# Heavy Metals Contamination in Roadside Dust along Major Roads and Correlation with Urbanization Activities in Cairo, Egypt

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**Abstract:** Heavy metal concentrations in roadside dusts are increasingly becoming of health concern. Street dust samples were collected from 46 sites representing different activities across the big city and analysed for Pb, Zn, Cd, Ni, Co, Cr, As, Ag and V. Size fraction of <125 µm, represented the greatest contribution of dust in residential, traffic roads and industrial areas, while coarse particles fraction (>200 µm) was the greatest portion of dust in rural sites. Metal concentrations indicated that roadside dust contained elevated levels of heavy metals and varied across Cairo districts. Concentrations of metals in fine fraction of <125 µm were greater than those in coarse fraction. Compared with residential and rural areas, metals concentrations in the dust were higher in traffic roads and industrial areas. Zinc and lead were the most available metals in both dust fractions from all areas. The correlation and ANOVA analysis confirmed the contribution of anthropogenic sources, traffic and industrial emissions, to metal levels in road dust in Cairo. Furthermore, size fraction and dominant urban activity are the main factors controlling metals concentrations in road dust. The contamination levels of the heavy metals in the road dust were evaluated on the basis of contamination factor ($Cf$), the degree of contamination ($C_d$), index of geo-accumulation ($Igeo$), ecological risk factor ($Er$) and the potential ecological risk index ($RI$). The contamination factors ($Cf$) revealed that road dust is highly contaminated by Pb, Zn, Cd, As and V than that contaminated by Ni, Cr, Co and Ag. These results are confirmed by the very high degree of contamination, particularly at traffic roads and industrial areas. Calculated $Igeo$ indicated that there is a moderate to heavy Pb, Zn and Cd pollution which mainly originated from traffic and industrial activities. Potential ecological risk indexes ($RI$) further indicated that Cairo was suffering from serious metal contamination. Pb and Cd presented higher ecological risks than any other metals, followed by V and Zn with a moderate potential risk. These results are important for the development of proper management strategies to decrease non-point source pollution by various remediation ways.
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**Keywords:** Cairo; Road dust; Heavy metals; Pollution indices; Potential risk

## 1. Introduction

Atmospheric pollution from industrial and road traffic activities in urban areas became severer and severer with the rapid urbanization and the accelerated development of the social economy over the world in the last decades (Fenger, 1999).

Cairo was listed as one of the most polluted cities in the world (Gurjar et al., 2010). Airborne particulate pollution is a serious problem to face Egypt, and Cairo in concern. Rapid increase in both energy consumption and vehicle quantities for the past decades, in addition to high population density with the invaded natural dust from Mokattam hill and large number of construction sites around the big city, are the main factors responsible for the continuity of the problem.

Solid matter, which is composed of soil, anthropogenic metallic constituents and natural biogenic materials, is called dust (Ferreira-Baptista and De Miguel, 2005; Faiz, et al., 2009). Dust deposits and accumulates on ground surfaces, along roadsides, are called road dust, which is contaminated by heavy metals and organic matters. Anthropogenic sources of heavy metals in urban road dusts include traffic emission (vehicle exhaust particles, tire wear particles, weathered street surface particles, brake lining wear particles), industrial emission (power plants, coal combustion, metallurgical industry, auto repair shop, chemical plant, etc.), domestic emission, weathering of building and pavement surface, atmospheric deposited and so on (Lu et al., 2009; Morton-Bermea et al., 2009; Wei et al., 2003; Sindern et al., 2007).

Road dust does not remain deposited in place for long. It is easily re-suspended back into the atmosphere, where it contributes a significant amount of trace elements. Two main sources of road dust, and consequently of the heavy metals found therein; these are deposition of previously suspended particles (atmospheric aerosols) and displaced soil (Ferreira-Baptista and De Miguel, 2005). Particles of different fraction sizes have different modes of transport (Han

et al., 2008). Strong wind is an important factor in transport of dust particles to affect regional environment and harm human health, as well as cause significant impacts on global biogeochemical cycle (Zhuang et al., 2002; Han et al., 2007).

Metals are non-biodegradable and accumulative in nature (Faiz et al., 2009; Kacálková et al., 2009). The prolonged presence of the contaminants in the urban environment can significantly amplify the exposure of the urban population to metals via inhalation, ingestion, and dermal contact (Boyd et al., 1999). These trace metals may include non-essential ones, such as Cd and Pb that can be toxic even at trace levels, and biologically essential elements, such as Cu and Zn, which might cause toxic effects at elevated concentrations.

A previous survey conducted in Cairo showed that the entire area of Cairo is severely affected by industrial and urban emissions of metals and metalloids. So, it is important to have thorough understanding of the nature and extent of heavy metal pollution to keep the environment clean and protect lives from heavy metal contaminants. Lots of studies on urban and industrial atmospheric particulate matter have been carried out over Cairo city (Hassanien and Abdel-Latif, 2008; Mostafa et al., 2009). However, only limited attention has been given to the mobility of heavy metals in different particle size fractions of road dust (Khairy et al., 2011).

There is a virtually lack of available information regarding the resources contributions of environmental pollution in Egypt. Not much is known about biogeochemical cycles of heavy metals in Egyptian ecosystem. Therefore, it is critical for further understanding the air pollution over Cairo.

The main objectives of this work are: (1) to evaluate the characteristics of the contents of nine metals; Cd, Pb, Zn, Ni, Cr, Co, Ag, As and V, with respect to two fine particle size fractions in road dusts, (2) to provide the scientific basis for the composition of road dust as indicator for the influence of urban traffics, residential and industrial activities on the metal content and (3) to evaluate the status of heavy metals pollution and quantify the overall potential ecological risk of observed metals in road dust due to different activities along Cairo city.

