JUEE

Journal of Urban and Environmental Engineering, v.4, n.1, p.1-8

ISSN 1982-3932

doi: 10.4090/juee.2010.v4n1.001008

Journal of Urban and Environmental Engineering

www.journal-uee.org

LEAD DISTRIBUTION BY URBAN SEDIMENTS ON IMPERMEABLE AREAS OF PORTO ALEGRE – RS, BRAZIL

Leidy L.G. Martínez[1*] and Cristiano Poleto[2]

[1]Hidraulic Research Institute, Federal University of Rio Grande do Sul, Brazil

[2]State University of Maringá, Brazil

Received 23 April 2009; received in revised form 15 June 2010; accepted 18 June 2010

Abstract: Heavy metals, like lead (Pb), are subproducts of industrial activities; however, in recent years, studies have shown that even in non-industrial areas, elevated concentrations of this element have been found. In this study, Pb concentrations were measured in 20 composite samples of urban sediments collected in an urban watershed of 4.85 km^2 with three types of soil use (commercial/residential, commercial and industrial) in the city of Porto Alegre, RS, Brazil. Concentrations were determined by acid digestion (EPA 3050) of the 209 µm, 150 µm, 90 µm, 63 µm and 45 µm fractions followed by atomic emission spectrophotometry with inductively coupled plasma. Average values of 178.1 $\mu g.g^{-1}$ (± 332); 226.5 $\mu g.g^{-1}$ (± 500); 245.2 $\mu g.g^{-1}$ (± 454.1); 272.4 $\mu g.g^{-1}$ (± 497.3) and 251.5 $\mu g.g^{-1}$ (± 322.6) were obtained in the 209, 150, 90, 63 and 45 µm fractions, respectively. Concentrations of the metals studied were interpolated and represented geographically using Idrisi© Andes. Results show that the greatest concentrations are located in the commercial part of the study area, characterized as presenting high vehicle flow most of the day, with this being considered a potential source of lead. All concentrations were above that of the local background. Studies of this type are important because they make the establishment of control targets possible within sustainable management of water resources, allowing inferences regarding future pollution scenarios of local water resources.

Keywords: Urban sediment; diffuse pollution; GIS; lead

* Correspondence to: Leidy L.G. Martínez, Tel.: + 55 51 3308 6686.
E-mail: luxgm@yahoo.es

INTRODUCTION

Most South American cities present accelerated growth trends; however, they are disorganized, generating negative impacts especially on bodies of water (Poleto *et al*,. 2009a; Deletic *et al*,. 1997), principally due to the increase of impermeable surfaces like roadways, roofs, parking lots, among other things, which reduce the rate of infiltration and increase surface runoff, thus increasing transport of urban sediment and pollutant loads to watercourses (Poleto *et al.*, 2009b; Taylor 2007; Charlesworth *et al.*, 2003; Deletic *et al.*, 1997). Urban drainage networks are responsible for conveying these loads and it is now known that they constitute important sources of degradation of rivers, lakes and estuaries Horowitz (2009), (Deletic *et al.*, 1997).

Sediments in urban areas are submitted to man-made alterations from different sources, as for example, the input of organic matter coming from discarding sewage in a clandestine manner, in the same way as particles of human origin present in large quantities in urban environments, such as glass particles, metallic particles, residues from industrial processes and civil construction, which present chemical and mineralogical properties different from sediment particles from natural sources, which results in these sediments interacting in a different way within the environment (Poleto & Martínez, 2009); Taylor (2007). Sediments deposited in roadways have become, through time, an important means for determining the human contribution of pollutants, especially that of heavy metals. The ubiquitous nature of road deposited sediments, their ease of sampling, their strong association with automobile emissions, and their relationship with nonpoint source pollution make them a valuable archive of environmental information (Sutherland 2003).

More precisely, one of the chemical characteristics of vital importance in the study of urban sediments is adsorption of heavy metals. Banerjee (2003) defines the behavior of heavy metals in terms of the most common different solid phases found in urban sediments in **Table 1.**

Affinity of heavy metals by sediments is strongly influenced by particle size (Deletic *et al.*, 1997; Charlesworth *et al.*, 2003; Sutherland, 2003; Taylor, 2007; Poleto *et al.*, 2009a). There is sufficient evidence that shows the fact that sediments are enriched with heavy metals, above all in the fine particle fraction. In a similar way to sediments in other environments, increase in the pollutant load in finer sized particles is generally associated with the increase of surface area in smaller sized particles, providing greater space for adsorption of metals in clay minerals or in organic matter present in sediment particles. Understanding that heavy metal loads are heterogeneously distributed is important in the formulation of pollution management and control strategies (Horowitz, 2009; Poleto *et al.*, 2009b; Taylor, 2007). Fergusson & Ryan (1984) studied

