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Heavy metal pollution in soils along the major road networks: A case study from Rawalpindi

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Abstract

Transportation is an important component of development and on-road transportation is the most essential and frequently used one. Apart from many services provided by the transport sector, it equally contributes to environmental pollution and is therefore considered as one of the significant sources of environmental pollution, posing various threats to the environment, human health and global climate. This study was an attempt to carry out an assessment of six heavy metals: Cu, Pb, Cr, Cd, Ni and Zn in the soil samples collected from different sites along the major road networks in Rawalpindi city, i.e. Murree Road, Islamabad Expressway, Grand Trunk Road and Rashid Minhas Road. After analyzing the heavy metals in the collected soil samples, various indices were computed in order to evaluate the impacts of heavy metal pollution and to categorize each site according to the traffic induced pollution burden, the indices computed were: contamination factor (CF), pollution load index (PLI) and integrated pollution index. The results indicated the contamination trend to be in the order: Murree Road > Grand Trunk Road > Islamabad Expressway > Rashid Minhas Road. The comparison of the results obtained for the samples collected from roadsides with those collected from the controlled site i.e. Morgah Biodiversity Park, showed that the greater pollution level along the roadsides may be due to the traffic loads on these roads.

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Introduction

The urban areas of the world are getting highly polluted due to the higher concentrations of air pollutants that come from multiple sources such as; vehicular emissions, power generation, residential heating, agricultural activities and manufacturing industries (Lopez *et al.*, 2005). Among the various sources, air pollution resulting from automobiles is the most prominent one which poses detrimental impacts on the environment as well as living beings (Agrawal, 2005).

Mobility and development are directly proportional to one another, therefore the transport sector is an important component of economy that impacts the development and welfare of population, moreover, it also carries an important social and environmental burden, which cannot be neglected (Gajghate and Hassan, 1999; Husain, 2010). The transportation corridors serve as major elements of the cities' infrastructure and the actions taken by transportation planners and designers pose great influence on the social community as well as ecology (Shabbir *et al.*, 2014). The traffic generated air pollution leads to acid rain and contributes to global warming. In the urban setups, about 50% of all the air pollution comes from automobiles traffic. Accidental oil spills from vehicles result in runoff and contaminate surface water as well as groundwater. Along with the deterioration of other environmental compartments, transport sector also consumes large spaces of land to support its infrastructure and the operations associated with these structures result in the loss of biodiversity and pose negative impacts on the landscape qualities and resources (Mage *et al.*, 1996; Gajghate and Hassan, 1999; Mayer, 1999; Gravano *et al.*, 2003).

Heavy metal pollution of the natural environment is a global issue as these metals are indestructible as well as non-biodegradable and most of them result in toxic implications on living organisms, even in very small concentrations (Alloway, 1995; Akoto *et al.*, 2008). Although heavy metals naturally exist in the environment, being components of the earth's crust but the anthropogenic activities result in their emissions in the form of fine particles that leads to environmental pollution as well as alters the chemical composition of the atmosphere (Varrica *et al.*, 2003).

The most commonly reported heavy metals found along roadsides that may have released from the transportation activities, are: Lead (Pb), Copper (Cu), Zinc (Zn), Cadmium (Cd) and Nickel (Ni) (Li *et al.*, 2001; Pagotto *et al.*, 2001; Elik, 2003; Sezgin *et al.*, 2003; Al-Khashman, 2004; Han *et al.*, 2007). Studies have shown that the roadside soils often have a higher degree of contamination as compared to areas at distance from roads, which may be attributed to the emissions from motor vehicles. Researchers have also found that a decline in the concentrations of the metals (Pb, Cd, Ni, Zn and Cu) occurred rapidly with a distance of 10-50 meters from the roads (Pagotto *et al.*, 2001; Elik, 2003; Sezgin *et al.*, 2003; Al-Khashman, 2004; Han *et al.*, 2007; Joshi *et al.*, 2010).

