Identifying Speed Hump, a Traffic Calming Device, as a Hotspot for Environmental Contamination in Traffic-Affected Urban Roads

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ABSTRACT: Despite several studies on traffic calming devices, information on particulate matter contribution by vehicle abrasion and wear nearby vertical deflections of speed humps is scant. Many studies have been performed in the recent past on heavy metal contamination at roads mainly at intersections. On the other hand, the traffic calming devices were studied for their effectiveness in reducing the vehicle speed and thereby increasing road safety, but their environmental effects are neglected. In the present study, the relation between the concentrations of Cu and Zn (marker heavy metals for traffic sources) at speed humps were nearly thrice to that in intersections, while for another marker heavy metal Pb, it was found nearly twice in comparison. Pollution load index >3 was observed upto 7.5−8.8 m distances of speed humps, and these were identified as hotspot zones for traffic-generated pollution. Furthermore, this heavy-metal-laden speed hump soil can pose a threat to living beings by virtue of resuspension produced by vehicular movements. Therefore, it is necessary to manage this emerging environmental issue, and we propose a traffic calming device with wheel cut-out provision for different vehicle classes as an alternate.

INTRODUCTION

Road characteristic is a well-known factor as a substantial contributor to affect traffic flow, traveler's safety, intrusive noise, air quality of nearby road microenvironments, and associated environmental issues.2 Over the last decade, unprecedented growth of personal vehicle usage in developing countries with limited development in road facilities has resulted in increasing time share in traveling and growing traffic accidents.3 Especially, at road networks where mixed traffic prevails, these personal vehicles travel with a much higher speed than slowly moving public vehicles. As a consequence of these factors, the augmented road accidents have further increased and are the growing menace on the roads the world over. This has resulted in increased frequency of traffic calming devices.4 Most of the urban air, road dust, and soil quality studies are carried out near intersections and street canyons,5−7 but information on heavy metal near these traffic calming devices is scant.

Nowadays, the most common traffic safety measures are related to vertical changes of the roads; such as speed humps, speed bumps, and speed tables; and horizontal changes on the alignment; such as roundabouts and chicanes.8 Most of the traffic calming devices were studied for their effectiveness in reducing the vehicle speed and thereby increasing road safety.9−12 The drastic change in traffic speed near traffic calming devices was highly correlated to gaseous pollutant emission.13−17 In developing countries, owing to lack of traffic rules to monitor fast moving vehicles, navigating to unpaved shoulders at the speed hump is also a unique driving behavior.18 Therefore, at first look, roads in these countries appear to have greater soil from the unpaved shoulders. In recent times, the variation in driving cycles of vehicle types in cities have been observed from their legislative ones.19 Furthermore, it is clear that the safer speed limits and the type and amount of traffic in developing countries are quite different from those in developed countries. Thus, the impact of traffic calming devices on nearby environment in such developing countries may differ significantly and therefore is required to be studied precisely in detail.

Concentrations of vehicular emitted heavy metals in roadside soils result in long-term environmental damage.20−22 It was reported that Cu, Zn, and Pb could indicate traffic pollution and could continue to accumulate in urban environment due to their nonbiodegradability and long residence time; thus, they are also known as “chemical time bombs”.23,24 Many studies have been performed on contamination of road soil due to vehicle-emitted marker heavy metals, Cu (brake wear), Zn (tire wear), and Pb (exhaust and nonexhaust emission), around the world.21,22,25−36 However, detailed investigation on traffic-generated heavy metals around speed humps in road soils is not yet reported.

The present study deals with the characterization and distribution of speed bumps and intersection soils along the road to find the information on interheavy metal relationship and impact of distance on speed hump road soil contamination. The assessment of the contamination level of heavy metals at these speed humps was compared to that at other sites using the contamination factor (CF), pollution load index (PLI), modified degree of contamination (mCd), geoaccumulation...
index (Igeo), and ecological risk index (RI). Much has been written on the impact of vehicular emission on the road dust and nearby soil, but its impact on speed hump microenvironment is limited. Therefore, the present study provides useful information on traffic contaminants and identifies an emerging urban hotspot zone for traffic-generated pollution.

