degree of contamination were evaluated for the 11 hotspots in the study area as presented in the Fig. 3. As Zn concentrations at sites are too high (see Table 1) compared to other metals, contamination factor (C_f) of Zn was reduced by 5 while plotted with contamination factors for other metals for ease of identification.

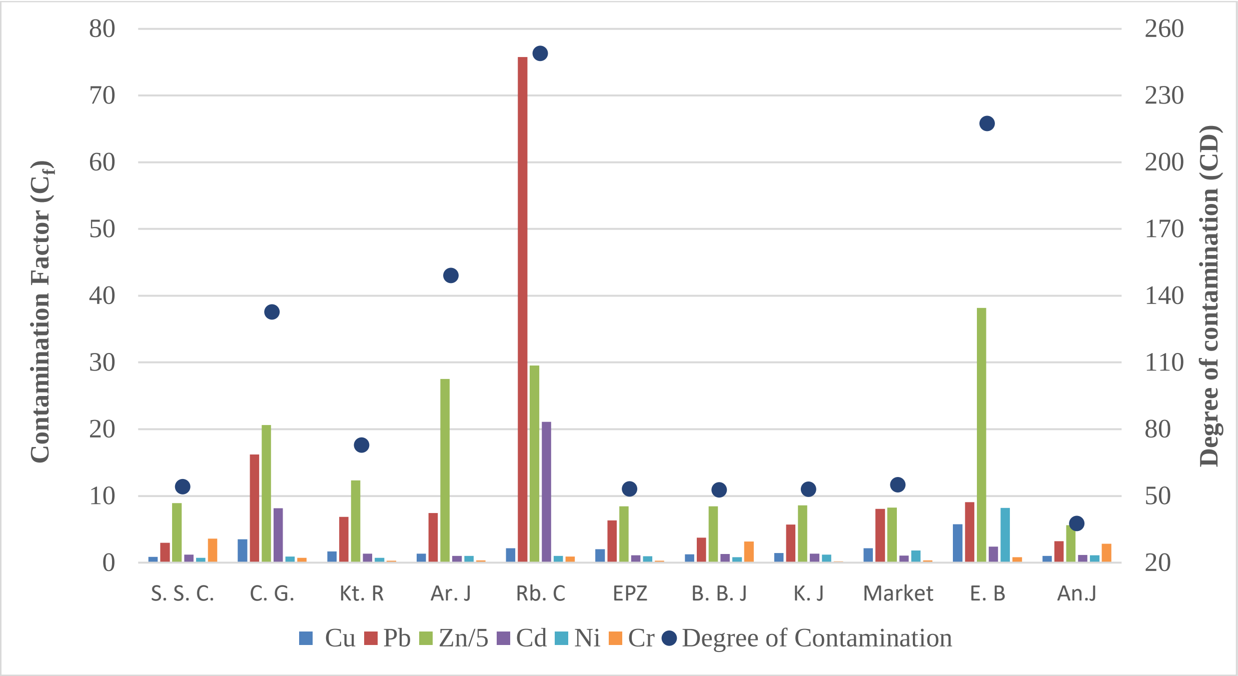

Fig. 3. Metal contamination factor and degree of contamination at different sites in Chittagong.

The contamination factor analysis revealed that extremely high contamination levels ($C_f \geq 6$) of Zn were prevailed in the all junctions. The lowest was with 28 at Andarkillah junction, while the highest contamination factor of 200 at Enayeth Bazar road sites. Among other sites, the greater contamination factor of Zn is observed as 150, 138, 103 and 61 at Ruby Cement, Airport Junction, City Gate and Katghar road sites, respectively. In this sequence, very high contamination of Pb are at Ruby Cement (contamination factor 76) and relatively higher contamination at City Gate (contamination factor 16) in addition to Zn transformed these two sites with very high degree of contamination along with Enayeth Bazar Junction where highest input from Zn is key factor with considerable input from Cu, Pb and Ni are also evident. It is therefore revealed that road sediment in Chittagong city is highly enriched with Zn followed by Cd, Pb, Cu, Ni and Cr compared to Indian natural soil quality, demonstrates anthropogenic inputs (more likely traffic induced pollution) seen that relatively significant contamination compared to soil background these three sites are also from Zn and Cd too compared to other eight sites.