In Pakistan, the transport sector is the 3rd largest energy consuming sector after the power generation and industrial sectors (Bailly, 1997). In Pakistan, the extent of traffic has increased abruptly in the last few years. Haphazard growth of automobiles on the roads has resulted in making the traffic congestion a norm and having a negligibly little scope for the improvement of road networks and/or traffic control systems (Ali and Athar, 2008). Task Force on Climate Change, in 2010, declared the situation of national transport sector to be responsible for up to 21% of the total national emissions (Economic Survey, 2009-10).

The aims of this study were: to investigate into the contamination level of the soil due to heavy metals, to evaluate each mentioned site individually and to categorize all the sites according to their pollution level.

Materials and methods

Study area

The current study was carried out along the green belts of major roads of Rawalpindi city. Rawalpindi lies in the Pothohar Plateau in the north of Punjab province near Islamabad and is the 4th largest city of Pakistan covering an area of approximately 154 km^2, of which the "urban Rawalpindi" covers about 94 km^2 (Government of Pakistan, 1999). The city is situated between 33^o 04' and 34° 01' north latitudes and 72° 38' and 73° 37' east longitudes (Shabbir *et al.*, 2014).

There exist lots of variations in the weather patterns of Rawalpindi due to its geographic location but generally the climate of Rawalpindi is temperate and warm. The monsoon season generally occurs from July to September and the average rainfall is approximately 90 mm.

The climate is mostly characterized as subtropical with long and hot summers with more rainfall in summer and having wet winters (Ahmad *et al.*, 2011; Abbas *et al.*, 2013). The map of the study area is given in Fig.1, which is showing the starting as well as ending points of each sampling site.

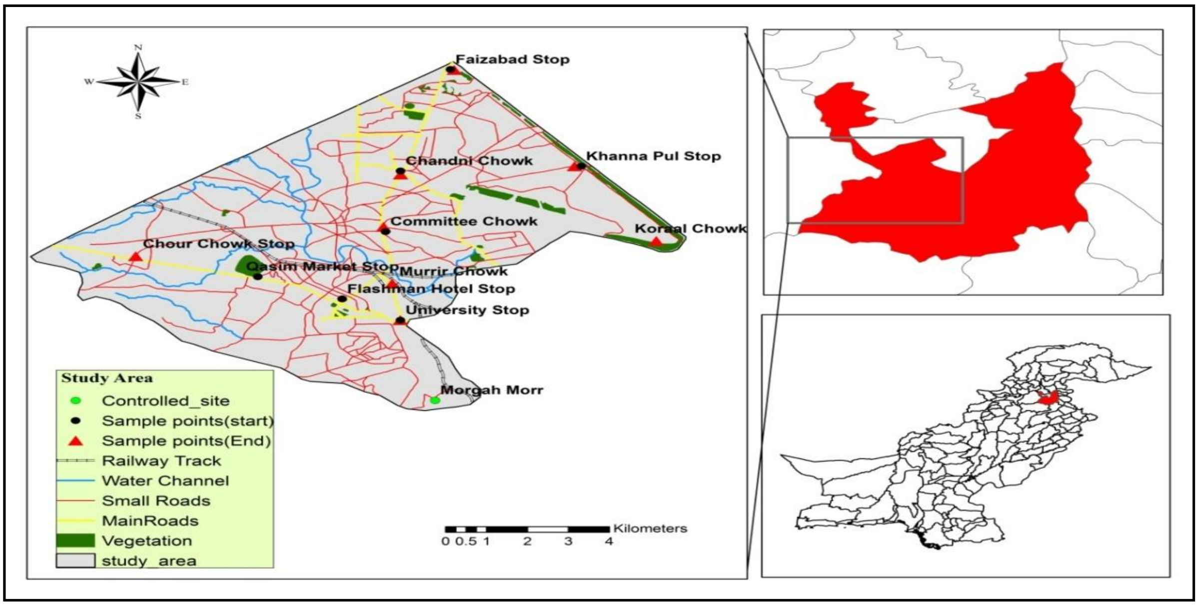

Fig.1. Map of the study area showing all sampling sites (Arc GIS 10).

Description of sampling sites

This study was conducted in order to analyze the impacts of environmental pollution due to heavy metals, along the major road networks in Rawalpindi city. The study area comprised of almost all the major roads of Rawalpindi. The major road networks were selected for the study because the transport sector is one of the most prominent and potential source of environmental pollution in the city.

