HUMAN EXPOSURE TO HEAVY METALS THROUGH ROAD-DUST IN VARYING TRAFFIC INTENSITY ROADS OF LAHORE

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ABSTRACT: Fine solid particles consisting of organic matters, anthropogenic metallic constituents, and the soil is called dust. This solid matter, suspended in the air when vehicles pass, accumulates along the sides of roads is known as road dust. Toxic heavy metals present in the road dust can pose serious health effects to humans. For this purpose, three roads of Lahore (Ferozepur Road, Wahdat Road, and Defence Road) were analyzed for the presence of heavy metals, human exposure, and their relation to traffic intensity. The metals under study present in road dust included cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn). Ferozepur road (heavy traffic road) had the highest concentration of Pb (118.84 mg kg^{-1}) and Cd (3.77 mg kg^{-1}). Contamination factor ranged from very high to low with Pb being the leading contaminant in heavy traffic roads. The degree of contamination of Ferozepur Road, Wahdat Road, and Defence Road was very high, considerable, and moderate, respectively. Igeo values indicated that Defence Road was uncontaminated with all metals under study except copper, while Ferozepur Road and Wahdat Road were heavily polluted with Pb. The risk index showed a low risk in the three roads, while Pb can cause moderate ecological risk in Ferozepur Road. According to Exposure assessment, the major route of human exposure is ingestion followed by dermal contact and inhalation. The values of non-carcinogenic indices (HQ and HI) for both children and adults were under the threshold limit. Ni and Cr in Ferozepur Road and Wahdat Road can cause carcinogenic risk to children.

Keywords: Heavy metals, dust, traffic intensity, human health risks.

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INTRODUCTION

Fine solid particles consisting of organic matters, anthropogenic metallic constituents, and the soil is called dust (Faiz, *et al*., 2009). Over the last few decades, an increasing rate of urbanization and haste in the developmental sector of the social economy, air pollution from industries and high traffic roads in metropolitan areas have become dreadful. Resulting in a variety of environmental problems (Fenger, 1999). One of the biggest concerns of urban environmental management is the settling of dust on impervious surfaces. Roadside dust does not retain a single place for a long time. It travels to different surfaces and areas through different processes. For example, fast-moving vehicles can re-suspend the dust in the atmosphere, making it an addition to trace elements or it is transported to the water bodies through rainfall, becoming a part of the suspended and dissolved matter causing a serious hazard to the aquatic life (Ferreira-Baptista and Miguel, 2005).

The presence of inorganic contaminants especially heavy metals in nature has largely increased since the industrial revolution between 1800 and 1900 (Wei *et al*., 2009). Heavy metals become a part of environment through human activities and natural processes. Some of the natural sources include soil erosion, weathering of buildings and the earth's crust, air pollution fall out, etc. According to various researches, sources of heavy metal from human activities can be divided into three groups namely natural elements, urban elements, and elements of a mixed source. Urban elements are vehicular emissions, wear and tear of tires and brake linings, establishment, and revamping of structures, rusting of metal structures, power plants, auto repair shops, mining, and so on (Lu *et al*., 2009). Elements of mixed source include those metal pollutants whose characteristics are altered by undergoing some kind of geochemical reaction. Numerous studies have shown that human activities are a major source of heavy metal in urbanized areas (Ming-Ho, 2005).

Heavy metals tend to stick to the surface of soil and road dust. Heavy metals are more likely to deposit from the atmosphere in the road dust that becomes a temporary sink for them. (Amato *et al*., 2010). Over time with a high level of emissions, the amount of heavy metal deposited on the surfaces becomes humungous. This causes potentially toxic metal pollution.). Inhaling dust particles with heavy metals adsorbed on them in high concentrations can place potentially harmful effects on the health of human beings. The exposure routes of heavy metals to the human population include ingestion, dermal contact, and inhalation. The exposure becomes significantly amplified when metal contaminants persist in the human environment (Boyd *et al*., 1999). Heavy metals under study include lead (Pb), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), and nickel (Ni). Pb, Zn, and Cu are most commonly found in dust of roads with heavy traffic whereas Cr and Cd originate from atmospheric pollution and industrial contaminants, respectively. Naturally occurring resources add Nickel (Ni) to the dust (Du *et al*., 2013).

In the present-day lead is being used in lead-acid storage batteries, used worldwide for providing instant backup power supply mostly for computer and telecommunication systems. The main source of cadmium in the air includes industries that use compounds of cadmium in the manufacture of products, such as nickel-cadmium batteries, pigments, and alloys (Harrison, 2001). Zinc is commonly used as an electrode in dry cell and storage batteries, in automotive equipment, alloys, dental, medical, and household applications (Simon-Hettich *et al*, 2001). Copper is widely used in the manufacture of copper pipes, brake pads of vehicles, metal finishing and galvanizing, fungicides, dental alloys, paints, lining in kettles, to prevent corrosion in cooling and boiling systems, etc. (Deswal *et al*., 2009). Nickel comes from many industrial and commercial sources including burning of fuel oil, coal, and diesel oil, chemical industries, incineration of waste, sewage, food processing industries (Campel and Nikel, 2006). Chromium is used to harden the steel, as an anticorrosive agent and primer, electroplating for protective or decorative purposes (Shanker *et al*., 2011).

From the past few decades, there has been an abrupt increase in industrialization and urbanization in Pakistan (Noman, 2015). This has caused an increase in urban air pollution in Pakistan, making it among the world's worst air quality countries and the highest in South Asia (Sánchez-Triana, 2014). Although Lahore, a mega-city in Pakistan, has one of these cases, there has been a lack of information regarding accumulation, contamination, spatial variation and distribution of heavy metals in outdoor dust especially on roads. Several studies can be found on sources of heavy metal contamination and distribution in cities. However, very few studies are done on potentially harmful heavy metals accumulated in the road dust of Lahore, Pakistan, and their risk to the residents (Faiz *et al*., 2009). The objectives of this study were to (1) examine the concentration and sources of heavy metals in road dust in relation to traffic; (2) identify the potential health effects of heavy metals; (3) study the metal contamination in road dust in accordance with traffic; (4) assess the health hazards linked with toxic metals in three roads of Lahore with varying traffic using the health risk assessment model.