Table 1. Affinity of heavy metals in sediments

Solid phase fraction	Affinity of heavy metal
Exchangeable	Cd > Pb > N i> Zn > Cu > Cr
Carbonate	Cd > Zn > Pb > Ni > Cu > Cr
Fe-Mn oxide bonding	Zn > Pb > Ni = Cu > Cd > Cr
Organic matter	Cu > Pb > Zn > Ni > Cd > Cr
Residual	Cr > Ni > Cu > Cd > Pb > Zn

Adapted from: Banerjee (2003).

the composition of particles deposited in urban areas, specifically particle size and the sediment source; they found that many of the elements analyzed increased with reduction in particle size, a result corroborated by Al-Rajhi *et al.* (1996).

In urban environments, heavy metals are part of our daily activities and many of them enter in the urban environment as subproducts of economic activities which are considered typical in urbanizing watersheds (Poleto & Charlesworth, 2010; Poleto *et al.*, 2009a; Poleto & Martínez 2009; Irvine *et al.*, 2009); in the case of lead, it frequently appears as a subproduct from petroleum and coal combustion; tire, oil, paint and welded part residues (Horowitz, 2009; Poleto & Merten, 2008; Charlesworth & Lees 1999). Lead concentration values are variable and depend in large part on surrounding local conditions; Sutherland (2003) found that 51% (221 $\mu g.g^{-1}$) of the lead load present in sediments deposited in urban roadways in Hawaii were found in the < 63 μm fraction; Robertson *et al.* (2003) found concentrations of 354 $\mu g.g^{-1}$ within the city of Manchester (United Kingdom); Charlesworth *et al.* (2003) found average values of 48 and 47.1 $\mu g.g^{-1}$ in the cities of Birmigham and Coventry (United Kingdom), respectively; Irvine *et al.* (2009) reported values of 276 $\mu g.g^{-1}$ in the city of Hamilton, Ontario (Canada); an average value of 230.52 $\mu g.g^{-1}$ with a maximum of 3060 $\mu g.g^{-1}$ were found by Yongming *et al.* (2006) in the province of Xi'an in China; McAlister *et al.* (2005) reported concentrations from 200 to 700 $\mu g.g^{-1}$ in areas with diverse soil uses in the city of Rio de Janeiro (Brazil) and Poleto *et al.* (2009) found concentrations from 16 to 110 $\mu g.g^{-1}$ in 20 cities in the South of Brazil.

Sediments deposited in roadways are commonly associated with risks to the environment and to human health, mainly in children (Taylor, 2007; Charlesworth *et al.*, 2003; Al-Rajhi *et al.*, 1996). Environmental and health effects initially depend on the mobility and availability of the elements, and the mobility and availability in terms of their chemical speciation and fractionation within or on particles (Banerjee, 2003). In the case of lead, there is evidence that indicates that exposure to this metal (inhalation or through consumption of contaminated foods) can trigger problems in the central nervous system, as well as having carcinogenic effects (Wang *et al.*, 2005).

In the present study, the lead concentration present in 20 composite samples of urban sediments collected at different points of the Tamandaré Basin (which drains into Guaíba Lake) and which present different soil uses was evaluated. Lead (Pb) concentrations were determined in different granulometric fractions of the sediments for the purpose of establishing a correlation; afterwards they were geographically represented through the use of a GIS, with values corresponding to the < 63 μm fraction, considered by diverse studies as that which presents the greatest heavy metal adsorption capacity.

MATERIAL AND METHODS

Study area

The study area chosen is located between the center downtown area and the northern part of the city of Porto Alegre, capital of the state of Rio Grande do Sul, in the South of Brazil (**Fig. 1**).

In accordance with the Koppen (1936) classification, the climate in the region is temperate, subtropical and humid. The study area is inserted within the urban Almirante Tamandaré sub-basin, which drains into Lake Guaíba and is georeferenced between the coordinates 476 561.77 E; 6 676 956.05 S and 481 482.71 E; 6 682 109.55 S. Within the study area, three areas representative of predominant soil uses in the city were chosen: industrial (3.0 km²), commercial (1.02 km²) and residential/commercial (0.83 km²), as represented in **Fig. 2**. The limits of the study area represent avenues of high vehicular traffic volume.

