Lead Concentrations in Inner-City Soils As a Factor in the Child Lead Problem

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Abstract. Soil samples were randomly collected from 422 vegetable gardens in a study area centered in downtown Baltimore, Maryland, and having a radius of 48.28 km (30 miles). The levels of lead, four other metals (cadmium, copper, nickel, and zinc), and pH were measured for each location. The application of multi-response permutation procedures, which are compatible with mapping techniques, reveals that lead (as well as cadmium, copper, nickel, and zinc) is concentrated and ubiquitous within the soils of the inner-city area of Metropolitan Baltimore. The probability values that the concentration of metals occurred by chance alone vary from about 10^{-15} to 10^{-23} depending on the metal considered. Our findings pose environmental and public health issues, especially to children living within the inner-city. (*Am J Public Health* 1983; 73:1366–1369.)

Health researchers in the United States have disclosed that undue exposure to lead is a nationwide public health problem which in the general population is prevalent among children and associated with degree of urbanization.[1] A federally funded child screening program, begun in mid-1971, revealed that excessive lead exposure was occurring among 15–20 per cent of the children in many inner-city locations,[2] although the average for all inner-city children is presently about 12 per cent.[1] Reduction of lead-based paint has been the prime focus for prevention of lead poisoning up to this time. However, about 40 to 45 per cent of the confirmed lead toxicity cases in the US could not be directly related to lead paint.[3] Research into non-traditional sources of lead is clearly needed and has been requested.[4] Leaded gasoline is also a significant source of lead.[5] Airborne lead has been recognized as a significant source of indoor lead exposure,[6] but exposure to urban outdoor lead sources has not received the same level of attention by researchers. Several studies describe lead levels in urban soils. For example, toward the city centers of London, Christchurch, and Boston lead levels have been found to increase substantially.[7–9] However, surveys to date have not used appropriate statistical techniques to describe the degree of concentration of lead within an urban area. Our study was designed to measure and survey the distribution of soil lead within metropolitan Baltimore. Since vegetable garden cultivation creates many opportunities for contact between humans and soils, either directly via hand-to-mouth activities or indirectly via food chain linkages or contamination of the living space, we focused our attention on vegetable garden soils.

Methods

Data Collection

We assumed that garden soils would be mixed to spade depth (about 20 to 30 cm). Soil samples were randomly collected from 422 locations within an area defined by a 48.28 km (30 mile) radius from a designated center point (intersection of Baltimore and Charles Streets) of downtown Baltimore. Samples were air dried and sieved with stainless steel (USGS #10) 2 mm mesh screen. Samples were prepared by shaking a 1:5 ratio of air dried soil to 1M nitric acid extraction solution for two hours. The extracts were filtered and the final extractions were analyzed for lead, cadmium, zinc, copper, and nickel using a Varian atomic absorption spectrophotometer with deuterium background correction. Duplicates were prepared and run for all samples. Soil pH of each sample was measured using a 1:1 ratio of soil and deionized distilled water. One set of measurements (the average of the duplicate samples and pH) was obtained for each of the 422 sites.

Statistical Analysis

The statistical analysis of these data are based on a recently perfected permutation technique termed multi-response permutation procedures (MRPP).[10,11] Unlike most statistical techniques, our MRPP analysis is compatible with the Euclidean geometry on which cartography is based.[12] The 422 soil samples from 422 distinct sample sites comprise the finite population investigated in this study. The response measurements for each soil sample are the x,y coordinates measured cartographically from the designated center of Baltimore. In order to investigate the geographic clustering of high soil lead levels, the 422 soil samples were partitioned at the median value into two groups of 211 each. The MRPP test statistic is based on the average distance between all pairs of sites within the group having higher lead values. The group having lower lead values is treated as the remaining part of the finite population of 422 sites. Under the null hypothesis that the 211 sites of the group having higher lead values have the same chance of arising from any of the 422 sites, the distribution of the standardized MRPP test statistic[10,11] is approximated by the standard normal distribution.[13]

Results

The results of the analysis are summarized in Table 1. In addition to lead, analyses are also reported for cadmium, copper, nickel, zinc, and soil pH. The probability value reported in Table 1 is the proportionate measure of having a

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TABLE 1—Probability of Being Clustered by Chance Alone and Selected Percentile Values for Each Metal (ppm) and Soil pH

