Characterization of road-deposited sediments in different land-use types in Tehran, Iran

Fatemeh KazemiParkouhi[1] , Masoud Tajrishy[2], Masoud Kayhanian[3]

[1] Sharif University of Technology, Tehran, Iran, f.kazemi135@gmail.com
[2] Sharif University of Technology, Tehran, Iran, tajrishy@sharif.edu
[3] University of California, Davis, California, U.S.A., mdkayhanian@ucdavis.edu

ABSTRACT

This study investigates the characteristics of road-deposited sediments (RDS) from selective impervious surfaces in the Metropolitan city of Tehran located in Iran. A total number of 19 RDS samples were collected from three different land-use types herewith denoted as residential, intense traffic and educational areas. The samples were fractionated into seven grain-size ranges (1000-2000, 600-1000, 300-600, 150-300, 75-150, 45-75, and <45 µm and analysed for particle size distribution (PSD) and heavy metal concentration. Approximately, 50-80% of the total sediment mass was related to particles <300 µm. The maximum mean concentrations of zinc, lead, copper, nickel and cadmium were respectively 536.4, 422.4, 210.3, 96.6 and 22.8 mg/kg. Samples from the intense traffic area had the highest metal concentrations except for cadmium. For all analysed heavy metals the highest mean concentrations were found in the particle size fraction in the range of <45 to 75 µm.

KEYWORDS

Heavy metals, Land use type, Particle size distribution, Road-deposited sediment, Tehran

1 INTRODUCTION

Tehran is facing many environmental problems due to expansion and population growth. Among these problems, stormwater pollution is becoming an important issue in urban areas. As the population grows and most pervious land uses are transformed into impervious surfaces, the discharge of point and non-point source pollution is expected to increase. As a result the quality of receiving waters in Tehran will further deteriorate. Compared with point-source pollution, management and control of non-point source pollution in urban area is more challenging. Natural and manmade pollutants accumulate on impervious surfaces including suspended solids, heavy metals and hydrocarbons which can come from wide sources including wet deposition, soil erosion, vehicle exhaust, vehicle and road wear and de-icing operations. These pollutants are washed off during rain events and because of the large volume and short duration, practical treatment is harder.

Urban pollution can be investigated as dissolved and particle bound. Because nearly all best management practice (BMP) treatment systems employed for urban runoff treatment are physically based unit operation, investigation of particle size distribution and size resolved pollutants is immensely valuable. To make our results more relevant to the literature, we tried to concentrate our review on available literature on areas in Asia comparable to Tehran. Many researchers have studied size-fractionated road sediments and evaluated their metal elemental compositions. Bian and Zhu (2008) found that 60-80% of RDS samples in Zhenjiang, China consist predominantly of particles <250 µm and the maximum mean concentration of Zn, Pb and Cu were 686.93, 589.19 and 158.16 mg/kg, respectively. Faiz et al. (2009) found that the average concentration of Cd, Cu, Ni, Pb and Zn were 5 ± 1, 52 ± 18, 23 ± 6, 104 ± 29 and 116 ± 35 mg/kg, respectively in dust samples collected from the Islamabad Expressway. Highest concentration of Cd, Cr, Cu, Ni, Pb and Zn in most areas of Haidian District, Beijing were 0.28-1.31, 57.9-154, 68.1-142, 25.8-78.0, 73.1-222 and 264-664 mg/kg, respectively (Zhao et al. 2010). While the particle size distribution and concentration of heavy metals in RDS vary from one city to another (Jiries et al. 2001), the above studies showed that highest concentration of metal pollutants are usually associated with smaller particle size range and the concentrations generally increased with decreased particle size.

Particle size distribution and size-resolved metal pollutants of road-deposited sediments in Iran has not been previously investigated which is the focus of this study. The major objectives of our study were: (1) to determine the particle size distribution of RDS, and (2) to quantify total mean concentration of heavy metals in RDS samples, and (3) to quantify the mean concentration of heavy metals in selective particle size range of the RDS. The results of this research will be used in future studies to estimate pollutant wash off characteristics and in developing adequate modelling tool for designing appropriate BMPs to address stormwater runoff management in Tehran.