The Morgah Biodiversity Park, Rawalpindi was selected as controlled/relatively less polluted site because the park is located in somewhat rural area, relatively far away from the major roads and urban development. Moreover, there were restrictions on operating any vehicles/automobiles inside the park premises. The details of selected sites and sampling points are given in Table1.

Table 1. Details of selected sites and sampling points.

Name of Road	Section No.	Starting - Ending Point
Murree Road	Section-I	Flashman Hotel - Committee Chowk
	Section-II	Committee Chowk - Chandni Chowk
	Section-III	Chandni Chowk - Faizabad
Mall Road (G.T-I)	Section-I	Kachehri chowk - Flashman Hotel
Peshawar Road (G.T-II)	Section-I	Qasim Market - Chur Chowk
Highway Road	Section-I	Koraal Chowk - Khanna pul
	Section-II	Khanna pul - Faizabad
Rashid Minhas Road	Section-I	Kachehri chowk - Murrir Chowk

Collection and analysis of soil samples

The soil samples were collected at about 10-15cm depth. The samples were packed in labeled plastic bags and were brought to the laboratory for analysis. The samples were air dried for about two weeks at room temperature, crushed well using a mortar and pestle and sieved through a sieve size of about 0.212mm. Then one gram of each soil sample was weighed into a 250ml conical flask and 12-15ml of freshly prepared aqua regia, 1:3 of HNO_3 (65% purity) to HCL (37% purity) was added. The mixture was heated at 80-100°C for about two hours, allowed to cool and filtered through a filter paper (Whatman No. 42), the volume of the filtrate was made up to 50ml by adding distilled water. The acid digests were then analyzed for different heavy metals such as lead, cadmium, copper, chromium, nickel and zinc, by using the flame atomic absorption spectrophotometer (FAAS-220 Spectra AA, Varian) (Malik *et al.*, 2010; Ehi-Eromosele *et al.*, 2012; George *et al.*, 2013).

Assessment of heavy metal pollution level

Various calculation methods have been used by different researchers in order to quantify the degree of heavy metal contamination in soils. In this study, the contamination factor (CF), pollution load index (PLI) and integrated pollution index (IPI), reported by (Thomilson *et al.*, 1980;Lu *et al.*, 2009; Mmolawa, 2011), respectively, were employed in order to assess the heavy metal contamination level in the soil samples collected from the vicinities of major road networks in Rawalpindi city. The methodology used for calculating these indices was as follows:

Contamination factor (CF): The level of contamination of soil by heavy metal(s) was expressed in terms of contamination factor, which was calculated as:

$CF = C_m \text{ Sample}/C_m \text{ Background}$ (1)

Where, C_m Sample = Average concentration of a specific metal in the polluted soil samples; C_m Background = Background value of metal concentration.

When $CF < 1$, the contamination will be low, $1 \le CF < 3$, the level of contamination will be moderate, whereas $3 \le CF \le 6$, there will be considerable contamination and $CF > 6$ indicates highest contamination (Thomilson *et al.*, 1980; Mmolawa, 2011).

Pollution load index (PLI): Each sampling site was evaluated for the extent of pollution by metals, by calculating the PLI for each site. PLI was calculated as:

$PLI = (CF_1{}^* CF_2{}^* CF_3{}^* .....CF_n)^{1/n}$(2)

Where, CF = Contamination Factor for each metal; n = the number of metals studied (6 in this study)

$PLI < 1$ represents the perfection of a site i.e. site is unpolluted

$PLI = 1$ denotes that only baseline levels of pollutants are present

$PLI > 1$ indicates that the site quality is deteriorated (Thomilson *et al.*, 1980; Mmolawa, 2011).

Integrated pollution index (IPI): Lu *et al.*, 2009, defined the integrated pollution index (IPI), as the mean value of the contamination factor (CF) also called as pollution index (PI), for every individual element, studied. The classification was as under:

$IPI \le 1$ low pollution level

$1 < IPI \le 2$ moderate level of pollution

$IPI > 2$ pollution level is high.