## 2. Materials and Methods
### The area under investigation

Cairo, the capital of Egypt, is the largest city in the Middle East. It was listed as one of the most densely populated city in the world, with lowest provisions of road space per capita. The population density is about 31,727 inhabitants per square kilometer. The number of private vehicles has dramatically growth in last decades. Cairo is a rapidly expanding city, which has led to many environmental problems. Cairo occupies about 214.2 km$^2$ stretching along the banks of the River Nile.
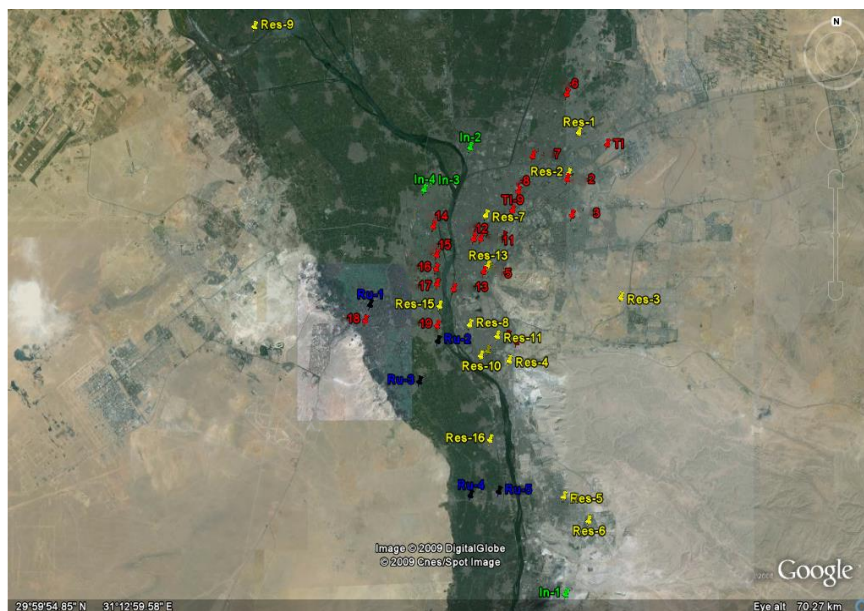


**Fig. (1): The sketch map of locations of the forty-six sampling sites along Cairo city.**

### Sampling

Forty six locations across the city area were selected in order to compare the contamination levels

of the metals and study the spatial distributions characterizing the different urban environments. Figure 1 shows the map of Cairo including the

measurement sampling sites. The selected sites for road dust measurements represent different dominant activities affecting the city environment (i.e. residential, industrial, heavy traffic and rural), and are spatially distributed over Cairo city. Sampling sites are characterized by different traffic density, different congestions and braking frequency of traffic, different component of vehicles, and also with different influences of industrial sources and natural sources and different pollution sources. Sampling sites were selected on asphalted pavement on the side of the road.  Chosen sampling sites include: (i) sixteen sites within the residential area, (ii) twenty one sites located on the main roads and squares to represent the traffic intense area, (which are the busiest and most heavily loaded traffic in Cairo), (iii) four sites representing the main industrial complex areas and (iv) five sites at ruler areas, with a small anthropogenic contribution for the purpose of comparison.

At each sampling point, approximately 200 g of road dust particles was collected on impervious surfaces at the roadsides (the sampling resolution is 1 × 1 m square) with a clean plastic dustpan and a brush and were transferred to self-sealing polyethylene bags for transport to the laboratory for further analysis. The samples were left to dry at room temperature for five days (Ferreira-Baptista and De Miguel 2005), and were subsequently sieved into three different particle size fractions: >200 μm, 200 - 125 μm and <125 μm, for a total of 3 x 46 sub-samples.

For determination of heavy metal concentrations, a wet digestion of 0.5 g of dried dust sample was done using nitric and hydrochloric acids mixture (v/v, 3:1) according to Harrison and Perry (1986). The content of the beaker was heated to $100^O$C, and the temperature was gradually increased to $250^O$C, and left at this temperature for 30 min. The beaker was cooled and the sample solution was filtered using Whatman filter paper (42). Clear solution was transferred into 50-ml volumetric flask, and completed to the mark with double-distilled water. Samples were stored in acid-washed polyethylene bottles at $4^O$C until analysis. A standard solution for each element under investigation was prepared and used for calibration. Measurements were done against metal standard solutions. All the chemicals used were analytical grade reagents and all the equipment and glassware were first acid-washed to avoid external contamination. The content of 9 elements (Pb, Zn, Cd, Co, Cr, Ni, Ag, As and V), was determined by Atomic Absorption Spectrometry (Perkin Elmer) model 3300 manufactured by U.S. Instrument Division, Norwalk, USA. Blank samples, standard samples and duplicate samples were analysed simultaneously in the experiments to provide quality control. The analytical precision, measured as relative standard deviation, was routinely 3–5%.

Metals were determined in dust samples with fraction sizes of 125-200 μm and <125 μm only, as these sizes are easily resuspended and can be inhaled through the nose or mouth during breathing.

**Assessment of metal contamination**

Contamination indices and ecological risk indices were analysed to assess heavy metal contamination of road dust using single and integrated indices. In this study, contamination factor (*Cf*), ecological risk factor (*Er*) and index of geo-accumulation (*Igeo*), as single indices, and the degree of contamination ($C_d$) and the potential ecological risk index (*RI*), as integrated indices, were calculated.