MATERIALS AND METHODS

Introduction to Research Area: Lahore, the capital of the Punjab province, is almost 2000 years old. It is situated at 31°N and 74°E (Fig. 3.1). Lahore is named as the second-largest city in the country in terms of industries, trade, and commerce (Merchant, 2017). Lahore is spread to an area of 1772 km^2 with a huge population of 12 million. Lahore contains more than 6 million motor vehicles in the city. The gross domestic product (GDP) of the city was found to be $40 billion in 2008 with a growth rate estimated to be 5.6% for the coming years. (Pakistan Bureau of Statistics, 2017).

Selection of Roads: Sampling sites were selected based on traffic volume on the road. Sampling was carried out in February 2020 on Ferozepur Road (High traffic area), Wahdat Road (Medium traffic area), and Defence Road (Low traffic area). Ferozepur road is 66 km long. Though it extends to India but in Pakistan it begins from Shadman (31.54°N, 74.31°E) and ends in Kasur (31.10°N, 74.46°E). It is accompanied with several markets, hospitals, and other commercial sites. Wahdat Road is a comparatively shorter road of 6.5 km in length. It connects Ferozepur Road at 31.52°N, 74.32°E to Multan Road at 31.49°N, 74.26°E. It is a mixture of commercial and residential area with fewer markets and hospitals. Beginning from Multan Road (31.40 N, 74.15 E), Defence Road is a 16 km long road intersecting Raiwind Road at 31.39°N, 74.22°E and ends at 31.41 N, 74.31 E. This road is majorly surrounded with residential areas with a few institutes.

Sample Collection: From each road, three samples were collected. The sampling areas are shown in Fig. 3.1. The two roads (Ferozepur Road and Wahdat Road) have high traffic in relation to Defence road that is in residential area. Samples were taken from the asphalted pavement of the roadside with 1 km. Selected sampling sites include one site within a residential area and eight sites located on the main road. Around 30g of road dust particles were gathered at each sampling point with the help of an uncontaminated plastic shovel and a small brush. The samples were collected in labeled polythene packets and were taken to university laboratory to analyze them.

Flame Atomic Absorption Spectroscopy Analysis

Pre-analysis treatment of samples: In the laboratory, the dust samples were sieved to remove impurities such as stones, paper, hair, grass, etc. The samples collected can be defined as dust because they became re-suspended in the air very easily and were inhalable. Before analyzing the samples on flame atomic absorption spectroscopy (FAAS), the samples were sieved to remove impurities. After sieving, ashing of samples was done to eliminate carbon content from samples using a muffle furnace. Around one gram of sample was taken in a porcelain crucible and placed for 30 minutes at 350°C in a furnace (Faiz *et al*., 2009). After ashing, the samples were cooled at room temperature and then digested for 30 minutes at 250°C using a 3:1 mixture of nitric acid (HNO_3) and hydrochloric acid (HCl). The digested solution was cooled and distilled up to the 50-ml mark on beaker. The solution was then filtered using Whatman filter paper and was stored in polythene bottles at a temperature of 4°C in a refrigerator until instrumental analysis (Abdel-Latif and Saleh, 2012).

FAAS analysis: Standard solutions of (0, 2, 4, 6, 8 ppm) for each metal understudy was prepared and was run on FAAS for calibration. Instrumental conditions according to the requirement of each metal were manually configured. To ensure the proper functioning of instrument, calibration was done before doing analysis. For calibration, four solutions (one blank solution and three standard solutions) for each metal were run on FAAS. A calibration curve was formed.

All glassware was washed with double-distilled water and was then dried in the oven before use. The content of 6 elements (Cd, Cu, Cr, Zn, Pb, and Ni), was determined by FAAS. After the calibration of the instrument, the prepared dust solution was inserted via a small tube into the instrument. Specific cathode lamps were used for each metal. The results were displayed on the screen.

Evaluation of Metal Contamination and Ecological Risks: To evaluate the contamination level, three factors were analyzed that included contamination factor (Cf) for individual metals, degree of contamination (Cd) for multiple metals, and geoaccumulation index (Igeo). For calculation of ecological risk, two indices were calculated. For individual metal analysis ecological risk factor (Er) was used, and for combined risk of metals ecological risk index (RI) was used.

Equations for C_d and C_f: To calculate the contamination factor, the following equation was used

$$C_f = \frac{C_s}{C_b}$$

And for the degree of contamination (C_d), the following equation was used

$$C_d = \sum C_f$$

Hakanson proposed that C_s refers to concentration of the metal under study in the road dust samples and C_b refers to the concentration of metal understudy found in background soil (Khairy *et al*. 2011).

According to Hakanson (1980), metal contamination levels can be divided into four categories according to their intensity that is: low (Cf value of less than 1), moderate (Cf value from 1 to less than 3), considerable (Cf value from 3 to less than 6), and very high (Cf value of 6 and greater).

In this study, the categories to calculate the degree of contamination (Cd) were as follows: low (Cd value less than 5), moderate (Cd values from 5 to less than 10), considerable (Cd values from 10 to less than 20), and very high (Cd value of 20 or greater) metal contamination levels (Duong and Lee, 2011).

Equation for I_{geo}: To calculate the I_{geo}, Muller (1969) derived an equation that is as follows::

$$I_{geo} = \log_2 \left[\frac{C_s}{(1.5C_b)}\right]$$

In this equation, factor 1.5 represents slight changes that might have taken place in background values due to natural or anthropogenic means. I_{geo} values for each metal have been divided into 5 categories by Muller (1969) shown in 3.1.