Furthermore, resolution of heavy metal issues in immediate effect as well as in long term at speed hump microenvironments is discussed. The present study draws the attention of environmentalists and strategy makers of developing countries toward speed hump’s deteriorating effect on ecology and proposes an alternative to encourage the management of this emerging environmental issue with the help of scientific approach.

RESULTS AND DISCUSSION

Heavy Metal Concentrations in Road Soil. The concentration profiles of Cu, Zn, and Pb in traffic sites were observed in the undertaken study at distances of 1, 2, 3, 5, 10, 50, 100, and 200 m away from the speed humps. Heavy metal concentrations at speed humps and intersections are presented in Figure 1. A total number of 255 heavy metal values (17 sites × 5 samples × 3 metals) along the road nearby speed humps and at five intersections are measured.

Among the Heavy Metals. Among the heavy metals, the mean concentrations of Cu, Zn, and Pb were obtained in the range of 51.9 ± 8.8 to 186.5 ± 18.7 mg kg⁻¹, 220.5 ± 55.3 to 548.6 ± 49.6 mg kg⁻¹, and 22.9 ± 11.6 to 61.1 ± 9.6 mg kg⁻¹, respectively. High concentration of heavy metals at speed humps may be a result of excessive brake wear, tire wear, and tailpipe emission. Heavy metals at speed humps were found in the order of Zn > Cu > Pb. The concentrations of heavy metals are very high with respect to their background values (their corresponding concentrations in preindustrial soil), which are 45, 95, and 20 mg kg⁻¹, respectively. At speed humps, metal concentrations were found to be >4-fold for Cu and Zn and ∼3-fold for Pb with respect to their background values. Their concentrations were found slightly greater than 2-fold with respect to the values at speed humps.

![Figure 1. Spatial distribution of mean concentrations of heavy metals in road soil on both sides (1 and 2) of speed humps at a 1–200 m distance and at intersections (I).](image1)

![Figure 2. Variations in the contamination factor (CF) of heavy metals in road soil on both the sides (1 and 2) of speed humps at 1–200 m distance and at traffic intersections (I).](image2)
indicated that these speed humps were even more contami-
nated than the intersections in terms of these heavy metals.

**Effect of Speed Humps on Contamination with Respect to Distance.** Among the heavy metals nearby speed humps, the highest mean concentrations obtained at 1 m for Cu, Zn, and Pb on side 1 were 186.5 ± 18.7 mg kg⁻¹ at 1 m, 541.6 ± 27.4 mg kg⁻¹ at 2 m, and 57.5 ± 12.6 mg kg⁻¹. Lowest values obtained for Cu, Zn, and Pb were 51.9 ± 8.8 mg kg⁻¹ (at 200 m), 158.4 ± 7.56 mg kg⁻¹ (at intersections), and 22.9 ± 11.6 mg kg⁻¹ (at 200 m), respectively. On moving along the road and away from speed humps on side 2, highest mean concentrations obtained for Cu, Zn, and Pb were 183.0 ± 17.4 mg kg⁻¹ at 1 m, 548.6 ± 49.6 mg kg⁻¹ at 1 m, and 61.1 ± 9.6 mg kg⁻¹ at 2 m, respectively. The sharp decrease in concentrations of heavy metals away from speed humps proves them as hotspots. Especially, at speed humps, deceleration is significantly high due to brakes exerted by drivers to minimize mechanical damage to vehicles. The high concentration nearby speed humps may be a result of excessive use of brakes by drivers while maneuvering their vehicles over them. Consequently, tailpipe emission also increases to accelerate just after the vehicle passes the speed humps. This could have resulted in the elevated heavy metal emission in nearby speed humps.

