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Lead distribution in near-surface soils of two Florida cities: Gainesville and Miami☆

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Abstract

Knowledge of the distribution of soil lead (Pb) is useful for making sound environmental decisions. The objective of this study was to determine soil Pb distribution in two Florida urban areas of similar size with different levels of industrial development and population: Gainesville and Miami. About 200 and 240 soil samples were collected within a depth of 0.2 and 0.1 m in Gainesville and Miami, respectively. These samples, from three land-use classes (residential, commercial and public land), were digested using USEPA method 3051a and analyzed using graphite furnace atomic absorption spectrophotometry (GFAAS). Soil Pb concentrations varied greatly in both cities, with geometric mean (GM) values of ~ 16 and ~ 93 mg kg^{-1} in Gainesville and Miami, respectively. Both the median (15 mg kg^{-1}) and the 95th percentile concentrations (101 mg kg^{-1}) of the whole dataset in Gainesville were below the Florida soil clean-up target level (SCTL, 500 mg kg^{-1}) for residential areas. Although the corresponding values (median and 95th percentile) for Miami were significantly higher, they were also both below the Florida residential SCTL for Pb (98 and 453 mg kg^{-1}, respectively). Residential and commercial areas in both cities showed higher Pb concentrations than public parks. Results from this study can be used as a rough guide on how Pb is distributed in Gainesville and Miami.

Keywords: Natural; Pedogenic; Anthropogenic background; Lead

1. Introduction

The contamination of soils by heavy metals in both agricultural and urban areas has gained considerable interest as their harmful effects became widely known (Senesi et al., 1999). However, most of the studies on trace metal contamination have concentrated on areas that are either suspected of being impacted by point sources (Chen et al., 1997) or “near pristine” areas (Chen et al., 1999). Relatively fewer studies have

Abbreviations: AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation; OC, organic carbon; SCTL, soil clean-up target level; MDL, method detection limit; GPS, global positioning system.

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looked at areas that may be under diffuse (non-point source) anthropogenic influence, e.g. urban areas (Angle et al., 1974; Chirenje et al., 2001; Chronopoulos et al., 1997; Fett et al., 1992; Rabinowitz and Bellinger, 1988; Stark et al., 1982; Weitzman et al., 1993). Such surveys of trace metal contents in urban areas are important because they can serve as a basis for planning management strategies to achieve better environmental quality.

Lead (Pb) occurs ''naturally'' in all soils, in concentrations ranging from 1 to 200 mg kg^{-1}, with a mean of 15 mg kg^{-1} (Zimdahl and Skogerboe, 1997). The ubiquitous nature of Pb in urban areas is a result of industrial emissions, and the widespread past use of alkyl-lead compounds as antiknock additives in gasoline, and Pb-based paint and pipes (Callender and Rice, 2000). This has resulted in an overabundance of studies on both roadside and residential Pb pollution.

The soil clean-up target levels (SCTLs) for Pb in Florida are 400 and 920 mg kg^{-1} for residential and commercial areas, respectively (Florida Department of Environmental Protection, FDEP, 1999). However, SCTL values are calculated for a depth of 0–0.6 m (2 ft), taking into account buried soils. Samples were collected to a depth of 0.2 m in this study to avoid the dilution that occurs with the depth of 0.6 m. While this depth does not give results that are diagnostic for environmental health (normally 0–0.05 or 0.1 m), it gives a valuable estimation of Pb distribution in near surface soils.

Numerous researchers have demonstrated the presence of elevated quntities of Pb in urban soils (Bak et al., 1997; Carlosena et al., 1998; Chen et al., 1997; Davies et al., 1987; Mielke et al., 1994; Senesi et al., 1999). Different sampling protocols have been used in studying the distribution and contamination of soils by Pb. In general, samples are collected in the upper 0.05 or 0.10 m in studies pertaining to human health issues (Brinkmann, 1994; Wilcke et al., 1997; Chen et al., 1997). Other studies related to urban Pb contamination have focused on residential areas due to the widespread use of Pb-based paint in the mid-1900s (Aschengrau et al., 1994; Brinkmann, 1994; Davies et al., 1987; Mielke et al., 1994; Sutton et al., 1995). In Florida, no large-scale studies have been conducted to determine the random distribution of Pb in urban soils.

The specific objectives of this study were (i) to determine soil Pb distribution in two urban areas (Gainesville and Miami) in Florida and (ii) to examine the relationship between Pb content in soils and soil properties and human activity.

2. Methodology

2.1. Soil sample collection based on land use

Details on protocols of soil sample randomization and collection processes can be found in Chirenje et al. (2001). Additional information on materials and methods used in this study can be found in Chirenje et al. (2003a).