The contamination factor (*Cf*) and degree of contamination ($C_d$) were suggested by Håkanson (1980), and defined as follows:

$$C_f = C_s / C_b \qquad (1)$$
$$C_d = \sum C_f \qquad (2)$$

Where, $C_s$ is the measured concentration of the examined metal in the road dust and $C_b$ is the geochemical background concentration or reference value of the metal or the background value of heavy metals in the uncontaminated soil (Khairy et al. 2011). Håkanson (1980) suggested four classes of *Cf* to evaluate the metal contamination levels (Loska et al., 2004) as follows: low (*Cf* <1), moderate ($1 \le Cf < 3$), considerable ($3 \le Cf < 6$), and very high ($6 \le Cf$) contamination levels.

In this study, four categories of $C_d$ were used to evaluate metal contamination levels as follows: low ($C_d < 5$), moderate ($5 \le C_d < 10$), considerable ($10 \le C_d < 20$), and very high ($20 \le C_d$) degree of contamination (Duong and Lee, 2011). If the $C_d$ values exceeded 20, then it was necessary to take immediate counter measures to reduce heavy metal contamination in the road dust.

An index of geo-accumulation (*Igeo*) was originally defined by Müller (1969), and can be calculated by the following equation:

$$Igeo = \log_2 [C_s / (1.5 C_b)] \qquad (3)$$

Factor 1.5 is used because of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences. Müller (1969) classified *Igeo* for each metal to 5 grade-categories (Table 1).

The potential ecological risk (*RI*) of the heavy metals is quantitatively evaluated by the potential ecological risk index (*Er*) (Håkanson, 1980; Zhu et al., 2008), which takes into account both contamination factor (*Cf*), and the "toxic-response" factor. The potential risk index can be acquired as follows:

$$Er = T_r \times C_f \quad (4)$$

$$RI = \sum Er \quad (5)$$

Where, *Er* and *RI* denote the potential ecological risk factor of individual and multiple metals, respectively. *Tr* denotes the "toxic-response" factor for heavy metals. Håkanson (1980) suggested that the *Tr* values of Cd, Cr, Ni, Pb, Zn, Co and As are 30, 2, 3, 5, 1, 5, and 10, respectively. The potential ecological risk values obtained were compared with categories grade of *Er* and *RI* of metal pollution risk on the environment suggested by Håkanson (1980) and Shi et al. (2010) (Table 1).

**Table (1): Grades of geo-accumulation index pollution and potential ecological risk of toxic metals.**

| Index of geo-accumulation[1] (*Igeo*) | | Individual ecological risk[2] (*Er*) | | Multiple ecological risk [3] (*RI*) | |
|---|---|---|---|---|---|
| Value | Pollution category | Value | Risk category | Value | Risk category |
| Igeo ≤ 0 | Unpolluted | Er <40 | Low | RI < 150 | Low |
| 0<Igeo≤1 | Unpolluted/Moderately | 40≤Er<80 | Moderate | 150≤RI<100 | Moderate |
| 1<Igeo≤2 | Moderately | 80≤Er<160 | Considerable | 300≤RI<600 | Considerable |
| 2<Igeo≤3 | Moderately/Heavily | 160≤Er<320 | High | RI ≥ 600 | High |
| 3<Igeo≤4 | Heavily/Extremely | Er≥320 | Very high | | |
| 4<Igeo≤5 | Extremely | | | | |

[1] Müller (1969); [2] Håkanson (1980); [3] Shi et al. (2010)

All statistical analyses were performed by using the Microsoft Excel 2007. One-way and two-way ANOVA of the concentration were performed using Statsoft statistical package, STATISTICA for Windows, Copyright StatSoft, Inc.

## 3. Results and Discussion

Roadway dust, in Cairo, receives varying inputs of anthropogenic metals from a variety of mobile or stationary sources, such as vehicular traffic, industrial plants, power generation facilities, residential oil burning, waste incineration, construction and demolition activities and re-suspension of surrounding contaminated soils. The presence of these potentially toxic contaminants in particulate matter is traditionally characterized in terms of total metal concentration, although it has been recognized that the environmental significance of a metallic element depends, besides other factors, on its specific partitioning within or on solid matrices.

**Size fraction**

The mean percents of size-fractionated particulate matter of road dust at the different activities sites are shown in Fig. (2). This figure shows generally that fine street dust particles, of size fraction **<**125 μm, has the greatest contribution percent of the total particulate matter in residential, traffic roads and industrial areas with a mean percentage of 49%, 44%, and 53%, respectively; while size fraction of **>**200 μm was the lowest percentage content of dust particulate for the corresponding areas with 16%, 17%, and 12%, respectively. The results show also that there is a considerable difference between >200 μm size fraction percentage in these areas compared to other

two size fractions. Contrarily, the results reflected the influence of rural activities on street dust as the highest percent fraction size recorded at rural sites was for coarse particles fraction (>200 μm) with a percentage of 38%, followed by the fine size fraction (<125 μm) with a percentage of 33%.

In a recent study to examine atmospheric fine particulates in the surroundings of rural, urban and industrial areas, North France, it was found that $PM_{2.5}$ was slightly more concentrated in industrial than urban atmospheres, and they were 3 to 4 times more than the rural area (Cazier et al., 2011). The predominant of the fine particle size is consistent with the finding that particles smaller than 100 μm move in suspension and the finest among them may remain airborne for prolonged periods of time (Charlesworth et al., 2011).