Table 3.1: Categories of Geo-accumulation index pollution (I_{geo})

Pollution Category	Unpolluted	Unpolluted/ Moderately	Moderately	Moderately/ Heavily	Heavily/ Extremely	Extremely
Value	$I_{geo} \leq 0$	$0 < I_{geo} \leq 1$	$1 < I_{geo} \leq 2$	$2 < I_{geo} \leq 3$	$3 < I_{geo} \leq 4$	$4 < I_{geo} \leq 5$

Equations for Er and RIl: To evaluate the ecological risk (Er) toxic response (T_r) was multiplied with contamination factor. Ecological risk index (RI) is the sum of the values of ecological risk (Håkanson, 1980).

$$E_r = T_r \times C_f$$

$$RI = \sum E_r$$

Where Tr values for Cd, Cr, Cu, Zn, Pb, and Ni are 30, 2, 5, 1, 5, and 3, respectively. The results of Er and RI of metals were compared with the categories of these indices proposed by Hakanson (1980) for Er (Table 3.2) and Shi *et al*. (2010) for RI (Table 3.3), respectively.

Table 3.2: Categories of individual Ecological Risk (Er).

Risk Category	Low	Moderate	Considerable	High	Very High
Value	Er < 40	40 ≤ Er <80	80 ≤ Er < 160	160 ≤ Er < 320	Er ≥ 320

Table 3.3: Categories of multiple Ecological Risk (RI)

Risk Category	Low	Moderate	Considerable	High
Value	RI < 150	150 ≤ RI < 100	300 ≤ RI < 600	RI ≥ 600

Health Risk Assessment

Average daily dose of a pollutant: An exposure dose of humans to metals present in road dust was calculated using a model proposed by USEPA. For calculating the average daily dose (ADD) (mg/kg/day) of a pollutant through three exposure routes namely ingestion, inhalation, and dermal contact, the following three equation from Exposure Factors Handbook were used:

$$ADD_{ing} = \frac{c \times R_{ing} \times CF \times EF \times ED}{BW \times AT}$$

$$ADD_{inh} = \frac{c \times R_{inh} \times EF \times ED}{PEF \times BW \times AT}$$

$$ADD_{derm} = \frac{c \times SA \times CF \times SL \times ABS \times EF \times ED}{BW \times AT}$$

Where, ADD_{ing} represents the average amount of metal exposed to humans through ingestion daily, ADD_{inh} represents the average amount of metal exposed to humans through inhalation daily, ADD_{derm} represents the average amount of metal exposed to humans through dermal contact daily all measured in mg/kg/day. Other factors in the equation and their values are given in Table 3.4 by USEPA and environmental site assessment guidelines (ESA) (2009).

Table 3.4: Values of exposure factors for dose models

Factor	Definition	Unit	Value		Reference
			Children	Adult	
c	the concentration of contaminant in dust	mg/kg			This Study
R_{ing}	ingestion rate of soil	mg/day	200	100	USEPA, 1989
EF	exposure frequency	days/year	350	350	ESA
ED	exposure duration	years	6	24	USEPA, 2001
BW	average body weight	kg	15	55.9	ESA
AT	average time	days	365×ED	365×ED	USEPA, 1989
CF	conversion factor	kg/mg	1×10^{-6}	1×10^{-6}	ESA
R_{inh}	inhalation rate	m^3/day	5	20	ESA
PEF	particle emission factor	m^3/kg	1.32×10^9	1.32×10^9	ESA
SA	the surface area of skin that contacts the dust	cm^2	1800	5000	ESA
SL	skin adherence factor for dust	mg/cm^2	1	1	ESA
ABS	dermal absorption factor (chemical specific)		0.001	0.001	ESA

Non-cancer risk

Hazard quotient: Health risk assessment was performed by using the HQ equation for non-carcinogenic risk. HQ formula consists of average daily dose divided by a specific reference dose.

$$HQ = \frac{ADD}{RfD}$$

Where RfD stands for reference dose that is the maximum amount of risk acceptable on a vulnerable group of human population based on daily exposure throughout a lifetime. There is a direct relationship between the average daily dose (ADD) and human health. The lower the value of ADD than the reference dose, the lower will be its health impact. RfD values proposed by USEPA for metals under study are given in Table 3.5

Table 3.5: Reference Dose values of Heavy Metals by USEPA

	Cd	Cr	Cu	Pb	Ni	Zn
RfDing (mg/kg/day)	1.00E-03	3.00E-03	4.00E-02	3.50E-03	2.00E-02	3.00E-01
RfDinh (mg/kg/day)	1.00E-05	2.86E-05	4.02E-03	3.52E-03	2.06E-02	3.00E-01
RfDderm (mg/kg/day)	1.00E-05	6.00E-05	1.20E-02	5.25E-04	5.40E-03	6.00E-02

Hazard index: Another index to measure the health impact caused by metals combined is HI. It is calculated by adding the HQ values of more than one metal for multiple exposure pathways.

$$HI = \sum_{i=1}^{3} HQ_i$$

According to USEPA (2001), the values under 1 are considered safe for HQ and HI. A value less than 1 indicates a negligible non-carcinogenic risk from metals. But if the calculated HQ or HI value exceeds the limit of 1, there is a higher probability of non-carcinogenic risk. The higher is the value, the higher is the probability of risk.

Cancer Risk: Carcinogenic risk of metals under study found in road dust was also measured. To estimate the cancer risk by metals, the average daily dose calculated is multiplied by the slope factor (SF) of the complementary metal. The threshold value for cancer risk range from 10^{-6} to 10^{-4}. Values above this threshold can cause risk to human health from metals present in road dust (USEPA, 1989).