Briefly, two different sets of surface soil samples, (i) soils collected from a relatively undeveloped city, Gainesville (population: 95,000, size: 93 km^2, lower population and traffic density), and (ii) soils collected from a relatively well-developed city, Miami (population: 370,000, size: 91 km^2, higher population and traffic density), were used. Soil sampling locations, based on land uses in these two cities, are shown in Fig. 1.

Five sampling classes (i.e., residential right-of-way, residential yards, public buildings, public parks and commercial areas) were selected from for Gainesville. Forty surface samples (0–20 cm) were collected from May to June 2000 from each category, resulting in a total of 200 samples. The sites for sample collection were randomly selected within each category using a set of strict criteria proposed in a protocol by Chirenje et al. (2001).

Samples from residential right-of-ways were later chosen to represent residential soil, reducing the number of classes from five to four for the Miami study. Sixty surface soil samples (0–10 cm) were collected from January to February 2001 from four land use categories in Miami: residential, commercial areas, public parks and public buildings.

2.2. Sample preparation and lead analysis

Details on sample preparation and analysis can be found in Chirenje et al. (2003b). The samples were digested in a microwave digester using USEPA Method 3051a, which is comparable to USEPA

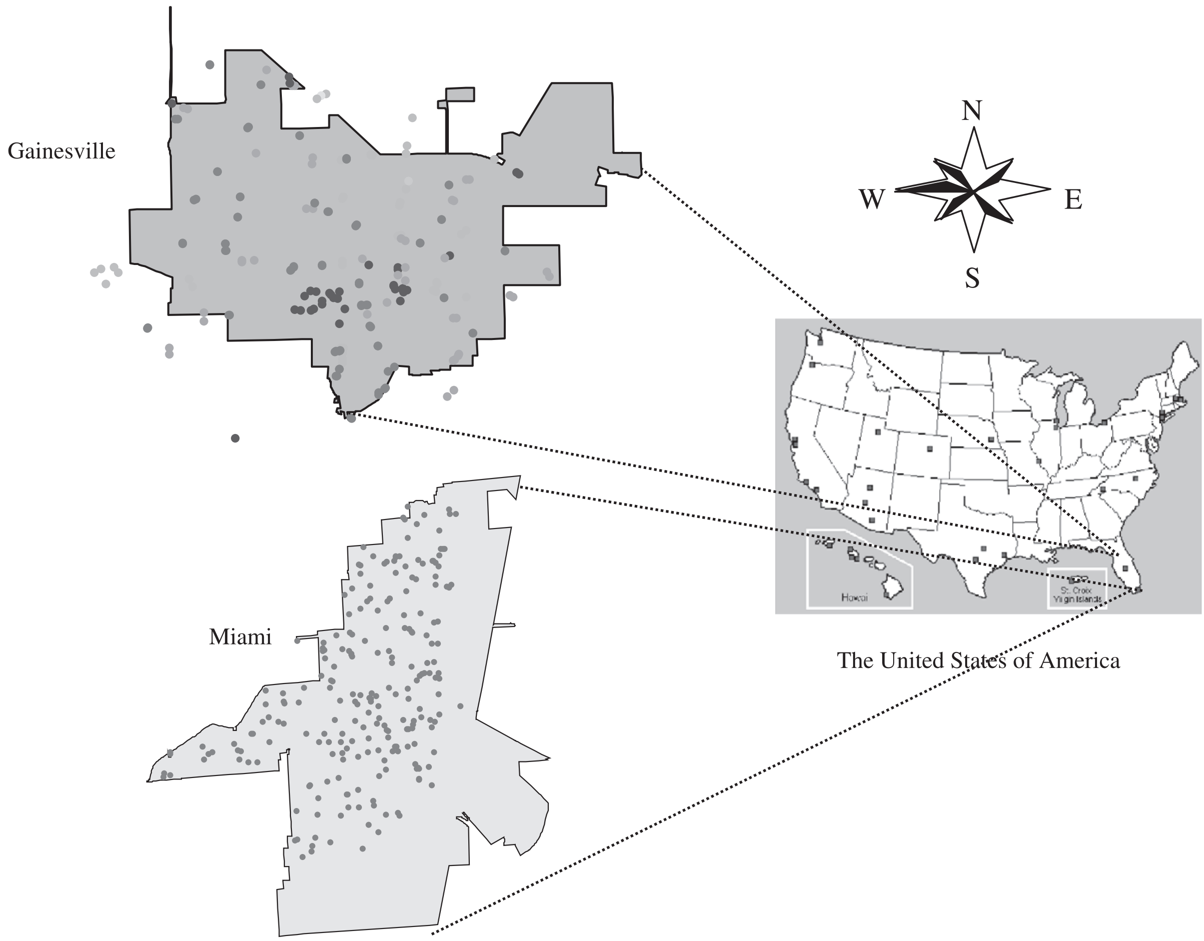

Fig. 1. The distribution of sampling locations in Gainesville and Miami, respectively. The vacant areas on the eastern side of Miami represent the intercoastal waterway, which divides the city of Miami from Miami Beach.