Sediment monitoring

During the month of June, composite samples of sediments accumulated from the streets of the study area were collected. The samples were the result of the composition of various sub-samples of dry sediment collected in an area of approximately 200 m² for each point chosen (thus reducing the influence of point source pollution, making the samples more representative), as represented in **Fig. 3** and following a methodology similar to that used by Poleto *et al.* (2009), Krčmová *et al.* (2009), Yetimoglu *et al.* (2008), Banerjee (2003), Charlesworth *et al.* (2003), Charlesworth & Lees (1999) and Deletic *et al.* (1997).

Approximately 500 g of dry sediment were collected for each point (Poleto *et al.*, 2009; Sutherland, 2003).

Samples were collected using a portable vacuum without metallic parts and which facilitated the collection of samples without direct manual contact and which lead to sampling of finer particle fractions. Collected samples were deposited in plastic bags and refrigerated for later performance of physical and chemical analyses.

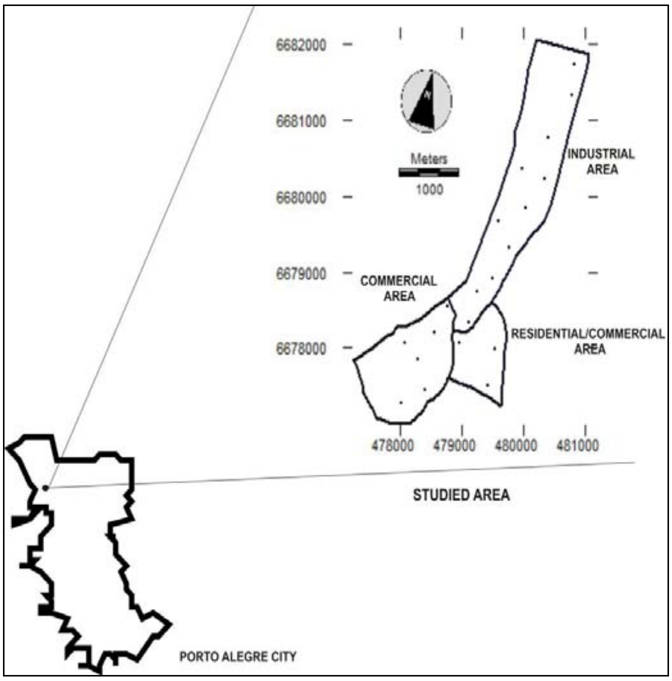

Fig. 2 Study area.

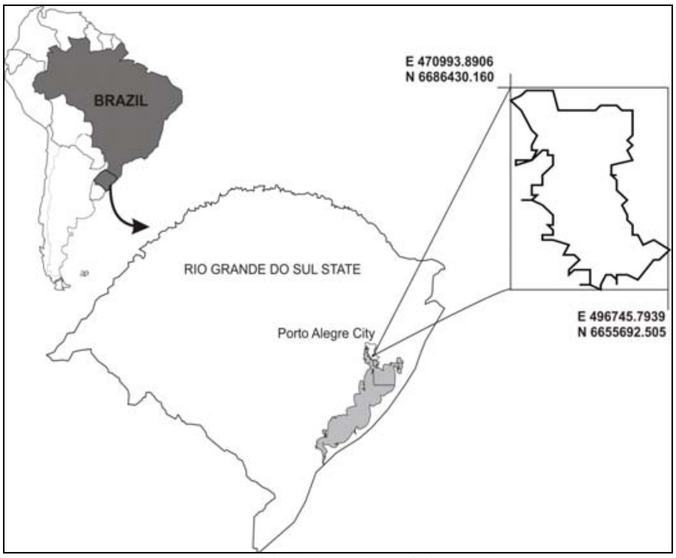

Fig. 1 Geographical location of the study area.

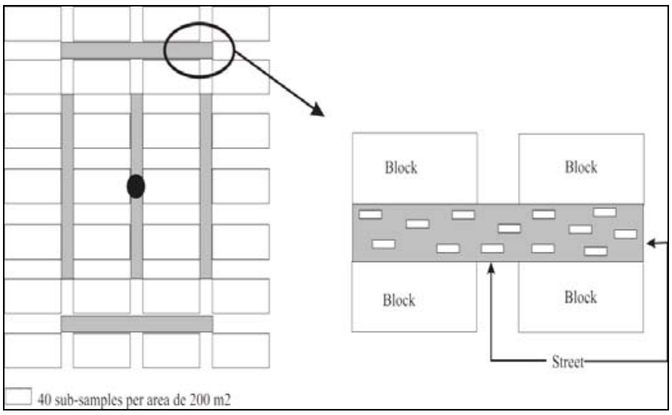

Fig. 3 Sample collection points.
Adapted from: Poleto *et al.* (2009a).