It has been pointed out that road dust resuspension contributes significantly to PM concentration levels in urban areas (Athanasopoulou et al., 2010; Karanasiou et al., 2009; Thorpe and Harrison, 2008). It was concluded that road traffic re-suspended dust in Beijing was the largest source of the dust emissions and reached more than 30% of TSP (Han et al., 2007). Moreover, Lenschow et al. (2001) mentioned that exhaust emissions and tyres abrasion contribute 55% and re-suspended soil material 45% to traffic-related $PM_{10}$.

It is generally accepted that the two main sources of street dust, and consequently of the trace elements found therein, are deposition of previously suspended particles (atmosphere aerosol) and displaced urban soil (Ferreira-Baptista and DeMiguel, 2005; Han et al., 2007).
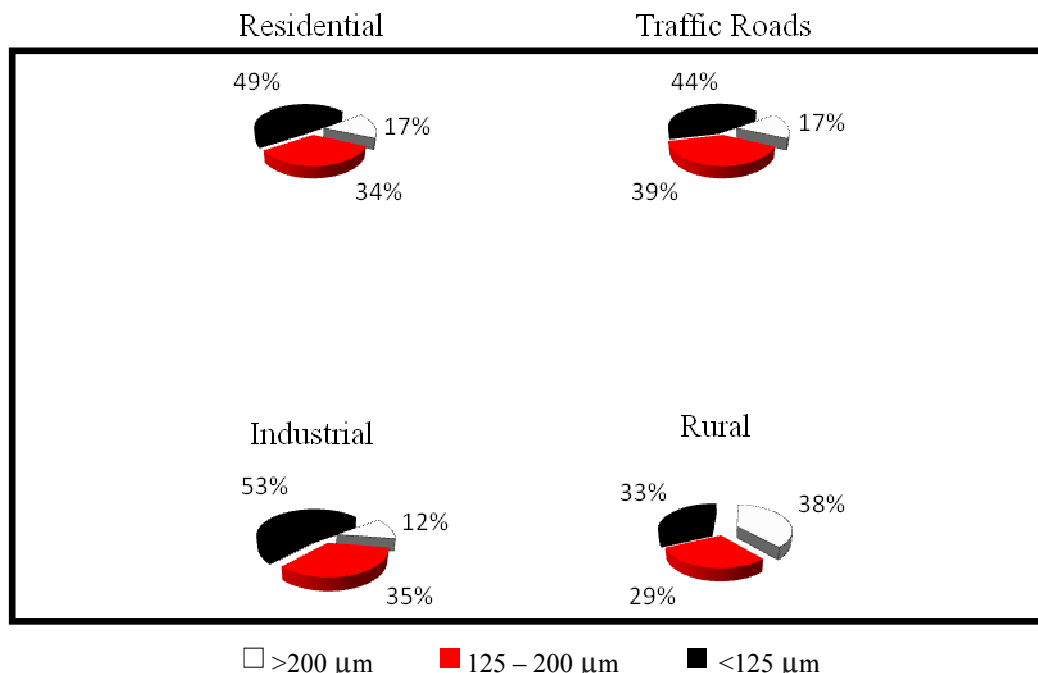
**Fig. (2): The percent contributions of various size fractions in road dust at the chosen sites.**

**Heavy metal concentration and contamination sources of road dust**

Concentrations of 9 metals; Pb, Cd, Zn, Ni, Cr, Co, Ag, As and V, were measured in two size fraction (<125 μm and 125-200 μm) of road dust collected from 46 sites representing different activities (residential, industrial, traffic roads and rural). Mean value concentrations were obtained by averaging the results of the samples collected from different roads sites.

Tables 2 shows mean concentrations of metals in dust from the four categories of sampling sites. The results show the wide ranges of mean concentrations for the studied metals, that is most likely indicative of the effect of motor vehicles, industrialization and urbanization. Generally, concentrations of detected metals in particles of <125 μm size fraction are higher than the corresponding concentrations in particle size of 125-200 μm, except for Zn in rural sites, as shown from the ratio obtained for metals contents in both size fractions (Table 2). Moreover, Cd concentration in rural area is independent of size fraction. The ratio of the concentration in size fraction <125 μm to that in size fraction 125–200 μm of Pb, Cd and Ag was the greatest in urban intense traffic roads. While the highest ratio for Zn and As was in industrial areas, rural dust exhibited higher ratio for Ni, Cr, Co and V. The results indicated that distribution patterns of all heavy metals concentration are almost differ significantly depending on the sampling areas according to major predominant activities. The results showed also that metals concentrations recorded for the traffic roads and industrial sites were higher, with few exceptions, than the corresponding levels in residential and rural sites.

Zinc was the most abundant metal, followed by Pb in both dust size fractions from all areas, except for size <125 μm of rural activity where vanadium was the most abundant metal. On the other hand, Cd, Ag and As were the least available metals in all collected dust samples. Despite the slight variation between As and Ag or Ni and Cr among 125-200 μm dust fraction of traffic roads and industrial areas, the overall total metals content in street dust for both size fractions and different activities shows the abundance order of: (Zn > Pb > V > Cr > Ni > Co > Ag > As > Cd). Fraction size 125–200 μm of rural areas dust has the same metals rank; however, fraction size <125 μm shows a different abundance order, with V as the more labile element (V > Pb > Zn > Ni > Cr > Co > As > Ag > Cd).