Method 3050, a hotplate digestion method (USEPA, 1995, 1996). The soils in this study were very sandy (< 10% clay); hence, the HNO_3 digestion solution was considered a strong enough extractant for total Pb based on previous studies by Chen et al., 1999). Lead concentrations were determined using a SIMAA 6000 graphite furnace atomic absorption spectrophotometer (GFAAS, Perkin Elmer, Norwalk, CT), using USEPA method 7060A (USEPA, 1995). A standard reference material (SRM 2709 Montana soil [NIST standard]) was used to check the extraction efficiency of the digestion method. Spikes, duplicates and reagent blanks were also used as part of our quality assurance/quality control (QA/QC). In addition, soil properties that have been shown to affect metal concentrations (pH, clay content, organic carbon (OC), and total Fe and Al) were also measured.

3. Results and discussion

3.1. Soil Pb distribution in Gainesville and Miami

Table 1 summarizes the relevant descriptive statistics for Pb concentrations in the Gainesville and Miami urban soils. Although samples were collected at different depths, the general distribution of Pb was not significantly affected by this. Analyses of samples collected at depths of 10–20 cm in Miami showed no

Table 1
Summary statistics for soil lead concentrations (mg/kg^{-1}) in different land uses in Gainesville and Miami

	Residential	Commercial	Public parks	Public buildings	Combined
Miami					
# of samples	60	60	60	60	240
AM[a]	161	223	107	118	152
ASD[a]	190	231	94.9	96.6	169
Median	121	146	82.0	84.0	98.0
GM[a]	102	120	78.8	76.9	92.9
GSD[a]	3.32	3.70	3.12	2.72	3.24
Gainesville					
# of samples	39	41	38	44	202
AM	66.9	37.5	22.2	43.5	39.6
ASD	182	81.4	40.7	89.6	102
Median	20.4	19.2	7.23	17.4	15.1
GM	22.6	18.4	9.97	19.5	16.4
GSD	4.18	4.04	3.12	2.97	3.60

[a] AM = arithmetic mean, ASD = arithmetic standard deviation, GM = geometric mean and GSD = geometric standard deviation.

difference from samples from 0 to 10 cm depth. Several soil samples from both cities were above the Florida SCTL for residential and commercial areas (500 and 1000 mg kg^{-1}; Table 2, Fig. 2). Approximately 4% and < 1% of the samples from Miami were above the Florida SCTL for residential and commercial areas, respectively, compared to < 1% each for Gainesville. Six of the nine samples that were above the residential SCTL in Miami were commercial area samples and two were from residential areas. The remaining sample was from public parks (data not shown). This pattern fits a more industrialized region in contrast to Gainesville where one of the two samples that were above the residential SCTL came from commercial areas and the other from residential areas. Chronopoulos et al. (1997) observed higher Pb concentrations around the perimeter of parks (where there had been higher traffic emissions) than in the interior in Athens, Greece. This corroborates other studies that have shown the relationship between human activity with Pb.

The Pb concentrations observed in this study highlight the large variation of Pb concentrations in urban areas, comparable to those observed in other studies (Bak et al., 1997; Brinkmann, 1994; Chen et al., 1997; Komai and Yamamoto, 1981; Rasmussen et al., 2001; Senesi et al., 1999; Short et al., 1986; Tiller, 1992). In a study of heavy metal contamination in urban soils, Komai and Yamamoto (1981) observed Pb concentrations in the range of 100 mg kg^{-1} in surface soils (0–1 cm) and about 50 mg kg^{-1} in subsurface soils in Sakai, Osaka (Japan). Short et al. (1986) observed concentrations of about 200 mg kg^{-1} in surface soils and approximately 100 mg kg^{-1} in subsurface soils around the Washington Mall in Washington, DC. Davies et al. (1987) went a step further and showed that high Pb concentration in urban soils (mean: 340 mg kg^{-1}, range: 60–789 mg kg^{-1}, standard deviation: 153, in London, England) often lead to increased plant Pb uptake (4–7 mg kg^{-1}