Lead analyses by granulometric fraction

Each sample collected was submitted to sieving (polyethylene sieves – without metallic parts), using screens or openings of 45 μm, 63 μm, 90 μm, 150 μm and 209 μm, following the methodology used by Banerjee (2003) and Charlesworth *et al.* (2003) and which shows the separation of the most important granulometric fractions for urban sediment quality studies.

Granulometric analysis was made by a laser particle analyzer Cilas® 1180 located at the Laboratory of the UFRGS Density Currents Study Center – Núcleo de Estudos de Correntes de Densidade da UFRGS. This piece of equipment allows one to differentiate particles from 0.04 to 2500 μm. The methodology used is described by Poleto *et al.* (2009a).

Samples were submitted to acid digestion (HCl, HF, HCLO4, HNO3), in accordance with methodology from the U. S. Environmental Protection Agency (EPA 3050). These analyses were duplicated and two USGS reference materials (SGR-1b and SCO-1) for quality control were used. Afterwards, total metal concentrations were determined by inductively coupled plasma optical emission spectrometry (ICP-OES) on a Perkin Elmer brand piece of equipment by the UFRGS Soil Laboratory.

All equipment and glass items used in the sample collection procedure and sample treatments were washed with distilled water, remained soaking in a 14% (v/v) nitric acid solution for 24 hours and once more rinsed with distilled water.

Interpretation of results

Descriptive statistics of the concentration data obtained from chemical analyses were calculated and, afterwards, linear regression of the concentrations was applied in terms of particle size for the purpose of establishing a correlation between these two variables, widely mentioned in studies of this type. In the event that the adjusted model presents poor correlation, the best adjustment would be applied with the averages from the data of each fraction studied, in accordance with that suggested by Al-Rajhi *et al.* (1996).

After this process, the non parametric Kruskall-Wallis Test was undertaken, followed by the Bonferroni test for the purpose of analyzing the significance of the sample collection location in respect to the Pb concentrations found, in accordance with that suggested by Irvine *et al.* (2009), Norra *et al.* (2006) and Kuang *et al.* (2004). The statistical analyses were undertaken using the software XLSTAT© v. 2009.

The lead values of the < 63 μm fraction were interpolated through the IDW (Inverse Distance Weight) method and the result was represented on a thematic map using the SIG Idrisi© Andes, which allowed visualization of the greatest lead concentration areas within the study area, as well as allowing inferences regarding the factors which had an influence on these results.

RESULTS AND DISCUSSIONS

Granulometry of urban sediments

The results of granulometric analysis undertaken in the samples collected in the study area are presented in **Fig. 4**. The < 63 μm fraction, which according to Poleto *et al.* (2009a), Poleto *et al.* (2009b), Irvine *et al.* (2009), Charlesworth *et al.* (1999; 2003), Robertson *et al.* (2003) and Sutherland (2003) is strongly correlated with the greatest concentrations of heavy metals, represents approximately 40% of the sediments collected in the area with commercial/residential soil use and 60% for the two other sampled areas. Sutherland (2003) found that the dominant fraction was the < 63 μm one with 38% of the total of analyzed fractions.

Descriptive statistics

The values of Pb concentrations obtained in the 20 sediment samples are presented in **Table 2**.

The fact of the median being greater than the average of the data says that the data distribution is asymmetrical to the right, which is corroborated by the Fisher coefficient ($\alpha = 0.05$). This asymmetry obeys the peaks of concentration found in some sampling points, which generates a considerable standard deviation for the data. Yonming *et al.* (2006) found values from 29 to 3060 $\mu g.g^{-1}$ and a Fisher coefficient of 5.34 in samples of urban sediments collected in the Xi'an province in Central China, showing the same trend of the values found in this study.

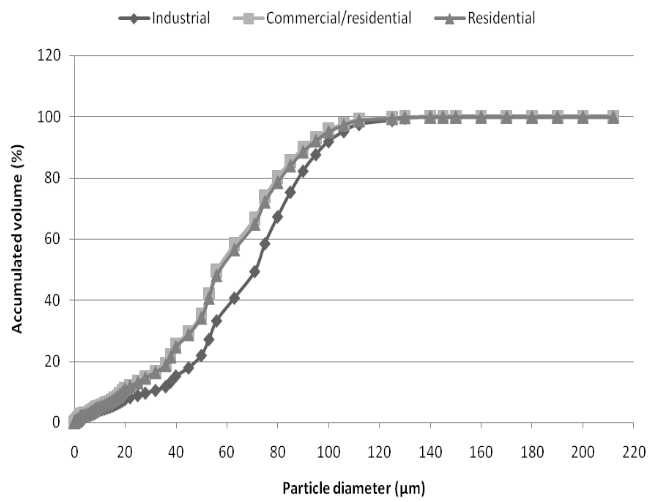

Fig. 4 Granulometric analyses of the urban sediment samples.