**Assessment of Road Contamination Using Indices.** CF values of the road soil along with the different grades of CF are presented in Figure 2. Values of CF for Cu revealed that upto 2 m it was strongly contaminated, whereas it was moderately to strongly contaminated upto 5 m. For Zn, upto 3 m significance of estimated CF values showed that upto 3 m strong to very strong contamination occurred. For Zn, upto 50 m distance, moderate to strong contamination was observed for Zn. The estimated significance of CF values for Pb showed that upto 3 m of distance was moderately to strongly contaminated. It has provided the basic information on the contamination of road soil near speed humps. Continuous emission of heavy metals from vehicles may result in a long-term environmental damage. For the assessment of environmental pollution or contamination at speed humps, other indices were used based on CF values. Heavy metals Cu and Zn at speed humps indicated that their values were nearly thrice to that in intersection road soil, whereas for Pb, it was nearly twice in comparison.

PLI values of heavy metals in road soil on both the sides (1 and 2) of speed humps at 1–200 m distance and at traffic intersections (I).

**Figure 3.** Pollution load index (PLI) of heavy metals in road soil on both the sides (1 and 2) of speed humps at 1–200 m distance and at traffic intersections (I).

**Figure 4.** Variations in the modified degree of contamination (mCd) in road soil on both the sides (1 and 2) of speed humps at 1–200 m distance and at traffic intersections (I).
intersections are presented in Figure 3. PLI values (>1) indicated progressive deterioration of the analyzed sites nearby speed humps. Distances upto 5 m showed PLI >3, whereas for distance >10 m, PLI values were <3. In the case of intersections also, it was observed to be 1.44, which showed that they are contaminated by heavy metals emitted from vehicles.

On the basis of cumulative effects due to heavy metals, mCd was estimated for road soil using their CF values for the respective distances. Estimated mCd values for each location are presented in Figure 4. Significance of mCd showed that upto 3 m distance, high degree of contamination occurred, whereas upto 50 m, moderate degree of contamination was estimated nearby speed humps. mCd values for speed humps were more than twice the values observed for intersections. mCd values indicate that at intersections moderate degree of contamination exists.

On the other hand, Igeo index values can be a quantitative measure of the degree of pollution in road soil. Igeo values of the road soil are presented in Figure 5. At speed humps, the observed Igeo for Cu, Zn, and Pb showed that contamination is not of huge concern. According to the Igeo index, only upto 5 m for Cu, 50 m for Zn, and 2 m for Pb were the distances that had contamination of moderate level. Rest distances were recognized as either uncontaminated to slightly contaminated (upto distances of 50 m (Cu), 200 m (Zn), and 10 m (Pb)) or practically uncontaminated thereafter. Negative Igeo values were observed for Cu and Pb at 100–200 and 50–200 m, respectively, which showed that the road soil is uncontaminated with these metals. For Zn, road soil is moderately contaminated upto 50 m and after that it is uncontaminated. For intersections, Igeo for all three metals in road soil depicted that they are uncontaminated.

The Igeo and CF values showed that the contamination levels were in order of Zn > Cu > Pb. They indicated the anthropogenic influence on those sites and hence their contamination level. Furthermore, speed humps had Igeo >1 for all three metals. This indicates that the road soils are moderately contaminated by the metals derived from anthropogenic sources. Results indicate that the road environment nearby speed humps is more than twice more polluted than that of intersections, which are already known sites for environmental pollution.

Estimated RI values (with maximum RI = 41) indicated no ecological risk at the studied speed humps because there was variation observed in different indices while identifying a distance upto which environmental pollution occurred near speed humps. Therefore, to exactly identify the length of hotspot for contamination due to traffic sources nearby speed humps, a zone was determined using PLI values.