Highest mean concentrations recorded for Zn and Pb in road dust samples at all areas, especially that collected from the heavy traffic and industrial areas for both size fractions, suggesting the responsibility of automobile emissions and industrial combustion processes. The highest mean concentration of Zn and Pb in <125 μm size fraction at the intense traffic roads were 638.4 and 234.6 μg/g, respectively; while the corresponding highest values detected in size fraction 125–200 μm were

332.1 µg/g for Zn at traffic roads, and 149.5 µg/g at the industrial area sites followed by 142.1 µg/g at traffic roads for Pb. Symmetric abundance-profile of Zn and Pb had already been reported by Maiz et al. (2000). It has been demonstrated that Zn could be derived from the mechanical abrasion of vehicles and tyres as it is a component of brake pads and brass alloy (Jiries et al., 2001; Fujiwara et al., 2011). Zn could be also attributed to brake linings, oil leak sumps, cylinder head gaskets and lubricating oils (Jiries et al., 2001). Zn has been proposed as future motor vehicle source profile characterization instead of lead and therefore as reliable tracers of the intensity of vehicle emissions in urban areas (Monaci et al., 2000). Regarding lead, brake wear and loss of Pb wheel weights have been considered as the main sources of this element in the urban environment (Smichowski et al., 2008). After phasing out leaded gasoline in Egypt, vehicular Pb emissions could be produced mainly from wear rather than fuel combustion (Fujiwara et al., 2011). Lead and Zn are not only present in brake pads and tyre rubber but also in fuels either as a natural component (Pb) or as an additive (Zn).

Cadmium exhibited the lowest levels in almost all the samples analyzed compared to other metals in consistent with the findings of Elik (2003), who concluded that the street dust generally contained lower levels of Cd than the other metals. Cd concentration was found to be higher in both size fractions samples collected from the traffic intense areas than that observed in the other areas, of different predominant activities mean range concentration of Cd varied from 0.25 µg/g (in rural area) to 0.82 µg/g (in traffic roads area). Higher levels of Zn and Cd in high traffic and industrial activities indicate that the fragmentation of car tyres is a likely source of these metals (Elik, 2003).

**Table (2): One-way ANOVA of metallic contents (µg/g) in <125 and 125 –200 µm road dust fractions.**

| Element | Residential | Road | Industrial | Rural | F-value | p-level |
|---|---|---|---|---|---|---|
| **Size fraction <125 µm** | | | | | | |
| Pb | 92.38a | 234.6b | 218.9b | 66.50a | 13.6*** | 0.0000 |
| Cd | 0.480a | 0.820b | 0.400a | 0.250a | 4.95** | 0.0049 |
| Zn | 230.6ab | 638.4c | 404.7a | 63.60b | 24.9*** | 0.0000 |
| Ni | 16.47a | 25.38b | 26.38b | 26.40b | 6.74*** | 0.0008 |
| Cr | 25.78a | 36.95b | 34.25ab | 24.70a | 3.49* | 0.0237 |
| Co | 5.030a | 5.240a | 5.290ab | 7.800b | 2.22ns | 0.1000 |
| Ag | 2.210a | 2.960a | 2.060ab | 0.630b | 5.05** | 0.0044 |
| As | 1.580a | 1.520a | 1.900a | 1.580a | 0.91ns | 0.4429 |
| V | 61.86a | 62.74a | 64.63a | 173.6b | 8.71*** | 0.0001 |
| **Size fraction 125 –200 µm** | | | | | | |
| Pb | 63.91a | 142.1b | 149.5ab | 43.70a | 3.97* | 0.0141 |
| Cd | 0.300a | 0.350a | 0.260a | 0.250a | 1.46ns | 0.2402 |
| Zn | 146.2a | 332.1b | 196.6ab | 100.2a | 9.18*** | 0.0001 |
| Ni | 11.03a | 14.67ab | 19.00b | 9.900a | 2.50ns | 0.0725 |
| Cr | 15.59a | 21.62a | 17.13a | 10.90a | 1.10ns | 0.3608 |
| Co | 2.670a | 3.240a | 2.750a | 3.320a | 0.51ns | 0.6790 |
| Ag | 1.040a | 1.010a | 1.040a | 0.500b | 3.48* | 0.0241 |
| As | 0.980a | 1.120a | 1.060a | 1.030a | 0.50ns | 0.6824 |
| V | 23.92a | 36.90b | 38.91b | 21.80a | 5.69** | 0.0023 |
| **Ratio (<125 / 125 –200)** | | | | | | |
| Pb | 1.45 | 1.65 | 1.46 | 1.53 | | |
| Cd | 1.62 | 2.31 | 1.52 | 1.00 | | |
| Zn | 1.58 | 1.92 | 2.06 | 0.53 | | |
| Ni | 1.49 | 1.73 | 1.49 | 2.67 | | |
| Cr | 1.65 | 1.71 | 2.00 | 2.27 | | |
| Co | 1.88 | 1.62 | 1.92 | 2.35 | | |
| Ag | 2.13 | 2.94 | 1.99 | 1.26 | | |
| As | 1.61 | 1.36 | 1.79 | 1.53 | | |
| V | 2.59 | 1.70 | 1.66 | 7.96 | | |

Significant at: * P < 0.05, ** P < 0.01, ***P < 0.001, ns = Non-significant
Mean values not followed by the same letter are significantly different from one another (P= 0.05).