Furthermore, the proportion of the contamination of each metal to the total degree of contamination (by adding the contamination of the six heavy metals) have been determined in the dust samples. The values were varied as follows: 0.86 to 3.98% for Cu, 4.18% to 30.46% for Pb, 59.41% to 92.48% for Zn, 0.69% to 8.48% for Cd, 0.41 % to 3.77% for Ni, 0.24% to 7.63% for Cr and is presented in Fig. S1. A very high degree of contamination was evaluated with magnitudes of 130, 64, 50 and 39 are at the Ruby Cement, Enayeth Bazar, City Gate and Airport road sites, respectively. A high degree of contamination in the Enayeth Bazar junction might be due to the heavy traffic movement related pollution (Zn is primarily derived from tire wear/abrasion) and the surrounding land uses of metallurgical activities. An extremely high degree of contamination in the Ruby Cement factory junction in addition to Zn are with Cd and Pb and might be linked to heavy loaded vehicles transporting goods, larger traffic volume causing traffic jam and that induced more exhaust, abrasion, wear and tear of tire and brake, oil drip due to stop and start maneuvering of traffic, and road junction is surrounded by cement industries, oil refineries, commercial activities that may also further influenced elevated concentrations [24, 26, 37]. The similar scenarios are at City Gate junction, due to increased rate of traffic start/stop activities as this site is the gateway from city to other districts. A considerable degree of contamination was found for Sher Shah Colony, Katghar, Airport junction, Barek Building circle and New Market, whereas moderate degree of contamination was seen for remaining 3 junctions. The considerable contamination in the 5 junctions (except Sher Shah

Colony junction) are related to vehicular inputs, e.g. tire abrasion and vehicular emission [12]. In contrast, the Sher Shah Colony has been contaminated by industrial intrusion to an additional input of vehicular emission refer to similar studies elsewhere [10, 20, 24, 26, 37].

3.3.2. Potential ecological risk (E_r) and risk index (RI)

The potential ecological risk in road dust was evaluated to assess the hazard of heavy metals contamination and related risks, once it can be deposited to the nearby waterbodies, and is shown in Fig. 4. The contamination posed by individual metals studied on the ecological risk assessment were found in the order of Cd > Zn > Pb > Cu > Ni > Cr. As seen in Fig. 4, a very high ecological risk factor (E_r) exceeding 320, are with Cd ($E_r = 631$) and Pb ($E_r = 380$) at Ruby Cement road also ranked it as high risk (RI = 1177) site exceeding the very high risk index (RI) value of 200 among 11 sites. In this sequence, based on ecological risk (RI) index, City Gate (RI = 450), Enayeth Bazar (RI = 380) and Airport Junction (RI = 220) sites are also posed high ecological risk, whereas other eight road sites fall into considerable ecological risk sites.