Determination of background values

As Rawalpindi lies in the Pothohar Plateau, the indigenous sediments in this area are mostly composed of argillaceous material dominated by shale (Faiz *et al.*, 2009).

The background values have been used as a basis for the evaluation of anthropogenic pollution, as done by many researchers (Turekian and Wedepohl, 1961; Muller, 1969; Forstner and Wittmann, 1983; Faiz *et al.*, 2009; Sadhu *et al.*, 2012).

The background concentration of six heavy metals: Cu, Pb, Cr, Cd, Ni and Zn, used in this study, as those of the average concentration of shale in earth material, is 50mg/kg, 20mg/kg, 100mg/kg, 0.30mg/kg, 68mg/kg and 90mg/kg, respectively (Turekian and Wedepohl, 1961; Muller, 1969; Forstner and Wittmann, 1983; Sadhu *et al.*, 2012).

Results and discussion

Table 2 shows the heavy metals concentrations in all the studied sites along with the controlled site and background content of each element.

The concentration of Cu, Pb, Cd and Zn were found to be highest at Murree road whereas highest concentration of Cr was recorded at Grand Trunk road and that of Ni at Islamabad Expressway. The lowest concentration of Cu, Pb, Cr, Ni and Zn were observed at Rashid Minhas road and that of Cd at Islamabad Expressway. By comparing the concentration of all the heavy metals in the samples collected from study sites with those of the background values, Cu, Cr and Ni were found in lowest concentrations than that of the background content, Zn was found in higher concentration than that of the background content only in the samples collected from Murree road, whereas Pb and Cd were found in considerably highest levels than that of the background content.

The integrated pollution index (IPI) given in Table 3, gives the mean level of contamination of all the studied heavy metals.

It was found that Pb (IPI = 20.23) and Cd (IPI = 4.78) were having highest pollution levels whereas all other metals were within safe limits.

The contamination factors (Table 3) calculated for Cu, Cr and Ni were less than 1 i.e. the levels of these metals were within safe limits, Zn contamination was moderate at Murree road while that was within safe limits at all other sites, Cd was highest of all and was in the order: Murree> Rashid Minhas> Islamabad Expressway> Grand Trunk and even some considerable contamination level was also observed at controlled site.

Table 2. Heavy metals concentration in soil samples (mg/kg).

Studied Site	Cu	Pb	Cr	Cd	Ni	Zn
Rashid Minhas Road	18.01	66.72	8.86	6.51	15.31	47.52
Grand Trunk Road	21.92	129.41	22.04	5.96	26.59	58.87
Murree Road	31.97	158.47	14.15	10.4	30.21	100.33
Islamabad Expressway	24.09	94.92	12.72	6.08	35.79	84.44
Controlled site	14.72	28.54	1.74	1.39	12.04	32.58
Shale/Background value	50	20	100	0.3	68	90

Table 3. Contamination Factors and Integrated Pollution Indices for Heavy Metals in Roadside Soil Samples.

Studied Site	Cu	Pb	Cr	Cd	Ni	Zn
Rashid Minhas Road	0.36	3.34	0.09	21.69	0.23	0.53
Grand Trunk Road	0.44	6.47	0.22	19.88	0.39	0.651
Murree Road	0.64	7.92	0.14	34.68	0.44	1.12
Islamabad Expressway	0.48	4.75	0.13	20.27	0.53	0.94
Controlled site	0.29	1.43	0.02	4.63	0.18	0.36
IPI	0.44	4.78	0.12	20.23	0.35	0.72

Pollution load index, PLI (Fig. 2), calculated for all sites showed that the heavy metal pollution trend was in the following order: Murree Road > Grand Trunk Road > Islamabad Expressway > Rashid Minhas Road.

The presence of these reported heavy metals in the study sites are in part due to their natural presence in the soil as well as due to certain anthropogenic activities especially the transportation, taking place at the observed sites.