Table 3.6: Slope Factors of Heavy Metals for Cancer-risk Assessment

	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)
SF_{inh} mg/kg	6.3	4.1	-	4.2×10^{-2}	0.0421	-
SF_{ing} mg/kg	3.8×10^{-1}	5×10^{-1}	-	8.5×10^{-3}	1.7	-
SF_{derm} mg/kg	-	-	-	1.5	-	-

Statistical Analysis: Results were arranged in the form of tables and graphs with the help of Microsoft Excel 2007. IBM SPSS Statistics version 24.0 was used for statistical analysis of data.

RESULTS AND DISCUSSIONS

Concentration of Heavy Metals in Road Dust: The concentration of copper, cadmium, lead, chromium, zinc and nickel was calculated in all 9 dust samples taken from three roads and 3 soil samples taken from a park in Defence. The minimum value, maximum value, and the mean concentrations of heavy metals in the dust samples of Ferozepur Road, Wahdat Road, Defence Road, and Defence Park are given in Table 4.1, 4.2, 4.3, and 4.4, respectively. A comparison of concentration values of elements found in three roads is shown in Fig. 4.1. The calculated concentration of heavy metals in other studies around the world, and permissible limits were compiled from literature for the sake of comparison with present study and are shown in Table 4.5. The results obtained from each road are discussed below.

Ferozepur Road: Analytical results of heavy metal concentration found in dust samples of Ferozepur Road are summarized in Table 4.1. The concentration of Cu, Cd, Pb, Cr, Zn, and Ni in road dust ranged from 13.50 to 20.00, 3.10 to 4.30, 117.28 to 120.00, 19.25 to 21.00, 119.00 to 150.70, and 10.10 to 13.87 mg/kg with means of 17.40, 3.77, 118.84, 19.85, 133.98, and 12.09, respectively. All the values crossed the background values. The order of metals formed according to increasing metal concentration is as follows: Cd > Ni > Cu > Cr > Pb > Zn.

Table 4.1: Heavy metal concentration (mg/kg) in the dust of Ferozepur Road

	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)
Minimum	3.10	19.25	13.50	117.28	10.10	119.00
Maximum	4.30	21.00	20.00	120.00	13.87	150.70
Mean	3.77	19.85	17.40	118.84	12.09	133.98
S.D.	0.61	1.00	3.44	1.40	1.89	15.92

Wahdat Road: The heavy metal concentration found in the dust of Wahdat Road is shown in Table 8. The mean values of concentration of Cu, Cd, Pb, Cr, Zn, and Ni are 13.72, 2.90, 79.82, 15.94, 52.69, and 8.62 ranging from 12.50 to 15.80, 2.80 to 3.00, 78.12 to 81.25, 15.00 to 17.10, 48.70 to 57.20, and 8.27 to 9.10 mg/kg, respectively. The value of road dust samples were greater than the values of the soil samples of Defence Park taken as background samples. The highest value was of Pb followed by Ni, Cu, Cr, and Zn with the lowest concentration of Cd.

Defence Road: Table 9 below shows the heavy metal concentration of metals found in dust collected from Defence Road. The concentration ranged from 5.2 to 10.9, 0.9 to 1.8, 9.25 to 15.73, 10.1 to 12.3, 19.23 to 21.2, and 3.2 to 4.29 mg/kg of Cu, Cd, Pb, Cr, Zn, and Ni, respectively. The highest concentration (in mg/kg) calculated was of Zn (20.22) followed by Pb (12.10), Cr (11.20), Cu (8.07), Ni (3.84), and Cd (1.27). All the values of concentration are higher from background values except of cadmium.

Table 4.2: Heavy metal concentration (mg/kg) in the dust of Wahdat Road

	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)
Minimum	2.80	15.00	12.50	78.12	8.27	48.70
Maximum	3.00	17.10	15.80	81.25	9.10	57.20
Mean	2.90	15.94	13.72	79.82	8.62	52.69
S.D.	0.10	1.07	1.81	1.58	0.43	4.27

Table 4.3: Heavy metal concentration (mg/kg) in the dust of Defence Road

	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)
Minimum	0.9	10.1	5.2	9.25	3.2	19.23
Maximum	1.8	12.3	10.9	15.73	4.29	21.2
Mean	1.27	11.20	8.07	12.10	3.84	20.22
S.D.	0.47	1.10	2.85	3.31	0.57	0.99

Table 4.4: Heavy metal concentration (mg/kg) in the dust of Defence Park as a background value

	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)
Minimum	2.22	5.76	4.33	4.34	1.22	12.35
Maximum	3.98	10.7	6.33	16.43	3.98	21.45
Mean	2.84	8.23	5.30	10.40	2.74	17.14
S.D.	0.99	2.47	2.77	6.05	1.40	4.57

Comparison of Three Roads: To compare the metal concentration found in the dust samples of three roads of Lahore i.e. Ferozepur Road, Wahdat Road, and Defence Road, a graph was made (Fig. 4.1). According to the graph, a similar pattern was observed. Ferozepur Road had a much high concentration of all metals in comparison with the other two roads with Defence Road having the least amount of metals present in road dust.

In the dust samples from Ferozepur Road and Wahdat Road, Pb and Zn were found in higher concentrations. The higher concentration of metals resulted due to the heavy traffic. The fuel used in vehicles contain Pb and thus has been considered a universal pollutant (Rashed, 2008). The same is the case in this study as well. Zn is found in lubricating oils, brake pads, and linings, tire rubbers. The leakage and abrasion of these cause high concentration of zinc in dust samples. Cd concentration was lowest in all the dust samples as compared to other metals. Cd is likely to be found in the least concentration in road dust because its sources are not vehicular-based (Abdel-Latif and Saleh, 2012).