Table 2 Descriptive statistics of lead concentrations (µg.g-1)

Descriptive Statistic	Particle size (µm)				
	209	150	90	63	45
Minimum	22	39	58	76	86
Maximum	1500	2300	2100	2300	1300
Median	91.00	93.00	121.00	123.50	147.00
Mean	178.10	226.45	245.20	272.35	251.54
Standard Deviation	331.99	499.99	454.15	497.29	322.59
Skewness (Fisher)	1.82	2.15	1.81	1.78	1.23

In the minimum values, one may observe the increase in lead concentration with reduction in particle size, which is corroborated by Poleto *et al.* (2009a), Irvine *et al.* (2009), Norra *et al.* (2006), Kuang *et al.* (2004), Charlesworth *et al.* (2003), Charlesworth & Lees (1999). Maximum values are commonly found in this type of study and were cited by Charlesworth et al. (2003) who found lead concentrations of 2 582.5 µg.g^{-1} for New York and 2241 µg.g^{-1} for London. Al-Rahji *et al.* (1996) perceived that these maximum values increase the standard deviation of the data and usually alter the correlations between particle diameter and concentrations of heavy metals.

Lead concentration values were correlated ($\alpha = 0.05$) with the opening of the mesh through a linear model; however, the results showed poor correlation, established by the value of the regression coefficient ($R^2 = 0.005$). This is explained by the fact that most of the values are outside the statistical confidence interval (95%), above all in the 63 to 150 µm fractions. Linear regression may be observed in **Fig. 5**.

To correct this, the average of the values of the concentrations in each one of the fractions was calculated and regression models were once more calculated. Of all the models tested, the exponential model presented the best correlation ($R^2 = 0.87$) at the same level of significance. This result is similar to that reported by Al-Rajhi *et al.* (1996), who found correlations above 80%. **Figure 6** presents the result of the exponential adjustment of the data obtained.

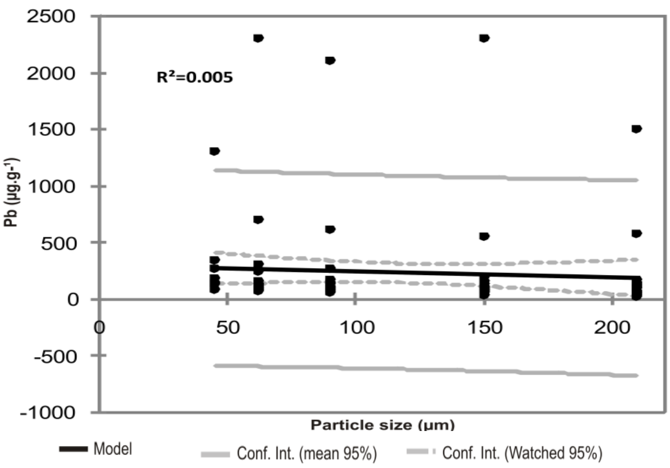

Fig. 5 Lead linear regression in terms of sieve size.

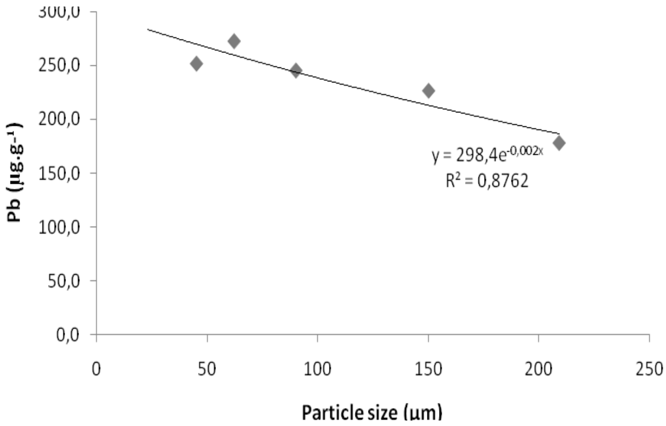

Fig. 6 Exponential regression model chosen.

The mathematical model obtained in this regression is presented in **Eq. (1)**.

$$Y = 298.4e^{-0.002x} \quad (1)$$

where x represents the particle diameter (µm) and Y the Pb concentration (µg.g^{-1}).