Enhanced concentrations of Ni, Co, Cr, Ag and As with decreasing particle size in all the samples collected from the different areas have been recorded. The increased concentration of Ni in industrial region for both size fractions indicated the contribution of fuel combustion for urban and industrial activities in agreement with Dongarrá et al. (1996). Higher concentration of Cr in traffic roads and industrial areas, compared to residential and rural areas, may reflect common traffic source and brake lining, as well as variety of industrial sources (Rodríguez et al., 2004). Higher frequency of stop and start-up of vehicles may emit more Cd, Ni, and Zn into the road dust (Wei et al., 2010).

Higher concentrations with decreasing particle size were also evident for V in samples from most areas. The ratio of the average concentration of vanadium in samples of size fraction <125 μm to that in samples of size fraction range 125–200 μm reached to 7.96 at the rural areas (Table 2). Increasing of V and Co in either size fraction to some extent in rural areas may be due to the influence of

the natural sources (Wei et al., 2010) as well as to the local anthropogenic contribution of domestic combustion processes and vegetation burning, in consistence with Han et al. (2007) and Rodríguez et al. (2004).

Ag in size fraction samples of 125–200 μm has average concentration at traffic intense areas approximately similar to that of residential and industrial areas. This may be due to the fact that metals derive from the mechanical erosion of vehicular parts or during fuel combustion once emitted into the atmosphere, adhere to pre-existing particles of any nature and dimension and then deposited to the ground.

For fine particle-fraction (<125 μm), moderate to high correlation coefficient was found between Pb and each of Zn, Cd, Ni and Cr with values of 0.578, 0.506, 0.429 and 0.703, respectively, may imply that these elements have somewhat similar sources; i.e. vehicular and industrial activities. This finding was confirmed by other correlation coefficient of Zn/Cd (0.573), and Ni/Cr (0.572) (Table 3).

**Table (3): Correlation coefficient between metals in the street fine-sized dust of different categories.**

|    | Pb | Cd | Zn | Ni | Cr | Co | Ag | As | V |
|----|----|----|----|----|----|----|----|----|----|
| Pb | 1.000 | | | | | | | | |
| Cd | 0.506 | 1.000 | | | | | | | |
| Zn | 0.578 | 0.573 | 1.000 | | | | | | |
| Ni | 0.429 | 0.282 | 0.423 | 1.000 | | | | | |
| Cr | 0.703 | 0.284 | 0.376 | 0.572 | 1.000 | | | | |
| Co | 0.068 | 0.027 | -0.199 | 0.522 | 0.439 | 1.000 | | | |
| Ag | 0.279 | 0.230 | 0.377 | -0.034 | 0.104 | -0.436 | 1.000 | | |
| As | 0.080 | -0.069 | -0.010 | 0.111 | -0.054 | 0.092 | -0.165 | 1.000 | |
| V | -0.102 | -0.234 | -0.312 | 0.387 | -0.011 | 0.462 | -0.375 | 0.404 | 1.000 |

A similar correlation was found for Pb with Cr, V and zn in medium particle-fraction (125–200 μm). Contrarily to fine dust, other important correlations were obtained for As and V with Pb, Cd, Zn, Ni and Cr in medium-sized dust (Table 4). It has

demonstrated that the most common heavy metals released from vehicles on road are cadmium, lead, nickel and zinc (Al-Khashman, 2004; Elik, 2003; Han et al., 2007).

**Table (4): Correlation coefficient between metals in the street medium-sized dust of different categories.**

|    | Pb | Cd | Zn | Ni | Cr | Co | Ag | As | V |
|----|----|----|----|----|----|----|----|----|----|
| Pb | 1.000 | | | | | | | | |
| Cd | 0.187 | 1.000 | | | | | | | |
| Zn | 0.411 | 0.554 | 1.000 | | | | | | |
| Ni | 0.279 | 0.243 | 0.550 | 1.000 | | | | | |
| Cr | 0.807 | 0.111 | 0.312 | 0.361 | 1.000 | | | | |
| Co | 0.365 | 0.340 | 0.242 | 0.382 | 0.489 | 1.000 | | | |
| Ag | 0.177 | 0.340 | 0.273 | 0.217 | 0.115 | 0.144 | 1.000 | | |
| As | 0.229 | 0.505 | 0.513 | 0.522 | 0.195 | 0.327 | 0.256 | 1.000 | |
| V | 0.443 | 0.116 | 0.473 | 0.735 | 0.482 | 0.255 | 0.162 | 0.320 | 1.000 |

The effect of major dominant activities on metallic contents in road dust is indicated by one-way ANOVA for the obtained results (Table 2). ANOVA

results showed that there were significant differences between mean contents of metals of different four categories sites for size fraction (<125 μm), while

less significant differences were there between mean metals contents for size fraction (125-200 μm). On the other hand, significant overall effects were obtained for the dominant activity difference on metallic contents of different sites for all elements of size fraction <125 μm, except for Co and As. In contrast, the significant overall activity effect was there for Pb, Zn, Ag and V only of size fraction 125-200 μm.