Identification of Hotspot Zones for Contamination Due to Traffic Sources Nearby Speed Humps. Data analysis at speed humps showed that distribution of heavy metals on both the sides (1 and 2) followed a nonlinear pattern and is presented in Figure 7. The observed data in the contamination of road soils encourages us to find the actual prone area or zone that is under the high influence of contamination due to traffic sources. Hence, the mathematical evaluation of this hotspot zone for pollutants using PLI values may provide necessary information to environmentalists and policy makers to act upon this emerging issue in urban speed.
hump microenvironments. The profile for distribution of heavy metals at the different distances on both sides from the speed humps upto 200 m is presented in Figure 7a. Results showed that the observed heavy metals were distributed in a logarithmic pattern along the roads at the speed humps. Mean values were traced and obtained logarithmic equations of their distribution are presented in eq 1 (with $R^2 = 0.971$) and eq 2 (with $R^2 = 0.976$), respectively. 

$$y_1 = -0.56 \ln(x) + 4.226 \quad (R^2 = 0.971) \quad (1)$$

$$y_2 = -0.53 \ln(x) + 4.131 \quad (R^2 = 0.976) \quad (2)$$

where, $y_1$ and $y_2$ are the values of PLI (unitless and dimensionless) for road soil at sides 1 and 2 of speed humps, respectively, and $x$ is the distance in meters.

Profiles of PLI of heavy metals on both the sides of speed humps for distances 10 m is presented in Figure 7b. Average values of PLI due to three heavy metals Cu, Zn, and Pb in the zone of upto 10 m on both the sides were also found to be in a nonlinear pattern and in a decreasing exponential form. Mean values were traced, and equations of their distribution are presented in eq 3 (with $R^2 = 0.957$) and eq 4 (with $R^2 = 0.943$), respectively. For this zone, the obtained equations were of exponential type and are expressed as follows

$$y_3 = 4.366 e^{-0.05x} \quad (R^2 = 0.957) \quad (3)$$

$$y_4 = 4.266 e^{-0.04x} \quad (R^2 = 0.943) \quad (4)$$

where $y_3$ and $y_4$ are the values of PLI (unitless and dimensionless) for road soil at sides 1 and 2 of speed humps, respectively, and $x$ is the distance in meters.

Using these distribution patterns, an area or a zone was estimated around the speed humps that represented the most affected area, as far as the environment is concerned. Distances at which PLI $\geq 3$ for heavy metals were considered highly contaminated, and the zones in between these distances were identified here as new hotspots for pollution on roads. These hotspots for road soil contamination due to heavy metals at speed humps in urban roadways of developing countries may pose harmful health effects to the commuters as well as residing inhabitants. The hotspots for metal contamination on road were estimated using eqs 3 and 4. Results revealed that upto 7.50 and 8.80 m distances on either sides of the speed humps needed strategies to decrease road soil contamination on urgent basis.

**Statistical Analysis of Heavy Metal Data.** Analysis of data for its quality was performed using different statistical tools. Significant Spearman’s $\rho$ correlation among Cu, Zn, and Pb with varying distances from the speed humps are presented in Table 1. Data analysis revealed that a significant negative correlation was present among heavy metals Cu, Zn, and Pb and distances from speed humps on either sides. Therefore, while moving away from the speed humps, heavy metal...
concentrations were found to decrease. Observed significant Spearman’s ρ correlation coefficients (r) (p ≤ 0.01) were −0.917, −0.938, and −0.802 between increasing distances and Cu, Zn, and Pb, respectively. On the other hand, a strong positive correlation between the couple heavy metals (Cu–Zn, Cu–Pb, and Zn–Pb) with r values 0.881, 0.809, and 0.781 were observed. Results signified that each paired heavy metal had common contamination sources, that is, traffic in this study. On the other hand, variation in their r values could be due to the fact that their generation was from different sources within the traffic. However, physicochemical properties and metal associations were not analyzed in the present study, to help in ascertaining these results. The analysis revealed that heavy metals had affected the speed hump microenvironments.