Table 2
The minimum, maximum, 1st, 2nd and 3rd quartiles, 95th percentile concentrations, and percentages of soil samples above the Florida SCTLs for Pb in Gainesville and Miami

	Residential	Commercial	Public parks	Public buildings	Combined
Miami					
# of samples	60	60	60	60	240
Minimum	2.89	3.27	10.2	2.13	2.13
1st quartile	71.0	50.2	45.3	56.5	53.2
2nd quartile[a]	121	146	82.0	84.0	98.0
3rd quartile	174	353	128	177	184
Maximum	1088	1091	550	444	1091
95th percentile	426	571	277	306	453
%>500 mg/kg	3.33	10.0	1.67	0.00	3.75
%>1000 mg/kg	1.67	1.67	0.00	0.00	0.83
Gainesville					
# of samples	39	41	38	44	202
Minimum	3.14	3.32	2.04	3.06	2.04
1st quartile	10.2	7.62	4.59	8.56	7.12
2nd quartile	20.4	19.2	7.23	17.4	15.1
3rd quartile	38.4	34.9	18.6	36.8	33.4
Maximum	1060	526	224	484	1060
95th percentile	246	84.8	173	89.0	101
%>500 mg/kg	2.50	2.50	0.00	0.00	0.99
%>1000 mg/kg	2.50	2.50	0.00	0.00	0.99

[†]500 and 1000 mg kg^{-1}: the Florida SCTL for Pb in residential and commercial areas, respectively.

[a] The median of the dataset.

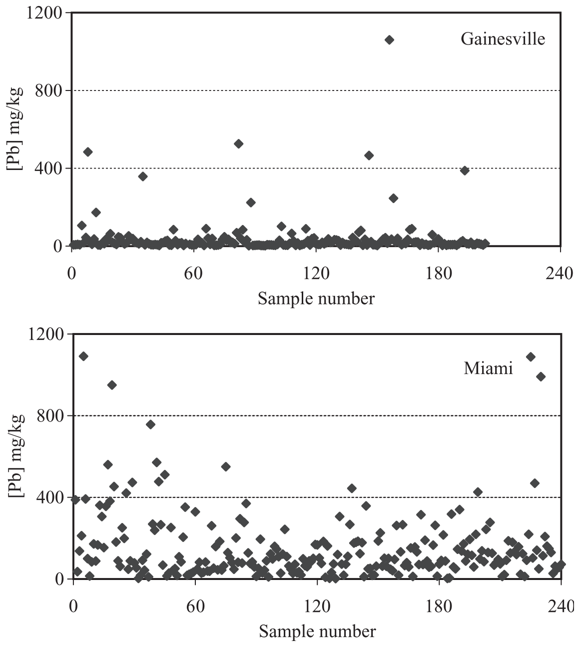

Fig. 2. Soil lead concentration distribution in Gainesville and Miami, respectively.

in vegetables), exposing urban consumers to potential risk.

As indicated in Fig. 2, Pb distribution was considerably different between the two cities. Approximately 87% of the samples from Gainesville had Pb concentrations < 50 mg kg^{-1} (3rd quartile = 33.4 mg kg^{-1}, i.e. 75% of the samples had Pb concentrations < 33.4 mg kg^{-1}, Table 2) compared to only 23% of the samples from Miami (3rd quartile = 184 mg kg^{-1}, Table 2). The majority of samples from Miami ($\sim$ 55%) were in the range of 51–200 mg kg^{-1} Pb. A considerable number, 12%, had Pb levels above 200 mg kg^{-1} in Miami.

In terms of pedogenic influences, Gainesville and Miami soils were derived from different parent materials. The predominant soil types in Gainesville were sandy (mean sand content $\sim$ 95%) siliceous, hyperthermic aeric hapladuods and plinthic paleaquults (USDA, 1982). On the other hand, most of the sample collection sites in Miami were comprised of soils classified as Urban land (>85% of the surface is covered by parking lots, streets, large buildings, shopping centers, houses and other structures; USDA, 1996). The urban land was mixed with Udorthent soils, usually a stony loam underlain by hard, porous, limestone bedrock. These differences manifest themselves in differences in both physical and chemical properties, notably particle size distribution, CEC, pH, hydraulic conductivity and OC, which affect Pb solubility and retention. Lead retention is greater in finer textured soils with high CEC and OC (Aloupi and Angelidis, 2001; Baize and Sterckeman, 2001; Chirenje et al., 2003a), which are more common in Miami than Gainesville soils. Hence, low Pb concentration in Gainesville may be due to both increased Pb mobility (low retention) in the area, as well as low input (low industrial activity).