2 METHODOLOGY

2.1 Study area

The study was performed in the Metropolitan city of Tehran, Iran (see Figure 1). Tehran lies on the southern foothills of the Alborz Mountains and is located between latitude 35° 34´–35° 50´ North and longitude 51° 08´–51° 37´ East. Its altitude varies from 1700 m in the North to 1200 m in the center and 1100 m in the South. Tehran's climate is hot and dry, and the average air temperature is 18º C with an average maximum and minimum temperature of 38.7 and -7.4° C, respectively. The annual precipitation ranges from 245 to 316 mm. Its 664 km^2 territory comprises 22 urban regions. According to the latest census conducted in 2006, it has 2.4 million households with population of 8.2 million and an average population density of about 12,350 inhabitants per km^2 (Mahdavi Damghani et al. 2008). According to the head of Tehran Municipality's Environment and Sustainable Development Office, Tehran has a capacity for 700,000 cars, but currently more than 3 million cars are on the roads in the capital. Therefore most of Tehran's streets are suffering from traffic congestion and pollutant emission (Municipality of Tehran, 2009).

2.2 Sample collection

A total of 19 RDS samples were collected from three different land use (herewith denoted as residential, intense traffic and educational) areas (see Figure 1). Residential and intense traffic sampling sites were located in Azadi St. with latitude 35° 42 North and longitude 51° 20´ East and latitude 35° 41 North and longitude 51° 20´ East respectively. The mean traffic density in Azadi St. is about 6000 vehicle/h. The educational sampling site was the campus of Tehran University with latitude 35° 42 North and longitude 51° 23′ East. The RDS samples were collected on September 2011 before midnight when the road cleaning was not practiced. In residential and intense traffic land use areas, RDS samples were taken every night over a one week period (7 samples from each site) and in educational land use areas samples were taken on workdays (5 samples). Each sample, approximately 100 to 400 g, was collected from the curbside using a clean plastic dustpan and a brush as described by Bian and Zhu (2008). The samples were stored separately in plastic bags and labelled before transporting them to the laboratory and subsequently each sample were processed and analysed chemically.

Figure 1. Map of study area

2.3 Sample processing and chemical analysis

The RDS samples were dried for 48 h at 105° C. They were stored in a cool, dark place before further fractionations and analysis (Bian and Zhu, 2008). Generally, particles larger than 2000 µm are of limited importance in transporting adsorbed metals in urban systems or easier to remove by conventional BMPs (McKenzie et al., 2008; Kayhanian and Givens, 2011). Therefore, metal concentration analysis was only performed for particles smaller than 2000 µm. The dried RDS samples were sieved using a 2-mm nylon mesh to remove gravel-sized materials and then screened into seven size fractions using standard sieving methods prior to metal fraction analysis. The size fractions and their descriptive classifications as used by the United States Department of Agriculture (USDA) classifications were: 2000-1000 µm (very coarse sand), 1000-600 µm (coarse sand), 600-300 µm (medium sand), 300-150 µm (fine sand) 150-75 µm (very fine sand), 75-45 µm (silt and clay) and <45 µm (clay).

For measuring total metals concentration of RDS from each landuse, a composite samples was prepared by mixing an equal mass (specify here) from each size fraction. About 300 mg of the composite sample from each landuse was mixed with 6 mL of concentrated HNO_3, 3 mL of $HClO_4$ and 3 mL of HF. Then, 10 mL of HCl was added to residuals and diluted to 50 mL deionised water following the procedure described in Bian and Zhu (2008). The digested solution was then analyzed to measure the concentrations of Zn, Pb, Cu, Ni and Cd using an atomic absorption spectrophotometer Varian 220A.

3 RESULTS AND DISCUSSION

3.1 Particle size distribution

The average results of particle size distribution (PSD) for all collected RDS samples are shown in Figure 2a. As shown, the trend in PSD for all samples within all land use areas is similar. The histogram of mean mass percentage versus grain size fraction is shown in Figure 2b. From these results it can be seen that the mass percentage for particles <75-150 µm increases in sequence order of intense traffic area, residential area and educational area. The mass percentages for particles >75-150 µm show the opposite trend. The mass percentages of particles <300 µm in these three areas are about 62, 74 and 76%, respectively. These results show that RDS samples in Tehran consist predominantly of finer sand, silt and clay particles.