Results demonstrate that urban sediments are enriched with Pb, above all in the fine fraction of the particles. In a similar way to sediments in other environments, the increase in pollution load in finer sized particles is generally associated with the increase in surface area in smaller sized particles, supplying a greater space for adsorption of metals in clay minerals or in the organic matter present in sediment particles. Robertson *et al.* (2003) suggested that the particles generated by automotive vehicles present a high Fe/Pb ratio and concluded that in their case the principal source of lead in urban areas was vehicular traffic.

Understanding that heavy metal loads are heterogeneously distributed is important in the formulation of pollution management and control strategies (Poleto *et al.*, 2009a; Irvine *et al.*, 2009; Taylor, 2007; Charlesworth *et al.*, 2003; Sutherland, 2003).

Spatial distribution of lead in the study area

Studies of lead associated with urban sediment particles were the first to be performed for the purpose of establishing the risk to human health generated by vehicle traffic, which in the past used lead in gasoline in abundance (Taylor, 2007; Robertson *et al.,* 2003). The results obtained were important in the decision to reduce lead concentration in gasoline in many countries.

To determine what the increase of Pb concentrations due to human activity is, there is the need to verify the value of the local background. As the study area is densely urbanized, it was not possible to find a naturally preserved area (without any human interference); for that reason we took into consideration the data obtained in the studies of Poleto & Merten (2005) and Poleto *et al.* (2008) which were obtained for the same watershed, which is a sub-watershed in the Porto Alegre metropolitan area. The value found by the authors is 31.30 $\mu g.g^{-1}$, thus, configuring elevated human enrichment in the study area.

Distribution of concentrations by soil use, represented in **Fig. 7**, shows how the lead concentration is greater in the commercial area, even greater than in the industrial area where gasoline selling stations and industries that use metals as raw material predominate. Nevertheless, most of the points sampled in the industrial area present a traffic volume in a lower proportion than in the two other areas studied. In this commercial area, two of the points sampled presented values above the average of the rest of the data and these points coincide precisely with a street of high city bus traffic. At this point, the presence of vehicle oil and tire particles on the surface was observed, indicating that this potential source would be the main lead potential in this area.

The result of the Kruskall-Wallis Test showed that the data is derived from the same population; whereas the Bonferroni Test showed that there is no significant relationship between the lead concentrations and the respective area of sample collection, to a 5% level of significance, similar to the results found by Charlesworth *et al.* (2003) in the city of Birmigham. The fact that soil use is not correlated with the lead concentration may indicate that there is an external factor that influences this behavior, which is probably the chemical composition of the sediment particles, which influences the rate of lead adsorption, in accordance with results presented by Banerjee (2003) and Robertson *et al.* (2003) who define that lead is associated with the residual fraction > Fe/Mn oxides > organic matter > exchangeable fraction > carbonates.

According to Krčmová, *et al.* (2009) and Charlesworth *et al.* (2003), it is still difficult to establish the main source of lead in urban sediments; nevertheless, some studies suggest that the presence of this metal together with zinc is associated with tire residues, which is directly associated with vehicular traffic volume.

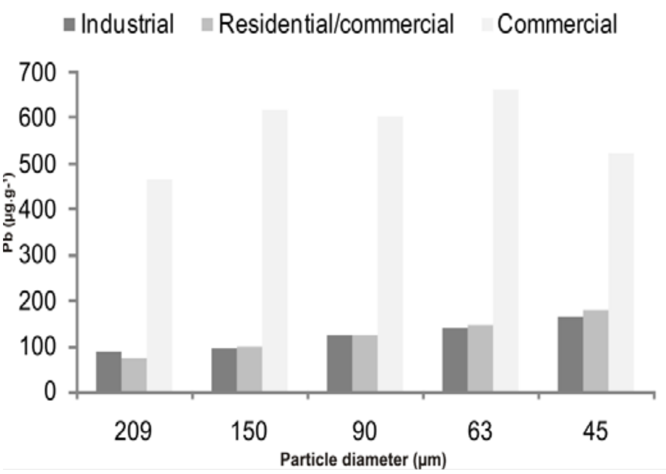

Fig. 7 Lead distribution by soil use.

Figure 8 presents the spatial distribution of Pb in the study area.

It is fitting to highlight that the commercial area of Porto Alegre presents a high volume of people and that high metal concentrations like the lead adsorbed in the finer particles may present health risks since this finer range is breathable. Likewise, the nearness of these areas to Guaíba Lake (main local body of water) may be contributing in a significant way to the increase of heavy metals in these ecosystems since the Lake is the final point in the urban drainage systems of this watershed.