Element N* Probability‡	Lead 422 10^{-23} in ppm	Cadmium 417 10^{-18} in ppm	Copper 422 10^{-15} in ppm	Nickel 419 10^{-18} in ppm	Zinc 420 10^{-19} in ppm	Soil Acidity (pH) 421 0.39 in ppm
Percentile						
Maximum	10,900.0	13.65	96.70	53.40	4,880.00	8.16
90	777.5	3.17	63.45	8.40	521.00	7.17
80	421.0	1.83	41.10	5.50	325.50	6.88
70	258.5	1.33	29.30	4.45	212.50	6.67
60	167.0	0.82	22.65	3.50	152.00	6.50
50 Median	100.0	0.56	17.25	2.80	92.00	6.32
40	55.5	0.41	13.45	2.40	55.55	6.14
30	35.0	0.29	10.15	1.75	33.45	5.83
20	24.5	0.19	7.40	1.40	18.80	5.51
10	14.5	0.12	5.35	0.85	10.65	5.06
Minimum	1.0	0.02	0.70	0.50	0.30	4.11

*Number of sites (N) varies because of missing values.
‡P-value based on the average distance between all pairs of sites with values greater than or equal to the median value.

more extreme result by chance alone. In the case of lead the odds are less than one in 10^{23} that the clustering of the high lead soils could take place by chance alone.*

The distribution of garden sites in metropolitan Baltimore is illustrated in Figures 1 and 2 for lead and soil pH. The excessive concentration of lead in urban garden soils is indicated by a comparison of locations having values greater than or equal to the median value with locations having values less than the median value in Figure 1. Although somewhat less extreme, analogous concentration patterns of the other metals (cadmium, copper, nickel, zinc) also occurred. In contrast, the location values in Figure 2 indicate no obvious pattern differences for soil pH. To illustrate the soil metal quantities encountered in this study, percentile values are tabulated in Table 1 for each of the five metals and soil pH. We expect that uncultivated soils of metropolitan Baltimore have metal concentrations and distribution patterns similar to the vegetable garden samples analyzed in this study.

Discussion

Although some literature proposes that house paint is the major source of soil lead contamination,[14,15] the urban patterns of soil lead in Baltimore suggests that the inner-city lead contamination is due to another source. Ninety per cent of the inner-city of Baltimore is characterized by unpainted brick buildings. Only in the less dense housing areas away from the city center, where they make up 40 per cent of the structures, do older painted homes become relatively common. However, the site of Baltimore has been the focus of a variety of activities during the course of its evolution from Baltimore Town in 1729 to the present urban industrial center.[16] The metal percentiles reported in Table 1 reflect the history of all activities which contribute metals to the environment such as emissions from industries and incinerators, paints, solders, insecticides, rubbish and relatively recently, emissions from vehicular traffic using leaded gasoline. The last item seems especially relevant because vehicle density and hence vehicular emissions are directly proportional to degree of urbanization.

Because the buildings of inner-city Baltimore are predominantly unpainted brick structures, vehicular traffic as a source of lead needs further comment. According to industry sources, at least 50,000 metric tons of lead were sold in the form of leaded gasoline in the state of Maryland from 1961 through 1981.[17,18] In 1981, Baltimore City accounted for about 8.5 per cent of the State's annual average daily traffic (AADT).** However, during the decades of the 1960s and 1970s, the rapid expansion of suburban communities caused a reduction in the proportion of Baltimore City AADT compared with State AADT. Thus, we estimate that about 5,000 metric tons of lead were emitted into the environment of Baltimore City during the period of 1961 through 1981, and furthermore, that between 5,000 and 10,000 metric tons of lead were emitted into the urban environment of Baltimore City by traffic alone during the past 40 to 50 years.

The lead generated by vehicular traffic is not evenly distributed in the city. It is well known that roadside soil lead levels are directly related to AADT.[19] As traffic increases toward the center of the city, roadside lead concentrations would also increase. Furthermore, a relationship has been demonstrated between lead levels of roadside soils and lead levels of building-side soils. Lead aerosols collect on the sides of buildings and are washed into the soils by precipitation.[20] Recognizing the thousands of tons of lead that have been emitted by traffic, these mechanisms suggest the necessary links between traffic, building sides, and soil lead to account for the elevated lead levels of garden soils near unpainted brick structures in the inner-city of Baltimore.