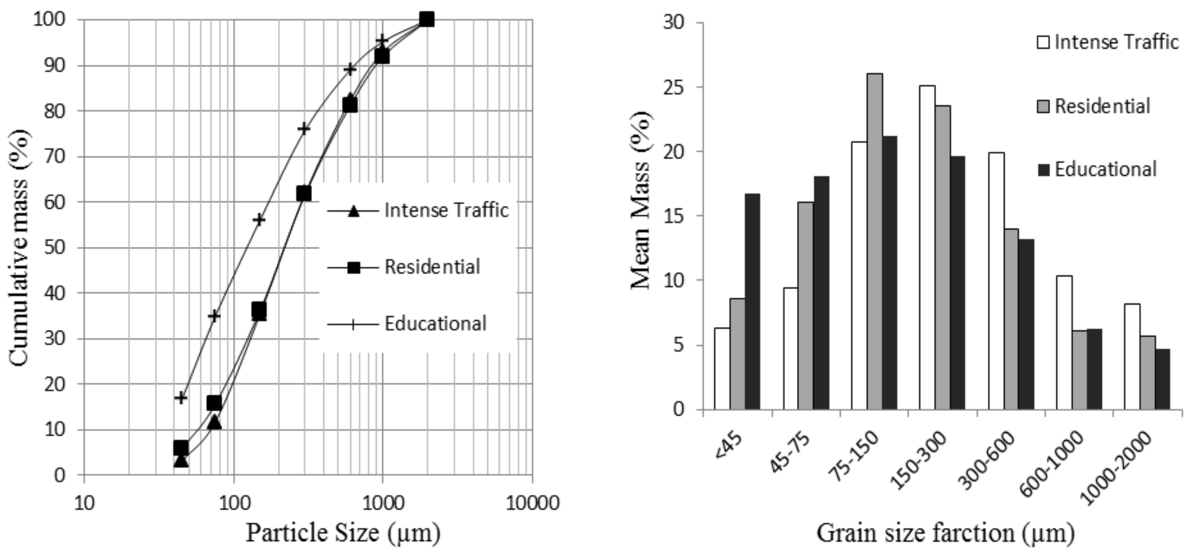

Figure 2. Particle size distribution and histogram of mean mass percentage versus grain size fraction for road-deposited sediment (RDS): (a) PSD and (b) histogram

Dust particles, particularly finer silt and clay size range can be re-suspended and blown by wind and be carried to great distances. For example, De Miguel et al. (1997) found that particles <100 µm are easily resuspended and retained in the atmosphere due to the wind and air movement caused by moving vehicles and breeze. This can be problematic when designing BMPs, particularly when the highest metal concentration is reported to be associated with particles smaller than 63 µm (Bian and Zhu 2008). The finer dust particles and any pollutant that are sorbed on them can be washed off during rain events and adversely impact the quality of surface and ground waters. To alleviate the dust problem in Tehran, street sweeping is used periodically. Street sweepers, however, are found to be less efficient in removing finer particulates. For example, their efficiency in removing particles between 63 and 600 µm is less than 50% (Sartor and Boyd 1972). Therefore street sweeping alone may not be a practical solution and other remedy such as construction BMPs may be necessary to further reduce the pollution in urban areas of Tehran. It is also worth to mention that the source contributions of dust particles in sampling areas in Tehran are not known and beyond the scope of this study. However, majority of dust particles in urban areas are identified as roads and building construction sites, fossil fuel combustion, power generation, vehicles wear, high temperature industrial processes such as metal smelting and atmospheric deposition (Gourdeau, 2004).