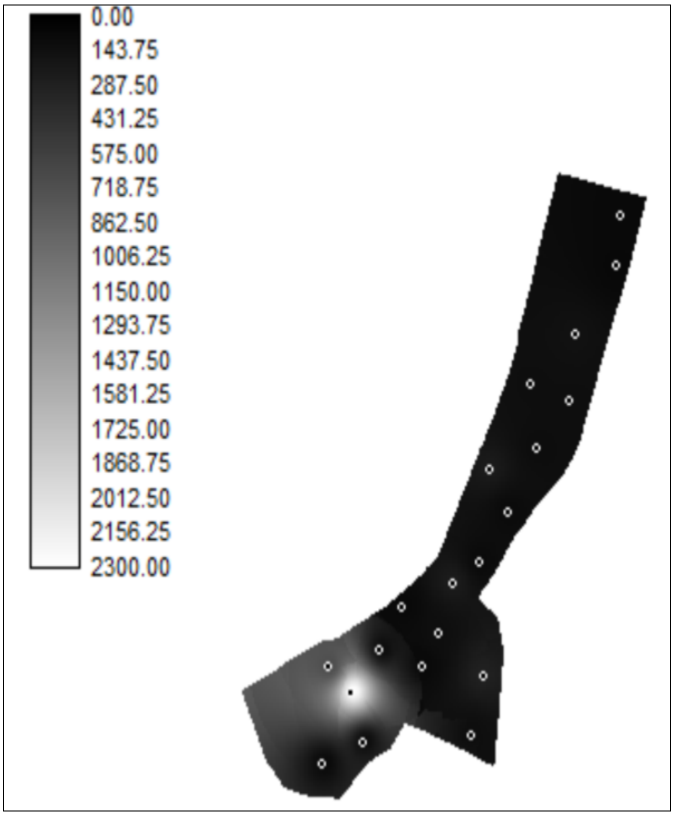

Fig. 8 Spatial distribution of Pb ($\mu g.g^{-1}$) in urban sediments in the study area.

CONCLUSIONS

- Pb is a heavy metal which is closely associated with urban sediment particles;

- Samples are composed of large percentages of fine particles (< 63 μm) in the three areas monitored;

- Maximum values of concentration were found in the finest particles of the collected sediment samples, regardless of the point of origin of the sample;

- The mathematical model which best explained the regression between the Pb concentration and the particle size was based on an exponential adjustment of the variables;

- The highest Pb values were found in commercial areas, a situation that may be explained in terms of vehicular traffic volume and this coincides with other studies in different cities in the world;

- Lead concentrations in urban sediments of the three areas went far beyond the local background concentration which was adopted;

- Research should be increased in regard to how to make urban systems more sustainable, reducing their pollution potential and minimizing the entrance of potentially polluting particles into bodies of water that pass through these urbanized areas.

Acknowledgments The Authors would like to thank CAPES, CNPq and Soils Analysis Laboratory of UFRGS.

REFERENCES

Al-Rajhi, M.A., Al-Shayeb , S.M., Seaward, M.R. & Edwards, H.G. (1996) Particle size effect for metal pollution analysis of atmospherically deposited dust. *Atmospheric Environment* **30**(1), 145–163.

Banerjee, A.D.K. (2003) Heavy metal levels and solid phase speciation in street dusts of Delhi, India. *Environmental Pollution* **23**(1), 95–105. doi: 10.1016/S0269-7491(02)00337-8.

Charlesworth, S.M., Everett, M., McArthy, R., Ordoñez, A. & de Miguel, E. (2003) A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK. *Environment International* **29(5)**, 563–573. doi: 10.1016/S0160-4120(03)00015-1.

Charlesworth, S.M. & Lees, J.A. (1999) Particulate-associated heavy metals in the urban environment: their transport from the source to deposit, Coventry, UK. *Chemosphere* **39**(5), 833–848. doi: 10.1016/S0045-6535(99)00017-X.

Deletic, A., Maksimovic, C. & Ivetic, M. (1997) Modelling of storm wash-off of suspended solids from impervious surfaces. *J. Hydr. Res.* **35**(1), 99–118. doi: 10.1080/00221689709498646.

Fergusson, J.E. & Ryan, D.E. (1984) The elemental composition of street dust from large and small urban areas related to city type, source and particle size. *Sci. Total Envir*. **34**(1), 101–116. doi: 10.1016/0048-9697(86)90363-3.

Horowitz, A.J. (2009) Monitoring suspended sediments and associated chemical constituents in urban environments: lessons from the city of Atlanta, Georgia, USA Water Quality Monitoring Program. *J. Soils and Sediments* **9**(4), 342–363. doi: 10.1007/s11368-009-0092-y.