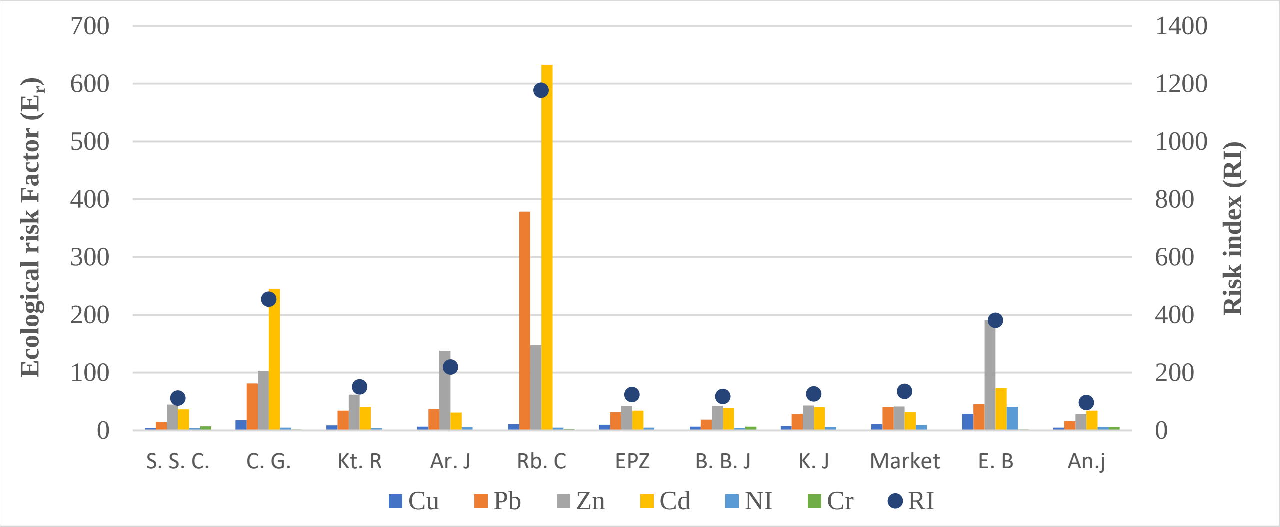

Fig. 4. Ecological risk factor and risk index in different road sites in Chittagong City.

Furthermore, the contribution of each metal to RI can be found in Fig. S2. Refer to Fig. S2, it can be exposed that Cd and Zn accounted for the highest total risk where the percentages ranged from 14% to 54% with a mean of 32.18% for Cd and the percentages ranged from 12% to 63% with a mean of 35.90% for Zn. In general, Cd, Zn and Pb are greater contributor (each contribution exceeds 20%), while Cu and Ni shared a small percentage and Cr contribution is very negligible among then among the six metals contributing to the total risk.

3.3.3. Pollution index (PI) & integrated pollution index (IPI)

Fig. 5 depicts the pollution index by each metal and integrated pollution index from all the six metals by their respective contributions. The pollution indices revealed the very similar trends as obtained for ecological risk factor and index (see Fig. 4). In align with previous discussion, it has been seen that sites are polluted by the significant contribution (PI>3 indicates high pollution) are with Cd, Zn and Pb and in some cases with Cu and Cr. Based on IPI, it is found that the IPI exceeding 18 illustrates high pollution are with Ruby Cement (IPI = 44), Enayeth Bazar (IPI = 22), City Gate (IPI = 20), while other sites fall into moderate pollution groups having IPI values range 6 to 18 (Fig. 5).