Cd concentration was almost similar to the background values that indicate that the natural sources were responsible for Cd in road dust. Cu found in the dust samples resulted from different activities such as wear and tear of tires, deterioration of the metallic body of cars, etc. The mean concentration of metals higher than background samples indicates that anthropogenic activities are the main source of these metals (Du *et al*., 2013).

According to the results, Zn and Pb had the maximum concentrations in Ferozepur Road that is a heavy traffic road, followed by Wahdat Road. Defence Road had the least amount of metal concentration because the samples were taken from near a residential area. In Ferozepur Road and Wahdat Road, samples were taken from points with frequent stops and start of vehicles that resulted in higher Ni and Zn concentrations (Wei *et al*., 2010).

Comparison of metal concentration with global values and permissible limits: The heavy metal concentration of dust collected from three different roads of Lahore has been compared with other countries around the globe in Table 4.6. The concentration of Cd in road dust of Lahore was lower than four cities i.e. Aswan City, Jeddah, Islamabad expressway, and Xiandao District. Cu, Ni, Zn, and Cr concentrations around the world are many times higher as compared to the three roads under study. In Ferozepur Road, the mean concentration of Pb was higher than seven cities namely, Jharia, Hongkong, Islamabad Expressway, Maha Sarakham City, Urumqi City, Villavicencio, and Xiandao District.

The difference in concentration can be due to several factors including variation in the elemental structure of the soil in every city, sampling locations, sampling method, and analytical methods. In addition, the roads selected in this study had no industrial activities around. These variations point towards the need to establish a standard and universally accepted procedure for sampling and analytical techniques for road dust samples (Ma and Singhirunnusorn, 2012).

The concentration of heavy metals found in Ferozepur Road, Wahdat Road, and Defence Road was also compared with permissible limits in Table 11. The mean concentration (in mg/kg) of Cd (3.77) and of Pb (118.84) present in the dust of Ferozepur Road exceeded the permissible limits of 3 and 100 mg/kg, respectively. The other heavy metals under study were within the safe limits (Sezgin *et al*., 2003).

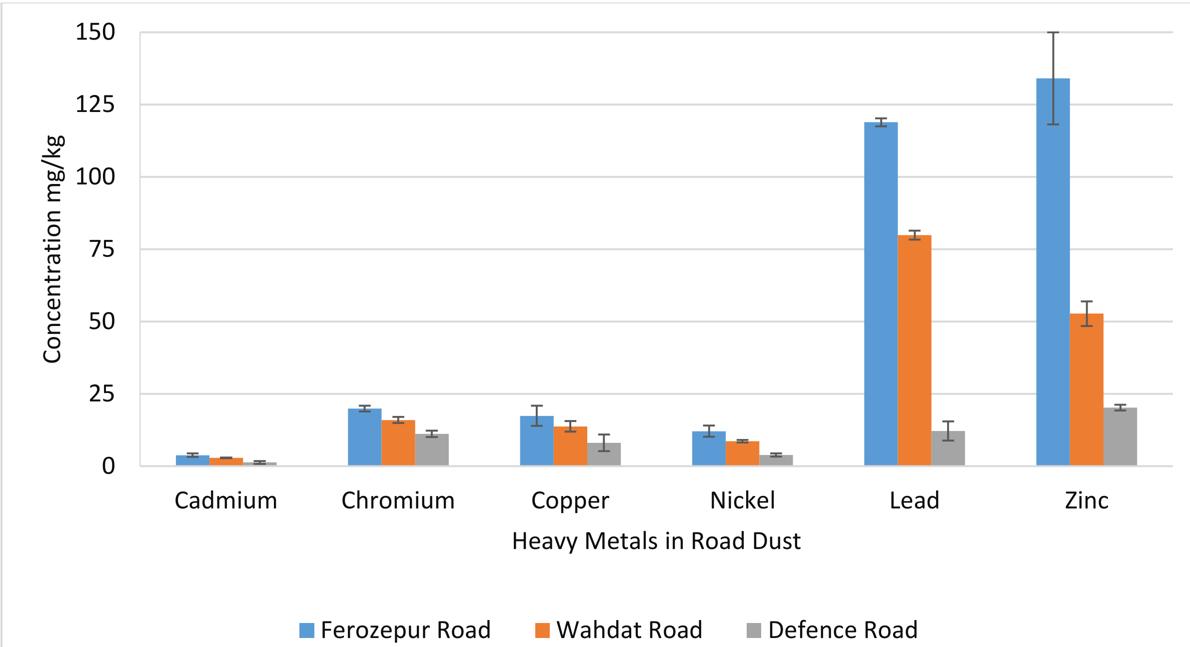

Figure 4.1 Showing comparison of heavy metal concentration in three roads of Lahore

Table 4.5: A comparison of heavy metal concentration in some countries of the world with the present study

City/Country	Metal Concentrations (µg/g)					
	Cd	Cr	Cu	Ni	Pb	Zn
Aswan City, Egypt	17.58	-	-	-	308	-
Beijing, China	0.64	69.33	72.13	25.97	201.82	219.20
Cairo, Egypt	0.35-2.31	1.71-36.95	-	1.73-25.38	1.65-234	1.92-638.4
Coal Mining Town, Jharia, India	0.78	75.4	56.8	66.0	67.8	163
Gela, Italy	-	11-109	16-442	14-54	10-265	76-499
Hassi Messaoud Town, Algeria	-	-	83.63	37.04	288.00	293.33
Hongkong, China	2.18	-	24.8	-	93.4	168
Inner Mongolia, China	2.20	141.24	36.39	31.25	183.93	299.37
Islamabad Expressway, Pakistan	5.0	-	52	23	104	116
Jeddah, Saudi Arabia	9.71	84.72	180.67	65.30	183.52	635.11
Luanda, Angola	1.1	26	42	10	351	317
Maha Sarakham City, Thailand	0.11	-	11.23	-	14.35	35.96
Massachusetts, USA	-	95	105	-	-	240
Nanjing, China	-	17-391	57-4237	18-158	22-832	32-720
Rafsanjan City, Iran	3.1	18.4	791.4	28.4	123.1	252.6
Shanghai, China	1.5	949.7	579.4	140.2	1016.1	1922.1
Urumqi City, China	1.17	54.28	94.54	43.28	53.53	294.47
Villavicencio, Colombia	-	9.4	126.3	5.3	87.5	133.3
Xiandao District, China	9.11	80.7	43.9	-	66.6	215
Lahore, Pakistan [Present Study]	1.27-3.77	11.20-19.85	8.07-8.62	3.84-12.09	12.10-118.84	20.22-133.98
Acceptable Concentration	3	100	50	50	100	300