**Table (5): Two-way ANOVA of metallic contents (μg/g) in <125 and 125 –200 µm road dust fractions.**

|  | Residential | | Traffic Road | | Industrial | | Rural | | Main Effects | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | <125 | 125 - 200 | <125 | 125 - 200 | <125 | 125 - 200 | <125 | 125 - 200 | Activity (1) | Size (2) | (1) × (2) |
| Pb | 92.38a | 63.91a | 234.6b | 142.1b | 218.9b | 149.5ab | 66.5a | 43.7a | 15.7*** | 6.25* | 1.16ns |
| Cd | 0.48a | 0.30a | 0.82b | 0.35a | 0.4a | 0.26a | 0.25a | 0.25a | 6.22*** | 7.30** | 2.93* |
| Zn | 230.6a | 146.2a | 638.4b | 332.0b | 404.7ac | 196.6ab | 63.6ad | 100.2a | 33.7*** | 12.0*** | 5.45** |
| Ni | 16.47a | 11.03a | 25.38b | 14.67ab | 26.38b | 19.00b | 26.4b | 9.90a | 7.22*** | 33.5*** | 2.16ns |
| Cr | 25.78a | 15.59a | 36.95b | 21.62a | 34.25ab | 17.13a | 24.7a | 10.90a | 3.88* | 17.6*** | 0.31ns |
| Co | 5.03a | 2.67a | 5.24a | 3.24a | 5.29ab | 2.75a | 7.8b | 3.32a | 2.12ns | 32.4*** | 1.17ns |
| Ag | 2.21a | 1.04a | 2.96a | 1.01a | 2.06ab | 1.04a | 0.63b | 0.50b | 6.68ns | 19.7ns | 3.20ns |
| As | 1.58a | 0.98a | 1.52a | 1.12a | 1.9a | 1.06a | 1.58a | 1.03a | 0.57ns | 34.2*** | 0.93ns |
| V | 61.86a | 23.92a | 62.74a | 36.90b | 64.63a | 38.91b | 173.6b | 21.80a | 7.08*** | 46.6*** | 10.0*** |

Significant at: * $P < 0.05$, ** $P < 0.01$, ***$P < 0.001$, ns = Non-significant
Mean values not followed by the same letter are significantly different from one another (P= 0.05).

Two-way ANOVA was carried out to examine the overall effects of size fraction and dominant activity on metallic contents of street dust in different areas categories. The main statistical effects of ANOVA for different metals are shown in Table 5. These results showed that all examined metals concentrations were found to be dependent upon size fraction, except for Ag only; while dominant activity had significant effects on metallic contents of street dust for all metals except for Co, Ag and As. The significance effects of the interaction between size fraction and dominant activity upon metallic contents of street dust in different areas categories, as shown from the 2-way ANOVA statistical analysis in (Table 5), were obtained only for Cd, Zn and V only.

**Pollution indices**
The heavy metal contamination of the road dust was evaluated based on the contamination factor and the degree of contamination suggested by Håkanson (1980). Table 6 shows values of the contamination factor of road dust and degree of contamination due to heavy metals. The contamination factors ($Cf$) indicated very high contamination levels ($6 \leq Cf$) of Pb (in all areas) and Zn (in heavy traffic roads and industrial areas). Concentrations of Cd, Zn and V from main roads, residential and rural areas, respectively, were categorized as considerable contamination levels ($3 \leq Cf < 6$). In the road dust from residential, industrial and rural areas of Cd and Zn (rural road dust only), the contamination factors indicated moderate contamination ($1 \leq Cf < 3$). Except for V in rural sites, concentrations of As and

V of road dust fall under moderate contamination factors category. Ni, Cr, Co and Ag, had low contamination factors ($Cf < 1$) according to their concentrations in road dust. These results indicate that the road dust is highly contaminated by Pb, Zn and Cd, followed by As and V.

The degrees of contamination by heavy metals in the road dust from main traffic road, industrial, residential, and rural areas were found to be 58.6, 51.7, 26.7 and 20.4, respectively. These results indicate that the road dust within Cairo city has a very high degree of contamination ($20 \leq C_d$), particularly at main road and industrial areas.

The results of Geo-accumulation Index ($Igeo$) in road dust calculation are shown in Table 6. The negative values of Ni, Cr, Co, Ag and As, according to contamination classification of Müller (1969), indicated that the soil was not polluted by these metals. Similarly, rural and residential areas were not polluted with Cd and V, respectively ($Igeo \leq 0$). Based on the results, $Igeo$ values for Cd (residential and industrial dust), Zn (rural dust) and V (traffic and industrial dust) were less than 1, revealing that road dust at the corresponding areas was unpolluted to moderately polluted ($0 < Igeo \leq 1$). Calculated values of $Igeo$ for Cd in intense traffic road dust, Zn in residential dust and V in rural dust indicated moderately polluted ($1 < Igeo \leq 2$) for these metals.

While rural and industrial dusts were moderately to heavily polluted ($2 < Igeo \leq 3$) with Pb and Zn, respectively; Pb in residential dust and Zn in heavy traffic road dust were under the heavily polluted class ($3 < Igeo \leq 4$). According to the classification, industrial and main traffic roads dusts

were characterized by a heavy to extreme level of Pb pollution ($4 \leq Igeo \leq 5$).

**Table (6): Contamination factors (*Cf*), degree of contamination ($C_d$), geo-accumulation index (*Igeo*), risk factors (*Er*) and risk indices (*RI*) of potential toxic metals.**