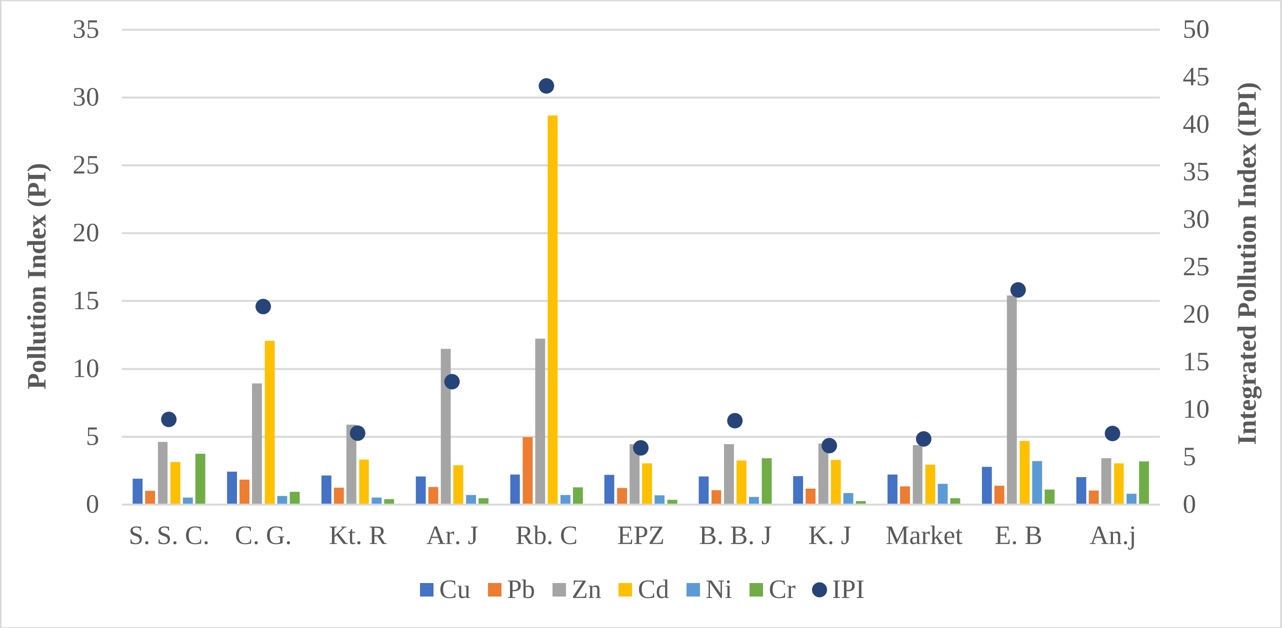

Fig. 5. Pollution index and integrated pollution index in the studied road network in Chittagong city.

The results obtained from Figs. 4 and 5, it can be noted that the sites with higher traffic volume, traffic movement pattern surrounded by industries and commercial activities left no places for road sediment to disperse from road and rather deposited on roads, while in contrast with even high traffic volume having openness of the sites allow dispersion of road sediment resuspended due to aerodynamic force by traffic movement along with wind. These site-specific characteristics are interesting facts that play a significant role in spatial variability among the sites and help further to identify the pollution hot spots sites.

4. Conclusions

The heavy metals of Zn, Pb, Cr, Cu, Ni, and Cd in road sediment and its distribution, emission pattern and potential ecological risk were evaluated in a city scale. The road deposited sediments of the city were found moderate to highly contaminated with heavy metals compared to the background soil values. The substantial variation across the 32 major road sites in Chittagong city were observed, signifying site-specific characteristics, e.g. road surface condition, traffic maneuvering pattern guided by road layout, road surroundings activities in addition to traffic volume and types of traffic. In comparison to several soil quality guidelines, road sediment across the sites showed significant enrichment with Zn, Cd and Pb, while that for Cu and Ni exhibit moderate and Cr demonstrate little enrichment. Based on heavy metal concentrations, 11 out of 32 major road sites are found substantially polluted in the city. Based on pollution assessments such as, degree of contamination, potential ecological risk index and integrated pollution index, it has been revealed that out of 11 the 3 sites named as Ruby Cement, City Gate and Enayeth Bazar road sites ranked top three in their order with extremely high to high pollution potential for ecological risk, while remaining 8 sites lie in moderate to considerable risk group that demand attention in context of urban pollution management. Nevertheless, the remaining 21 sites across the city also showed low to moderate level of pollution and risk potentials may bring forward to abate pollution rate further. The site-specific characteristics are interesting facts that play a significant role in spatial variability among the sites and help further to identify the pollution hot spots sites. It could be useful to assess road runoff quality from these sites to have a comprehensive evaluation that may help in decision making for adoption of sustainable road drainage for limited impact from the road traffic environment.

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Author Contributions

K.K.N (PG Student) conducted field, laboratory work, analyses and initial draft of this manuscript. S.K.P (Professor) supervised the works and generate the idea of the paper along with proof reading S.H (CSO) supervised in conducting the analytical part of the works at BAEC, Chittagong Lab. A.K (PG Student) conducted statistical analyses along with preparing initial draft of this manuscript.

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