Metal Contamination

Contamination Factor and Degree of Contamination of metals: To categorize the contamination level of toxic metals in road dust, C_f, and C_d was calculated using Hakanson's (1980) equation. The results are shown in Table 12. Cf classified a very high (>6) level of contamination of Pb (in Ferozepur Road and Wahdat Road) and Zn (in Ferozepur Road). Concentration of Cu and Ni from Ferozepur Road, Ni, and Zn from Wahdat Road were categorized as considerable levels of contamination ($3 \leq Cf < 6$). The concentration of Cd (in Ferozepur Road and Wahdat Road), Cu (in Wahdat Road and Defence Road), Pb, Ni, Zn (In Defence Road only), Cr in the road dust from Ferozepur Road, Wahdat Road, and Defence Road were categorized as moderate contamination ($1 \leq Cf < 3$). Cd concentration in Defence Road had a low C_f (< 1).

The C_d of heavy metals in the dust of Ferozepur Road, Wahdat Road, and Defence Road were 30.68, 19.45, 7.07, and can be categorized into very high, considerable, and moderate, respectively.

Table 4.6: Contamination factor and Degree of contamination of heavy metals in the dust of Ferozepur Road, Wahdat Road, and Defence Road.

	Cd	Cr	Cu	Pb	Ni	Zn	Degree of Contamination (C_d)
Ferozepur Road	1.33	2.41	3.29	11.43	4.41	7.82	30.68
Wahdat Road	1.02	1.94	2.59	7.68	3.15	3.07	19.45
Defence Road	0.45	1.36	1.52	1.16	1.40	1.18	7.07

Geo-accumulation Index: The calculated values of Igeo for metals in the road dust are given in Table 13. According to Muller (1969), the negative values of Cd (in all roads), Cu, Cr, Pb, Zn, and Ni in Defence Road indicate no pollution from these metals (I_{geo} less than 0). The value of I_{geo} for Cr (Ferozepur Road and Wahdat Road) and Cu (Wahdat Road) was <1, indicating that dust in these two roads was unpolluted to moderately polluted. The value of I_{geo} for Cu in Ferozepur Road, Ni in Ferozepur Road and Wahdat Road, and Zn in Wahdat Road are classified as moderately polluted. Pb from Ferozepur Road and Wahdat Road and Zn from Ferozepur Road was under the moderately to heavily polluted class.

Table 4.77: Geo-accumulation index (Igeo) of heavy metals in the dust of Ferozepur Road, Wahdat Road, and Defence Road

	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)
Ferozepur Road	-0.18	0.69	1.13	2.93	1.56	2.38
Wahdat Road	-0.55	0.37	0.79	2.36	1.07	1.04
Defence Road	-1.75	-0.14	0.02	-0.37	-0.10	-0.35

Ecological Risk and Ecological Risk Index: The results of the Er are summarized in Table 14. It shows the values of individual risk by metals in the three roads. According to these results, road dust posed low to moderate ecological risk. The Er values of all metals in Ferozepur Road, Wahdat Road, and Defence Road, except Pb in Ferozepur Road, were below 40 (Er < 40) indicating low potential ecological risk. The ecological risk of Pb in Ferozepur Road was above 40 (Er = 57.13), indicating that Pb posed a potentially moderate ($40 \leq Er < 80$) risk to the surrounding environment.

To evaluate the combined Er of metals in dust samples gathered from roads, all the values of Er were summed up. The RI value of three roads ranged from 34.91 to 139.22 (Table 14). According to the classification, the overall Er calculated of heavy metals in dust of Ferozepur Road, Wahdat Road, and Defence Road was low (RI < 150).

The sensitivity of an ecosystem to toxic heavy metals can be characterized by RI and it also represents the total contamination that can cause ecological risk (Shi *et al*., 2010). The highest Er to RI percentage was by Pb (37%), followed by Cd (30%) and Cu (13%) making up 80% of total potential ecological risk. Thus, it can be concluded that these three metals are dominant in causing ecological risk.

Human Exposure Risk Assessment

Average daily dose of a pollutant: Risk assessment of toxic metals present in road dust was done to measure the exposure to children and adults via three different pathways (inhalation, dermal contact, and ingestion). The results of these calculations for Ferozepur Road, Wahdat Road, and Defence Road are shown in Table 15, 16, and 17, respectively. The average uptake daily dose of heavy metals in all three roads was highest through ingestion pathway, then contact through skin, and least through inhalation pathway.

Children are at higher risk through ingestion of dust and skin contact in all three roads as compared to adults, while adults are at higher risk through inhalation of road dust than children are. Zheng (2010) and Fang (2010) also achieved the same results and they stated that inhalation of road dust through mouth or nose is negligible. In Ferozepur Road and Defence Road, the ADD of heavy metals calculated can be written as: Cd > Ni > Cu > Cr > Pb > Zn while in Wahdat Road, the ADD of heavy metals in increasing order was: Cd > Ni > Cu > Cr > Zn > Pb. These results showed that human exposure to the dust of Defence Road is less in comparison with the other two roads.