One-way ANOVA was performed to test the overall influence of the distance from speed humps on heavy metal concentration. On detection of significant differences (p ≤ 0.05) between the mean concentrations at varying distances from speed humps, Tukey’s honestly significant difference (HSD) test was performed. Tukey’s HSD was performed to identify the variation pattern between the distances for their heavy metal concentrations. Tukey’s HSD analysis showed homogeneity in Cu concentration at 1–3 and 3–5 m, whereas significant difference in the mean concentration was observed at a 5–10 m distance. Tukey’s HSD analysis showed homogeneity in Pb concentration in road soil collected at 1–5 and 3–10 m, whereas significant difference in the mean concentration was observed at a 10–50 m distance. The analysis showed a homogeneity in Zn concentration at distances 1–3, 3–5, and 5–10 m, whereas significant variations in mean concentrations were observed at 10–50 and 50–200 m. Data analysis for heavy metal concentrations at different distances at speed humps showed that the contamination of heavy metals indicated less variation upto 10 m distance.

Proposed New Traffic Calming Device for Developing Countries. The new design focused on avoiding mechanical disturbances to the vehicles in low-traffic regions without affecting its target speed reduction. Without simplicity and low costs there will never be any large scale use. The driving behavior to navigate over the unpaved surface at speed humps may be avoided by implementation of vertical structures in the estimated hotspot zone and providing wheel cut-outs (Figure 8) (longitudinal gap provided to allow vehicles to avoid traveling over the vertical hump) of width slightly greater than that of wheels of different vehicle types. It is expected here that these wheel cut-outs may turn the heterogeneous type traffic (characteristics of city traffic mainly in developing countries) into homogenous type and also allow unimpeded passage by emergency vehicles. Provision to warn drivers of the presence of speed hump by posting suitable advance warning sign should be placed 40 m before the speed hump. Speed limit imposition combined with traffic law enforcement is one of the best ways to make vehicles slow down. Studies in many countries have indicated that the introduction of speed limits often has only a short-term effect in reducing speeds unless police regularly enforce the limits.38 Posted speed limits alone will not guarantee compliance. It is only when backed up by strict police enforcement that speed limits reduce speed. Furthermore, it should be painted with luminous and alternate color bands. Regular cleaning of this traffic calming device may increase its performance level as well. After some new traffic calming device’s design implementation like this, one can gradually build up a general design for developing countries.

Limitations of the Proposed New Traffic Calming Device. The proposed calming device has its limitations, and it may affect the traffic in very crowded roads. The proposed traffic calming device considers only the emission reduction as the area of concern and not the other parameters concerned with flow of traffic. This proposed traffic calming device may perform well in low-trafficked arterial roads as well as in urban roads of developing countries like India, prevailing mixed traffic and where the average speed itself has been reported to be lesser than that of other developed countries. For example, Adak et al. developed emission factors of three major vehicle types: two wheelers, three wheelers, and four wheelers for Dhanbad, India, using real-world driving cycle.19 They have reported the average speeds of these three types of vehicles to be 27.8, 13.4, and 17.4 km h⁻¹, respectively, which is much lower than the designed speed for the roads. In another study, real-world vehicle emission was observed to vary with the corresponding driving cycle of the country used for regulatory purpose.39 They have reported that the road driving occurred at lower average speeds with higher frequency and magnitudes of accelerations. Moreover, in India, for speed breakers, the preferred advisory crossing speed of 25 km h⁻¹ was also specified in the guidelines of IRC 99 (1996).40 Furthermore, the effect of the proposed traffic calming device on traffic flow in different cities of developing countries may vary with their respective traffic characteristics. Therefore, a performance study of the proposed traffic calming device can be conducted to examine its effect on traffic flow.

Existing Mitigation Techniques. The proposed design for new traffic calming device could turn into a useful alternative for the identified hotspot by its implementation along with the existing measures.