Gainesville soils had a lower pH (mean 6.31) compared to Miami (mean pH $\sim$ 7.23; Table 3). This is consistent with results from Suave et al. (1998) who observed increased Pb solubility when pH was lowered from 6 to 3. Calcite, oxides and hydroxides of Al, Fe and Mn have also been recognized as important sorbents for Pb (Kinniburgh and Jackson, 1981). For example, Elkhatib et al. (1991) demonstrated that Pb sorption in calcareous soils, similar to those found in South Florida (Miami), was almost double that of non-calcareous soils comparable to those from Gainesville. Other researchers have also shown increased trace metal adsorption on oxides and hydroxides of Al and Fe, including Pb (Ainsworth et al., 1994). Thus, low pH, OC and clay content in Gainesville soils may all have contributed to its low soil Pb concentrations compared to Miami soils (Table 3).

Table 3
Comparison of soil pH, OC and clay + silt content between Gainesville and Miami soils

	Residential	Commercial	Public parks	Public buildings	Combined
Miami					
PH	7.27	7.17	7.10	7.37	7.23
OC (%)	5.80	6.96	4.12	6.38	5.74
Clay + silt (%)	26.3	31.1	25.3	29.5	28.0
Gainesville					
PH	6.39	7.12	5.36	6.25	6.31
OC (%)	1.44	1.47	1.12	1.57	1.41
Clay + silt (%)	9.30	10.7	8.60	8.70	9.30

Apart from soil factors, there is a multitude of other factors that affect Pb concentrations in soils. One of these, human activity, has been shown to be an important factor in explaining Pb distribution (Mielke et al., 1994; Senesi et al., 1999; Chen et al., 1997; Aloupi and Angelidis, 2001), particularly in urban areas. For example, Mielke et al. (1994) showed that Pb concentrations in the right-of-way in residential areas of Minneapolis were directly correlated with traffic volume. No such correlation was performed in this study due to the high variation in the sampling sites. However, traffic emissions, albeit from the past, must have played a role in Pb distribution observed in this study because most soil samples were collected from the public utility right-of-way and Pb is not mobile under typical soil conditions. The Gainesville study confirmed this, showing that residential yard samples ($n = 40$) had significantly lower mean Pb concentration (~ 27 mg kg^{-1}, data not shown) compared to about 67 mg kg^{-1} in the public utility right-of-way samples (Table 1).

Senesi et al. (1999) showed that the application of sludge in urban soils increased Pb concentration from ~ 26 to 45 mg kg^{-1} in Italy. The heavy use of sod in Miami may have influenced Pb concentration in both residential and commercial areas. The use of sod in the more affluent neighborhoods in Gainesville may also explain the higher concentrations in these areas compared to public parks and buildings (Tables 1 and 2).

3.2. Impact of land use on soil Pb distributions in two cities

In terms of current land-use, Pb concentrations in Gainesville increased in the following order: public parks, commercial areas, public buildings and residential areas, with geometric mean (GM) ~ 10, 18, 20 and 23 mg Pb/kg soil, respectively. Public parks had the lowest Pb concentrations because they represent the areas with the least anthropogenic disturbance in urban areas. The order was slightly different in Miami, soil Pb concentrations increasing from public buildings, public parks and residential to commercial areas (with GM ~ 77, 79, 102 and 120 mg Pb/kg soil, respectively; Table 1). Preliminary studies revealed that there was frequent use of fill materials in Miami parks (data not shown); hence, the high concentrations of Pb in this category. The high concentrations of Pb in residential and commercial areas in both cities in our study can also be explained by the location of sampling sites in these areas. Soil samples were collected from the public utility right-of-ways where the use of pesticides, e.g. Pb arsenate and exposure from leaded-gasoline is more prevalent than areas away from the road. Although the use of Pb as an anti-knocking agent in gasoline was banned decades ago, the contribution from automotive exhaust should not be discounted because of the low mobility of Pb in the soil. The higher concentrations in Miami could also be due to soil properties rather than just anthropogenic factors as noted by Chen et al. (1999).

4. Conclusions

This study determined Pb distribution in urban soils based on four land-use categories in two cities, Gainesville and Miami. Lead could be divided into two groups in Miami (commercial and residential areas, with high concentrations and public buildings and public parks, areas with low Pb concentrations). Soil lead concentrations in Gainesville public buildings were lower than the other three land-use classes, which were all comparable to each other. This study demonstrated that the immobility of Pb causes it to persist for long periods of time in the soil. It also showed that high Pb concentration seems to be prevalent in both cities, although they had different population densities (different traffic volumes). There is need for future studies to determine the human health impact of these distributions, using samples collected only in the top 1 or 2 cm.

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