3.2 Total concentrations of heavy metals in RDS

The mean values of total heavy metal mass concentrations as mg/kg in each of the initial RDS collected from the three land use areas are presented in Table 1. Zn showed the highest mean concentration (536.4 mg/kg) followed by Pb, Cu, Ni and Cd, with total concentration of 422.4, 210.3, 96.6 and 22.8 mg/kg, respectively. In addition, spatial variability of heavy metal concentration was observed among different land use areas indicating that lower mean concentration in educational land use compared with intense traffic land use area.

Table 1. Total heavy metal concentration of RDS sampled from three land use areas

Heavy metals	Total particulate mean concentration (mg/kg) from three land use areas[a]		
	Intense Traffic	Residential	Educational
Zn	536.4	319.3	430.4
Pb	422.4	502.9	219.4
Cu	210.3	114.2	189.8
Ni	96.6	124.6	92.1
Cd	16.6	30.3	16.3

[a]The concentration was measured based on single composite sample prepared from a mixture of equal mass from each size fraction for each land use area.

The impact of various land use on pollutant concentration is beyond the scope this study. However, as mentioned before, a variety of sources could contribute to the presence of heavy metals in the monitoring site areas. Examples of known sources of some metals such as Cd, Cu, Pb, Zn and Ni in urban areas include: the wear of tires and brake pads, fuel combustion, combustion of lubricating oils, metal finishing industrial emissions, corrosion of galvanized metals, corrosion of building parts, wear of moving parts in engines, metallurgical and industrial emissions, fungicides and pesticides, power plants and trash incinerators and petroleum refinery (Makepeace et al. 1995; USEPA 1996; Hogan et al. 2011). Because of the intense traffic and semi industrial and commercial activities in and around the metropolitan area of Tehran, it is possible that most metals measured in our study are generated from combination of sources mentioned above. The exact source identification of pollutants is beyond the scope of this study and will be considered in our future monitoring study.

3.3 Size resolved heavy metal concentrations

Fig. 3 shows the relationship between heavy metal concentrations with different particle size fractions. The highest metals concentrations in different size fractions (except for Cd at the residential area) occurred at the intense traffic area. Zinc was the most abundant metal element in different size fractions at all land use areas. As shown in Fig. 3, the concentration of all heavy metals increased with decreasing particle size a trait which was shown to be fairly consistent among all three land use areas. Other than a few exceptions, generally, the highest concentrations were measured in the smallest particles (<45 µm). The results obtained from this study are consistent with previous size resolved metals concentrations reported by McKenzie et al (2008) and Kayhanian and Givens (2011), indicating the importance of finer particles in roadway runoff and dry deposited particles. It is important to note that while the particulate metals concentrations are higher in smaller particle size ranges, their mass contribution can be substantially lower (see figure 2a). However, the contribution of pollution related to these finer mass particles is still significant due to their bioavailability, mobility and transformation in both the atmospheric and aquatic environment. Higher concentrations can also pose toxicity problem when discharged into receiving waters. Hence, source reduction is a viable option since the treatment and removal of finer particles (<45 mm) and pollutants associated with them can not easily be accomplished by conventional BMPs. Therefore, a more advanced treatment BMPs may be considered and that can be very costly.