Table 4.8: 8Ecological risk and ecological risk index of heavy metals in the dust of Ferozepur Road, Wahdat Road, and Defence Road.

	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)	Ecological Risk Index (RI)
Ferozepur Road	39.79	4.82	16.43	57.13	13.24	7.82	139.22
Wahdat Road	30.63	3.87	12.95	38.38	9.44	3.07	98.35
Defence Road	13.38	2.72	7.61	5.82	4.20	1.18	34.91

Table 4.9: Average Daily Dose of heavy metals found in dust samples of Ferozepur Road

Ferozepur Road						
	ADD_{ing} mg/kg/day		ADD_{inh} mg/kg/day		ADD_{derm} mg/kg/day	
	Children	Adult	Children	Adult	Children	Adult
Cadmium (Cd)	4.82E-05	6.46E-06	9.12E-10	9.79E-10	4.33E-07	3.23E-07
Chromium(Cr)	2.54E-04	3.41E-05	4.81E-09	5.16E-09	2.28E-06	1.70E-06
Copper (Cu)	2.22E-04	2.98E-05	4.21E-09	4.52E-09	2.00E-06	1.49E-06
Lead (Pb)	1.52E-03	2.04E-04	2.88E-08	3.09E-08	1.37E-05	1.02E-05
Nickel (Ni)	1.55E-04	2.07E-05	2.93E-09	3.14E-09	1.39E-06	1.04E-06
Zinc (Zn)	1.71E-03	2.30E-04	3.24E-08	3.48E-08	1.54E-05	1.15E-05

Table 4.10: Average Daily Dose of heavy metals found in dust samples of Wahdat Road

Wahdat Road						
	ADD_{ing} mg/kg/day		ADD_{inh} mg/kg/day		ADD_{derm} mg/kg/day	
	Children	Adult	Children	Adult	Children	Adult
Cadmium (Cd)	3.71E-05	4.97E-06	7.02E-10	7.54E-10	3.34E-07	2.49E-07
Chromium(Cr)	2.04E-04	2.73E-05	3.86E-09	4.14E-09	1.83E-06	1.37E-06
Copper (Cu)	1.75E-04	2.35E-05	3.32E-09	3.57E-09	1.58E-06	1.18E-07
Lead (Pb)	1.02E-03	1.37E-04	1.93E-08	2.07E-08	9.19E-06	6.85E-06
Nickel (Ni)	1.10E-04	1.48E-05	2.09E-09	2.24E-09	9.92E-07	7.40E-07
Zinc (Zn)	6.74E-04	9.04E-05	1.28E-08	1.37E-08	6.06E-06	4.52E-06

Table 4.11: Average Daily Dose of heavy metals found in dust samples of Defence Road

Defence Road						
	ADD_{ing} mg/kg/day		ADD_{inh} mg/kg/day		ADD_{derm} mg/kg/day	
	Children	Adult	Children	Adult	Children	Adult
Cadmium (Cd)	1.62E-05	2.17E-06	3.07E-10	3.29E-10	1.46E-07	1.09E-07
Chromium(Cr)	1.43E-04	1.92E-05	2.71E-09	2.91E-09	1.29E-06	9.61E-07
Copper (Cu)	1.03E-04	1.38E-05	1.95E-09	2.10E-09	9.28E-07	6.92E-07
Lead (Pb)	1.55E-04	2.08E-05	2.93E-09	3.14E-09	1.39E-06	1.04E-06
Nickel (Ni)	4.91E-05	6.58E-06	9.29E-10	9.97E-10	4.41E-07	3.29E-07
Zinc (Zn)	2.58E-04	3.47E-05	4.90E-09	5.25E-09	2.33E-06	1.73E-06

Non-cancer risk

Hazard quotient and Hazard index*:* The results of HQ and HI for Ferozepur Road, Wahdat Road, and Defence Road are listed in Table 18, 19, and 20, respectively. The HQ and HI of heavy metals in each road have the same trends for children and adults. The HQ of different routes in increasing order are inhalation < skin contact < ingestion. The HQ_{ing} to HI percentage calculated was greater (78%) than HQ_{inh}, and HQ_{derm}. According to the results, ingestion of dust by humans can cause much more damage than inhaling the dust particles or if the dust comes in contact with the skin. Some researchers in the past also verify these results (Ferreira-Baptista and Miguel, 2005).

The results showed that the HQs and HIs of all six metals on the three roads for both children and adults were under the safe limit (=1). In Ferozepur Road, hazard index values in the increasing order are Cu <Zn <Ni <Cd <Cr <Pb. In Wahdat Road, the value of HI can be arranged as Zn <Cu <Ni <Cd <Cr <Pb, while in Defence Road, it increases as: Zn <Ni <Cu <Cd <Pb <Cr. The highest value of HI was of Pb in Ferozepur Road (HI=0.460) and Wahdat Road (HI=0.309) for children. Therefore, more focus is required on Pb due to its higher potential of causing ill health effects (Shi *et al*., 2011). It can be the main cause of blood Pb in children (Du *et al*.13). In heavy traffic roads, Cr is also a threat to children due to the high value of HI (HI=0.123) and should be focused. The HI values of these six metals for adults were much lower than children were and can be overlooked. Children are at a higher health risk than adults.