Improving the Environment of Speed Humps by Washing. The vehicle-emitted heavy metal buildup can accumulate (do not degrade with time) on road surfaces and roadside soil, and hence it contributes in air, soil, and water pollution.41–45 A provision to wash off the paved road
contaminated surface at an area nearby speed humps may provide the immediate and cost-effective solution to remove the heavy metals from road surfaces. It was assumed in this study that regular cleaning of road dust buildup at this speed hump hotspot with water may bring about a significant improvement to environment by removing entrained particles at the hotspot zone. The study attempted for washing of leaves nearby pollution sources showed significant decrease in heavy metal's impact on plants. However, as the hotspot zone is identified, control of the resuspension process could diminish the further contamination to produce better and promising results.

In previous published studies, suitable analytical parameters were identified for road surface cleaning, runoff waters, etc. Researchers have recognized that wash-off is influenced by water intensity, duration, and runoff volume. Furthermore, buildup contaminant’s wash-off from the road surface was usually analyzed using exponential equations. Considering these parameters to wash off at speed hump hotspots may play a better role in this process. In general, water quality models like storm water management model (SWMM) use a constant value of $k$. The value of $k$ is site-specific and may vary with the road soil type, rainfall intensity, catchment area, and catchment slope. A constant value was reported to perform notably well in the estimation process, and use of a constant value of $k$ had reduced the wash-off equation’s complexity. Similarly, for speed humps, the best possible values of $k$ may produce reliable results using the theory of least squares to replicate the observed wash-off patterns by providing water jets of calculated flow rate, amount, and duration.

**Additional Parameters To Improve Road Environment at Speed Humps.** Road gradient was reported as another important parameter in road surface cleaning or runoff simulation studies. The water jets could be drained passively from water outlet nozzles, placed at a relatively higher road grade, to the other end along with the heavy metals removed from that zone for that particular period. The contaminated water can be collected in storage tanks for its treatment by the filtration process with a provision to recycle it back to the upper end using pumps. Filter strips, swales, infiltration trenches, filter drains, and soakways for road surface runoff treatment have been studied for car parking runoff. Furthermore, pollutants at speed humps could be removed through mechanisms adopted by previous researchers in laboratories, such as filtration, adsorption, sedimentation, and biological uptake factors affecting the phenomenon was also important in terms of pollutant mass transport in road dust cleaning. In addition to this, different paving materials having a higher advection property at roads with environmental pollution may also be used to reduce its pollutant load.

The findings of this study encourage the environmentalists, planners, and strategy makers in the developing countries to implement immediate alternatives to not only remove but also avoid continuously increasing traffic-emitted toxic heavy metals and their long-term persistence nearby traffic calming speed humps. Therefore, the proposed new traffic calming device, especially nearby sensitive locations in cities, such as schools, hospitals, residential areas, and minor roads, prone to higher accidental cases, may act as an efficient and a low-cost alternate to this existing environmental concern without affecting its safety aspects. Furthermore, effective monitoring with a detailed study on the performance of the proposed traffic calming device is necessary.

**Materials and Methods**

**Sample Collection.** Road soil was collected following the method described by Fujiwara et al. Samples were collected at speed humps along the road (sides 1 and 2) and intersections in urban roads (Figure 9). To study the environmental effects caused by speed humps, road soils were collected from the sampling sites at distances of 1, 2, 3, 5, 10, 50, 100, and 200 m from the speed humps.