| | *Cf* | | | | *Igeo* | | | | *Er* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Res. | Road | Ind. | Rural | Res. | Road | Ind. | Rural | Res. | Road | Ind. | Rural |
| Pb | 15.95 | 38.44 | 37.59 | 11.24 | 3.41 | 4.68 | 4.65 | 2.91 | 79.74 | 192.19 | 187.96 | 56.22 |
| Cd | 2.23 | 3.34 | 1.89 | 1.43 | 0.57 | 1.156 | 0.33 | -0.07 | 66.86 | 100.29 | 56.57 | 42.86 |
| Zn | 4.86 | 12.51 | 7.75 | 2.11 | 1.70 | 3.06 | 2.37 | 0.49 | 4.86 | 12.51 | 7.75 | 2.11 |
| Ni | 0.37 | 0.53 | 0.61 | 0.48 | -2.03 | -1.49 | -1.31 | -1.63 | 1.10 | 1.60 | 1.82 | 1.45 |
| Cr | 0.41 | 0.59 | 0.51 | 0.36 | -1.86 | -1.36 | -1.55 | -2.08 | 0.83 | 1.17 | 1.03 | 0.71 |
| Co | 0.10 | 0.11 | 0.11 | 0.15 | -3.87 | -3.73 | -3.81 | -3.34 | 0.51 | 0.57 | 0.54 | 0.74 |
| Ag | 0.07 | 0.08 | 0.06 | 0.02 | -4.53 | -4.24 | -4.60 | -6.05 | - | - | - | - |
| As | 1.28 | 1.32 | 1.48 | 1.31 | -0.23 | -0.18 | -0.02 | -0.20 | 12.80 | 13.20 | 14.80 | 13.05 |
| V | 1.43 | 1.66 | 1.73 | 3.26 | -0.07 | 0.147 | 0.202 | 1.12 | - | - | - | - |
| $C_d$ | 26.69 | 58.58 | 51.72 | 20.36 | | | | | | | | |
| *RI* | | | | | | | | | 166.7 | 321.6 | 270. 5 | 117.2 |

Variations in the calculated values of *Igeo* for Zn, which ranged from moderately to extremely polluted, may indicate that Zn has different emission sources with different contribution levels are in agreement with Khairy et al. (2011) who reported variable *Igeo* for Zn in soil of Delta region, Egypt.

The ecological risk assessment results of toxic metals in road dust, summarized in Table 6, showed that the potential ecological risk factor of individual metal values (*Er*) varied belonging the studied metals in road dust as well as in the different areas. These results indicated that road dust posed a low to high potential ecological risk. Among the four categories of activities, intense traffic road and industrial areas suffered the most serious pollution, which posed a high contamination ecological risk above 160; whereas residential and rural areas of had a moderate degree of pollution according to *Er* values (Table 6).

Among the studied metals, Pb and Cd presented higher ecological risks than any other metal, because of their higher toxicity coefficient. The average ecological risks of Pb in both main road and industrial dusts were above 160, indicating that Pb posed a potentially high risk to local environment. Similarly, Cd ecological risk in main road dust was 100.3 denoting a considerable risk to the environment. Other *Er* values for Pb and Cd were between 40 and 80, indicating moderate potential ecological risk. The other heavy metals had *Er* values under 40 and consequently low potential ecological risk.

In order to quantify the overall potential ecological risk of observed metals in road dust, *RI* was calculated as the sum of all calculated risk factors (Table 6). *RI* values ranged from 117.2 for rural dust to 321.6 for main traffic road dust. According to the grades, the overall risks caused by the studied metals were low for rural dust, moderate for residential and industrial dusts, and considerable ecological risk for main road dust.

*RI* could characterize sensitivity of local ecosystem to the toxic metals and represents the ecological risk resulted from the overall contamination (Shi et al., 2010). The contribution percent of individual metal to overall potentially ecological risk revealed that the two most toxic metals, i.e. Pb and Cd, contributed nearly 90% of the total potentially ecological risk (59% for Pb and 30% for Cd). It could be concluded that the high ecological risk was primarily dominated by Pb and Cd metals.

**Conclusions**

Understanding the levels, distribution and sources of heavy metals in road dust can aid environmental managers and facilitate the supervision of air quality. Therefore, it is critical for further understanding of the air pollution over Cairo. Fine soil of size <125 μm was associated with the emissions from urban activities (i.e. industry, traffic roads and residential); meanwhile, the biggest size fraction >200 μm was the most in rural road dust. As it was confirmed for big cities (Ferreira-Baptista and Miguel, 2005), road dust is significant source of heavy metals in Cairo, and fine fractions of local road dust were generally enriched with elements.

Elemental profile is a useful tool for distinguishing the contribution of different sources to shed light on how local factors influence dust characteristics (Fujiwara et al., 2011). The results of the present work indicate that road dust within Cairo contain higher concentrations of elements reflecting the contribution of vehicular traffic and the industrial activities. Previous studies on street dust pollution

have revealed the direct responsibility of traffic and industrial activities on the extent of metal pollution in road dust with the highest metal concentrations generally being found at locations with industrial emissions or heavy traffic. Contrarily, the lowest levels of metals in street dust are often found at rural areas of relatively low vehicular traffic and low population density. The levels of examined metals in street dusts are not evenly distributed throughout the studied areas and overall metals concentration in the present study was in order of Zn > Pb > V > Cr > Ni > Co > Ag > As > Cd. In spite of decreasing the trend of Pb that observed in the urban atmosphere of Cairo (Zakey et al., 2008) after phasing out leaded gasoline and transferring smelters outside Cairo city. Pb is still a significant urban pollutant, due to fuel combustion in industry and other urban activities, and road dust has been recognized by the current study to be enriched with Pb.

Contamination assessment based on pollution indices showed that road dust is highly contaminated by Pb, Zn, Cd, As and V, according to their high degree of contamination, particularly at main traffic road and industrial areas. Concerning *Igeo* values, Ni, Cr, Co, Ag and As presented uncontaminated road dust, whereas Pb, Zn, Cd and V of the road dust had variable *Igeo* values ranged from moderate to extreme pollution categories. The ecological risk assessment results showed that road dust posed a low to high potential ecological risk. Pb and Cd presented higher ecological risks than any other metal, particularly in both main intense traffic roads and industrial dusts.

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