Table 4.12: Hazard Quotient and Hazard Index values of heavy metals found in Ferozepur Road

	Ferozepur Road							
	HQ_{ing}		HQ_{inh}		HQ_{derm}		HI	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Cd	4.82E-02	6.46E-03	9.12E-05	9.79E-05	4.33E-02	3.23E-02	9.16E-02	3.89E-02
Cr	8.46E-02	1.14E-02	1.68E-04	1.80E-04	3.81E-02	2.84E-02	1.23E-01	3.99E-02
Cu	5.56E-03	7.46E-04	1.05E-06	1.12E-06	1.67E-04	1.24E-04	5.73E-03	8.72E-04
Pb	4.34E-01	5.82E-02	8.18E-06	8.77E-06	2.60E-02	1.94E-02	4.60E-01	7.77E-02
Ni	7.73E-03	1.04E-03	1.42E-07	1.53E-07	2.58E-04	1.92E-04	7.99E-03	1.23E-03
Zn	5.71E-03	7.66E-04	1.08E-07	1.16E-07	2.57E-04	1.92E-04	5.97E-03	9.58E-04

Table 4.13: Hazard Quotient and Hazard Index values of heavy metals found in Wahdat Road

	Wahdat Road							
	HQ_{ing}		HQ_{inh}		HQ_{derm}		HI	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Cd	3.71E-02	4.97E-03	7.02E-05	7.54E-05	3.34E-02	2.49E-02	7.05E-02	2.99E-02
Cr	6.79E-02	9.11E-03	1.35E-04	1.45E-04	3.06E-02	2.28E-02	9.86E-02	3.20E-02
Cu	2.76E-03	3.70E-04	5.19E-07	5.58E-07	8.27E-05	6.16E-05	2.84E-03	4.32E-04
Pb	2.92E-01	3.91E-02	5.49E-06	5.89E-06	1.75E-02	1.30E-02	3.09E-01	5.22E-02
Ni	5.51E-03	7.40E-04	1.01E-07	1.09E-07	1.84E-04	1.37E-04	5.70E-03	8.77E-04
Zn	2.25E-03	3.01E-04	4.25E-08	4.56E-08	1.01E-04	7.53E-05	2.35E-03	3.77E-04

Table 4.14: Hazard Quotient and Hazard Index values of heavy metals found in Defence Road

	Defence Road							
	HQ_{ing}		HQ_{inh}		HQ_{derm}		HI	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Cd	1.62E-02	2.17E-03	3.07E-05	3.29E-05	1.46E-02	1.09E-02	3.08E-02	1.31E-02
Cr	4.77E-02	6.40E-03	9.48E-05	1.02E-04	2.15E-02	1.60E-02	6.93E-02	2.25E-02
Cu	2.58E-03	3.46E-04	4.86E-07	5.22E-07	7.74E-05	5.77E-05	2.66E-03	4.04E-04
Pb	4.42E-02	5.93E-03	8.32E-07	8.93E-07	2.65E-03	1.98E-03	4.69E-02	7.91E-03
Ni	2.45E-03	3.29E-04	4.51E-08	4.84E-08	8.18E-05	6.09E-05	2.53E-03	3.90E-04
Zn	8.62E-04	1.16E-04	1.63E-08	1.75E-08	3.88E-05	2.89E-05	9.00E-04	1.45E-04

Cancer Risk: Carcinogenic risk assessment through ingestion route, inhalation route, and dermal route of exposure was performed for metals present in the three roads of varying traffic intensity. Calculated values of carcinogenic risk of Ferozepur Road, Wahdat Road, and Defence Road are given in Table 21, 22, and 23, respectively. The highest risk calculated was through ingestion of the dust particles and then by skin contact and least through inhaling the dust particles. The risk was greater for children than adults because of their low body weight. The cancer risk value lower than 1×10^{-4} is considered to be safe (Hu *et al*., 2011). The values that crossed these limits include Cr having 1.27E-04 cancer risk value in Ferozepur Road, and Ni having 2.63E-04 cancer risk value in Ferozepur Road and 1.87E-04 cancer risk value in Wahdat Road, for children through the ingestion of dust containing toxic heavy metals. This means that children are at higher carcinogenic risk from Ni and Cr present in dust of heavy traffic roads of Lahore than adults.

Conclusion: In this research work, human exposure assessment to road dust from three different roads of varying traffic intensity was carried out. It was revealed from the results that the highest concentration of metals was found in dust of Ferozepur Road that is a very busy high traffic road followed by Wahdat Road, having lower traffic flow than Ferozepur Road. The least amount of toxic metals were found in Defence Road that is in a residential area having minimum traffic movement. In Ferozepur Road, the concentration in mg/kg of Pb (118.84) and Cd (3.77) was higher than allowed limits of 100 and 3 mg/kg, respectively.

Different indices were used for calculating the pollution levels of dust samples. According to the results of the contamination factor, the contamination ranged from very high to low with Pb causing the highest contamination in two major traffic roads. The degree of contamination indicated that Ferozepur Road had very high, Wahdat Road had considerable, and Defence Road had a moderate degree of contamination. Concerning Igeo values, road dust of Defence Road was uncontaminated with Zn, Cd, Pb, Cr, and Ni while Ferozepur Road and Wahdat Road were heavily polluted with Pb. The Er showed that Pb contitute a moderate ecological risk in Ferozepur Road. According to RI, all three roads fall under the low (RI < 150) category.

To evaluate the risk of human exposure to toxic heavy metals, non-carcinogenic risk and cancer risk via three pathways of exposure to road dust were measured. The results of ADD showed that the major route of exposure for children and adults to metals is through ingestion. The HQ_{ing} contributed 78% in HI assessment of all metals in all three roads. The HQ and HI values for children and adults were below safe limits (=1). However, the highest value of HI was of Pb in Ferozepur Road (HI=0.460) and Wahdat Road (HI=0.309) for children. The HI value of every heavy metal in dust posed more risk to children than adults, this indicates that children are at higher health risk from metals in dust of heavy traffic roads of Lahore. Ni and Cr present in road dust of Ferozepur Road and Wahdat Road crossed the threshold value of cancer risk and pose a carcinogenic risk to children.

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