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**Figure 9.** Study sites for collection of road soil at speed humps and traffic intersections in Dhanbad, India (Map source: Wikimapia.org).
The concentration of heavy metals Cu, Zn, and Pb was determined in the collected samples. These three selected heavy metals are well-known markers of traffic-associated emission. Cu, Zn, and Pb in soil were reported to be generated from brake wear, tire wear, and exhaust, respectively.\textsuperscript{31,32–34}

**Chemicals and Reagents.** Digestion of road soil samples for heavy metal analysis was done using the method described by Ogunde\textit{e} et al.\textsuperscript{56} Road soil samples were air-dried, then crushed with a clean dry mortar and pestle, and then sieved through a 2 mm sieve to make it fine. Sieved samples, weighed 3 g, were then digested with a mixture of 10 mL of concentrated hydrochloric acid and 3.3 mL of concentrated nitric acid. For better mixing, they were left overnight.\textsuperscript{57,58} Distilled water was added to the digested sample, and then the sample was filtered with a Whatman No. 42 filter, pore size 2.5 μm, and topped up to 20 mL volumetric flask with distilled water.\textsuperscript{56} The solutions were transferred into sampling bottles for analysis.

The infiltrates were examined for metal concentration level from their acid extracts using atomic absorption spectrophotometer (AAS) (GBC Avanta PM, Australia) at wavelengths, λ, Cu = 324.8 nm, Zn = 213.9 nm, and Pb = 217.0 nm, using air acetylene flame. Standard Reference Materials (AccuTrace, AccuStandard Inc.; Matrix 2–5% HNO\textsubscript{3}; CRM uncertainty ± 5%\textsubscript{i} verified against NIST SRM# 3128 for Pb; 3168 for Zn; and 3114 for Cu) were used for the preparation and calibration of each analytical batch.

**Evaluation Method.** To interpret and assess the contamination status for heavy metals in collected samples, several indices, such as CF, PLI, mCd, Igeo, and RI, were estimated using eqs 5–10. The level of heavy metal contaminations with respect to its corresponding values in native soil before industrialization took place can be expressed by the CF. Hence, CF is the ratio of the concentration of heavy metal in the sample to that in its corresponding background.\textsuperscript{37} It is an effective tool for monitoring the pollution over a period of time and defined as

\[
CF = \frac{C}{B_n}
\]  
(5)

where \(C\) is the concentration of heavy metal “n” in the sample and \(B_n\) is the concentration of heavy metal “n” in the background. The contamination levels were classified by Hakanson\textsuperscript{59} based on their intensities on a scale ranging from 1 to 6, as presented in Table 2. The highest number indicates that the metal concentration is 100 times greater than what it could be expected in the earth crust.\textsuperscript{59,60}

Using the CF values estimated for heavy metals, other four indices (PLI, mCd, Igeo, and RI) were estimated. The PLI was proposed by Tomlinson et al.\textsuperscript{61} It provides some understanding about the measure of a component in the particular environment. PLI for each site was evaluated as indicated by

\[
PLI = \sqrt[\sum_{i=1}^{N}(CF_i)}
\]  
(6)

where \(N\) is the total number of heavy metals analyzed (three in the present study) and CF is the contamination factor.\textsuperscript{52–64} Zero PLI value indicates perfection, a value of one indicates the presence of only baseline levels of heavy metals, and values above one would indicate progressive deterioration of the analyzed site.\textsuperscript{60,64,65}

Another contamination identifying index mCd was also used to examine the contamination in road soil by heavy metals and was calculated based on the equation provided by Abraham and Parker\textsuperscript{66}

\[
mCd = \frac{1}{N} \sum_{i=1}^{N} CF_i
\]  
(7)

where CF is the contamination factor, \(N\) is number of heavy metals in the study, and mCd is the modified and generalized form of the degree of contamination (Cd) proposed by Hakanson.\textsuperscript{59} It is calculated by summing all individual contamination factors and defined as

\[
Cd = \sum_{i=1}^{N} CF_i
\]  
(8)

where CF is the contamination factor, \(N\) is the total number of heavy metals analyzed (three in the present study), and Cd is the degree of contamination. Abraham and Parker\textsuperscript{66} have reported that this generalized formula allows the incorporation of several heavy metals without the restraint of an upper limit. The mCd may be classified into different classes, which are presented in Table 3.