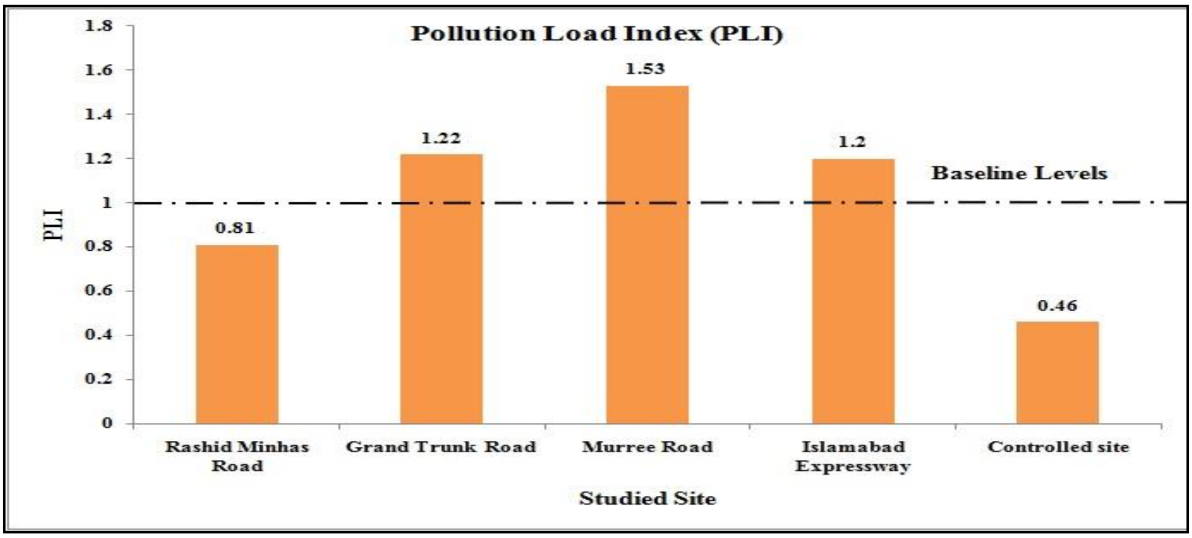

Fig. 2. Pollution load index, PLI for the studied sites.

However, some sources of these metals at similar were observed in the literature, such as, Cu, an essential trace element, is widely found in the environment. In its elemental form, Cu does not break down easily in the environment. The Pb concentration at the studied sites may be due to traffic burden and some usage of leaded gasoline, although Pb in petrol has been phased out in 2005 in Pakistan (Faiz *et al.*, 2009). Moreover, most of the light duty vehicles in Pakistan have been converted to CNG (compressed natural gas). Cadmium is mostly present in automobile fuel. Nickel is mostly released into the atmosphere from burning of fossil fuels/oils as well as from coal burning power plants (Faiz *et al.*, 2009). Ni and Cr are mostly used during chrome plating of some parts of motor vehicle, while Cu is a mainly used in some parts of engine, whereas Cd and Zn are commonly used in various lubricating oils as well as in tyres of automobiles (Lagerwerff and Specht, 1970). Being indestructible and persistent, heavy metals tend to stay in the environment for long times. In temperate environments, a residence time of about 1000-3000 years has been estimated for these metals (Bowen, 1979). Pakistani soils are generally alkaline in nature i.e. having higher pH values that lead to greater retention and lower solubility of metals in the soil medium. Moreover higher pH tends to stabilize the toxic elements and prevent leaching (Liu *et al.*, 2005).

Conclusion

As a result of this study, it was concluded that the ever increasing number of vehicles coupled with inefficient and environmental unfriendly fuels has led to the deterioration of environmental quality in the city. Vehicular emissions are one of the significant sources of toxic heavy metals in the environment. These metals are extremely persistent and stay for long time in the environment as their degradation is a quite tricky process. Of the six elements, discussed in this study, Cu, Ni, Zn and Cr have certain biochemical functions in plants as well as in humans, they tend to become toxic when their levels rise up in the body and only then can pose threats, whereas Cd and Pb have no biological roles and result in severe toxicity when get bio-accumulated and tend to persist in within the biological system(s). The traffic and thus the pollution burden in the city is increasing day by day just like in any urban center of the world, therefore it is imperative to regularly monitor and to efficiently control the emissions of such toxic substances into the environment, in order to protect environment and biota from more hazards.

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