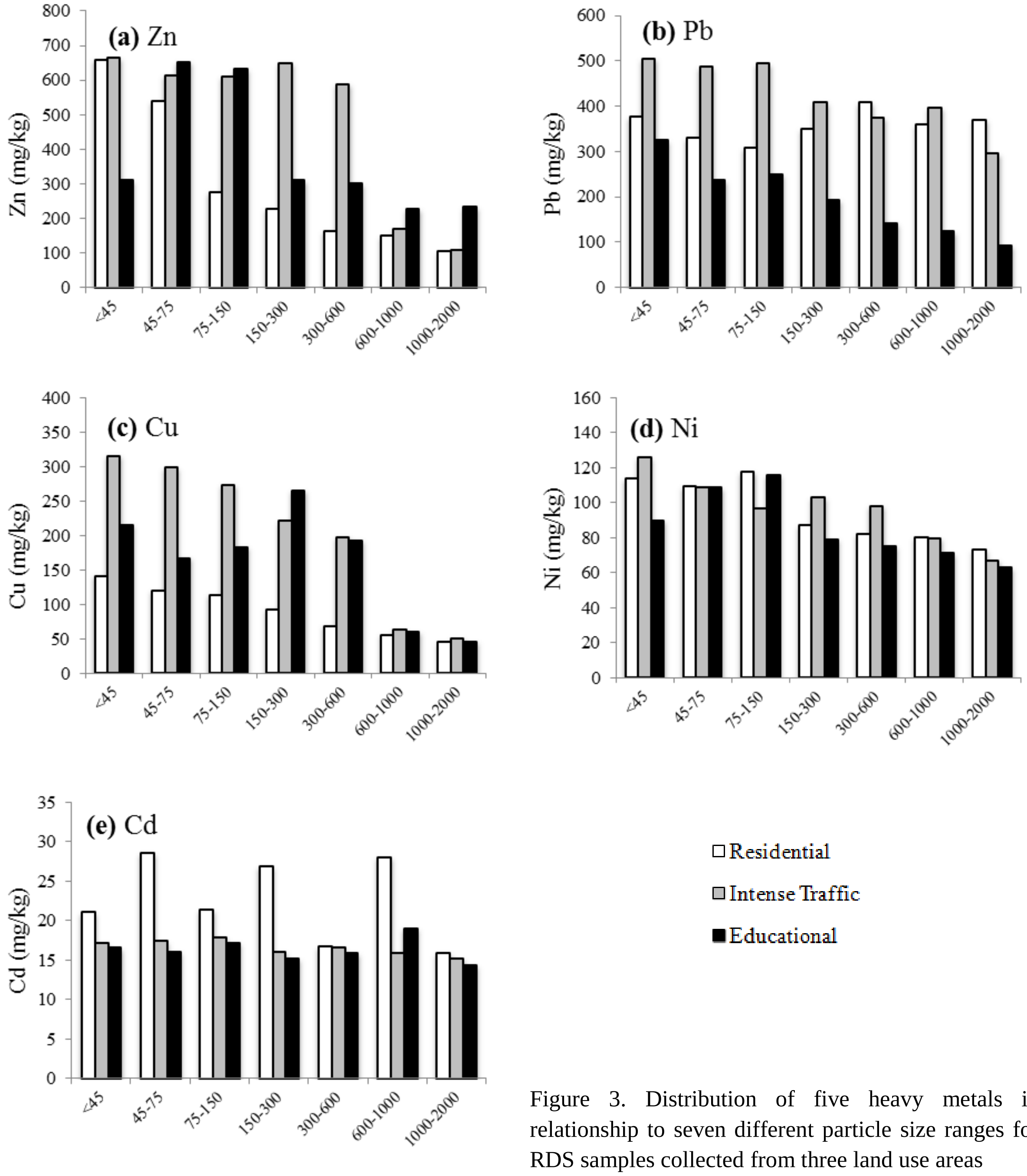

Figure 3. Distribution of five heavy metals in relationship to seven different particle size ranges for RDS samples collected from three land use areas

4 CONCLUSION

1. Land use can play an important role on particle size distribution of RDS. While the trend in particle size distribution in all land use areas were the same, their mass distribution was different. The results showed that the percent mass distribution of finer particles <45 µm in educational and residential areas were higher than that of intense traffic areas. The highest mass distribution (up to about 80%) of particles for all land use areas were within the particle size range of < 300 µm.
2. The highest average concentrations of five heavy metals measured (Cd, Cu, Pb, Ni and Zn), with the exception of Cd at the residential area, were related to the intense traffic land use. The order of the average measured metal concentration in intense traffic and educational landuse were Zn > Pb > Cu > Ni > Cd and in residential landuse were Pb > Zn > Ni > Cu > Cd.
3. The metal concentration generally increased with decreasing particle size. Maximum average heavy metal concentrations frequently occurred in particle size smaller than 75 µm.

ACKNOWLEDGEMENTS The authors would like to thank Material and Soil Lab, Department of Civil Engineering, Sharif University of Technology and Institute of Water and Energy, Sharif University of Technology for their assistance in laboratory.

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