Irvine, K., Perrelli, M.F., Ngoen-klan, R. & Droppo, I. (2009) Metal levels in street sediment from an industrial city: spatial trends, chemical fractionation, and management implications. *J. Soils and Sediments* **9**(4), 328–341. doi: 10.1007/s11368-009-0098-5.

Krčmová, K., Robertson, D., Cvecková, V. & Rapant, S. (2009) Road deposit-sediment, soil and precipitation (RDS) in Bratislava, Slovakia: Compositional and spatial assessment of contamination. *J. Soils and Sediments* **9**(4), 304–316. doi: 10.1007/s11368-009-0097-6.

Koppen, W. (1936) *Das geographisca system der climate. In: Handbuch der klimatologie*, (Ed. By G. Geiger), 1–44. Gebr, Borntraeger.

Kuang, C., Neumann, T., Norra, S. & Stuben, D. (2004) Land-used related chemical composition of street sediments in Beijing. *Environ. Sci & Poll Res*. **11**(2), 73–83. doi: 10.1007/BF02979706.

McAlister, J., Smith, B., Baptista, J. & Simpson, J. (2005) Geochemical distribution and bioavailability of heavy metals and oxalate in street sediments from Rio de Janeiro, Brazil: a preliminary investigation. *Environ. Geochem. Health* **27**(6), 427–441. doi: 10.1007/s10653-005-2672-0.

Norra, S., Lanka-Panditha, M., Kramar, U. & Stuben, D. (2006) Mineralogical and geochemical patterns of urban surface soils, the example of Pforzheim, Germany. *Applied Geochemistry* **21**(12), 2064–2081. doi: 10.1016/j.apgeochem.2006.06.014.

Poleto, C. & Charlesworth, S. (2010) *Sedimentology of Aqueous Systems*. London: Wiley-Blackwell.

Poleto, C., Bortoluzzi, E. Charlesworth, S. & Merten, G. (2009a) Urban sediment particle size and pollutants in Southern Brazil. *J. Soils and Sediments* **9**(4), 317 – 327. doi: 10.1007/s11368-009-0102-0.

Poleto, C., Merten, G. & Minella, J.P. (2009b). The identification of sediment sources in a small urban watershed in southern Brazil: An application of sediment fingerprinting. *Environ. Techn.* **30**(11), 1145–1153. doi: 10.1080/09593330903112154.

Poleto, C. & Merten, G.H. (2005) *Otimização do uso de metodologia de digestão ácida total de sedimentos para a identificação de fontes de sedimentos urbanos*. In: XVII Simpósio Brasileiro de Recursos Hídricos, 16p.

Poleto, C., Merten, G.H. (2008) Elementos traço em sedimentos urbanos e sua avaliação por Guidelines. *Holos Environment* **8**(2), 100–119.

Poleto, C. & Martínez, L.G. (2009) *Introdução aos Estudos de Sedimentos*. In: C. Poleto (Ed.), Introdução ao Gerenciamento Ambiental. Rio de Janeiro: Editora Interciência.

Robertson, D.J. & Taylor, K.G., Hoon, S.R. (2003) Geochemical and mineral magnetic characterization of urban sediment particulates, Manchester, UK. *Applied Geochemistry* **18**(2), 269–282. doi: 10.1016/S0883-2927(02)00125-7.

Sutherland, R. (2003) Lead in grain size fractions of road-deposited sediment. *Environ. Pollution* **121**(2), 229–237. doi: 10.1016/S0269-7491(02)00219-1.

Taylor, K. (2007) *Urban Environments*. In: Environmental Sedimentology (Ed. by K. Taylor, C. Perry), Manchester: Blackwell, 191–222.

Wang, X., Sato, T., Xing, B. & Tao, S. (2005) Health risks of heavy metals to the general public in Tianjin, China via comsumption of vegetables and fish. *Sci. Total Environ.* 350(1), 28–37. doi: 10.1016/j.scitotenv.2004.09.044.

Yetimoglu, S. & Ercan, O. (2008) Multivariate analysis of metal contamination in street dusts of Istanbul D-100 highway. *J. Braz. Chem. Soc.* **19**(7), 1399–1404.

Yongming, H., Peixuan, D., Junji, C. & Posmentier, E. (2006) Multivariate analysis of heavy metal contamination in urban dust of Xi'an, Central China. *Sci. Total Environ.* **355**(1), 176–186. doi: 10.1016/j.scitotenv.2005.02.026.