**Table 2. Interpretation of Heavy Metal Contamination Using Contamination Factor (CF)\textsuperscript{59}**

| CF | contamination level |
|---|---------------------|
| 0 | none                |
| 1 | none to medium      |
| 2 | moderate            |
| 3 | moderate to strong  |
| 4 | strong              |
| 5 | strong to very strong |
| 6 | very strong         |

**Table 3. Interpretation of Heavy Metal Contamination Using Modified Degree of Contamination (mCd)\textsuperscript{66}**

| mCd ranges | significance               |
|------------|-----------------------------|
| mCd < 1.5  | nil to very low degree of contamination |
| 1.5 ≤ mCd < 2 | low degree of contamination |
| 2 ≤ mCd < 4 | moderate degree of contamination |
| 4 ≤ mCd < 8 | high degree of contamination |
| 8 ≤ mCd < 16 | very high degree of contamination |
| 16 ≤ mCd < 32 | extremely high degree of contamination |
| mCd ≥ 32 | ultrahigh degree of contamination |

Pollution levels of heavy metals around speed humps could be characterized by the Igeo. This method has been used by Müller for several heavy metal studies throughout the world.\textsuperscript{62,63} It is computed using the following equation

\[
Igeo = \log_2 (C / 1.5B_n)
\]  
(9)

where \(C\) is the measured concentration of individual heavy metal in the sample and \(B_n\) is the background value of individual heavy metal. The control samples were taken to represent the background, and 1.5 is the unvarying factor. Table 4 represents seven classes of Igeo as proposed by Müller.\textsuperscript{57}

Hakanson\textsuperscript{59} provided the ecological risk index (RI), which integrates the factors of ecological risk potentials (E) for each heavy metal and associates their ecological and environmental effects with their toxicology.\textsuperscript{65} Its calculation is done as
### Table 4. Seven Descriptive Classes of Geoaccumulation Index ($I_{geo}$)

| $I_{geo}$ | Description |
|-----------|-------------|
| $< 0$     | Practically uncontaminated |
| $0−1$     | Uncontaminated to slightly contaminated |
| $1−2$     | Moderately contaminated |
| $2−3$     | Moderately to highly contaminated |
| $3−4$     | Highly contaminated |
| $4−5$     | Highly to very highly contaminated |
| $> 5$     | Very highly/strongly contaminated |

\[
RI = \sum Er' i \times C_{fi}' = \frac{\sum_{i=1}^{n} C_{fi}'}{C_{f}}
\]

\[(10)\]

where $C_{fi}'$ corresponds to the pollution factor for individual heavy metals, $C_{f}$ is the background concentration, $Er'$ is the toxic response coefficient developed by Hakanson\(^{59}\) (toxic response coefficients for $Cu = 5$, $Zn = 1$, and $Pb = 5$), and $RI$ is the ecological risk index. The interpretation categories for $RI$ are presented in Table 5.

### Table 5. Interpretation Categories for the Pollution Factor, Potential Ecological Risk, and Ecological Risk Index

| $Er'$ | Potential ecological risk |
|-------|--------------------------|
| $< 40$ | Low                      |
| $40 \leq Er' \leq 80$ | Moderate                  |
| $80 \leq Er' \leq 160$ | Considerable              |
| $160 \leq Er' \leq 320$ | High                      |
| $320 \leq Er'$ | Very high                 |

| $RI$ | Category |
|------|----------|
| $\leq 150$ | Low       |
| $150 \leq RI \leq 300$ | Moderate |
| $300 \leq RI \leq 600$ | Considerable |
| $600 \leq RI$ | High |

### Statistical Analysis

To determine statistical parameters and for further analysis of data for its quality, one-way analysis of variance (ANOVA) and Spearman $\rho$ correlation analysis were conducted using Statistical Package for Social Science (SPSS) of IBM Statistics version 21.0.

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