The excessive concentration of lead in inner-city Baltimore soils probably has a bearing on that city's child lead problems.[21] The acidic pH of the gastric juices provides conditions whereby soil lead becomes readily extracted and available for absorption in the gastro-intestinal tract.[22] It has

*If the MRPP test statistic for soil pH is based on the average distance between all pairs of sites with values less than the median value, (i.e., more acid soils) then the probability value for pH would be 0.56 instead of 0.39 given in Table 1.

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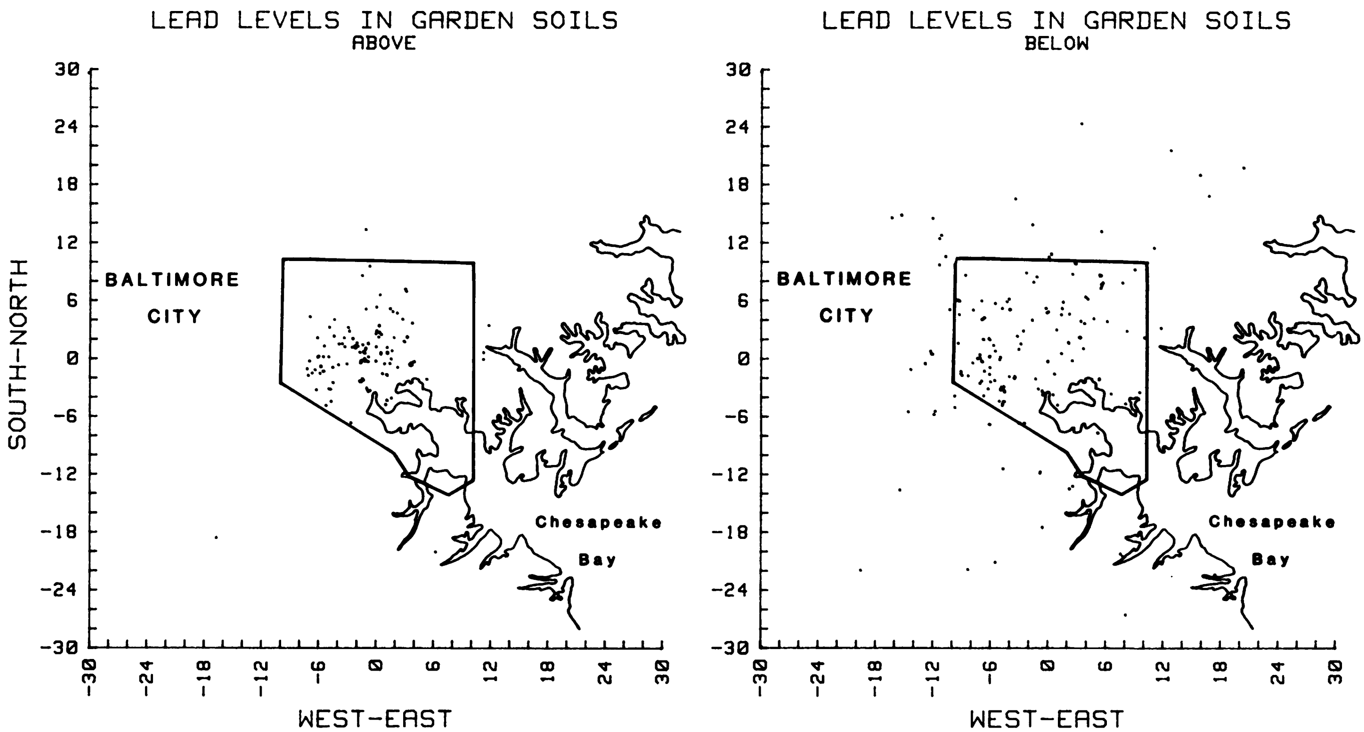

FIGURE 1—Comparison of locations of garden soils exhibiting lead values greater than or equal to the median value (left) with locations of garden soils exhibiting lead values less than median value (right). Note the clustering of garden locations associated with the higher soil lead levels within Baltimore City. Analogous results were also found for cadmium, copper, nickel, and zinc.

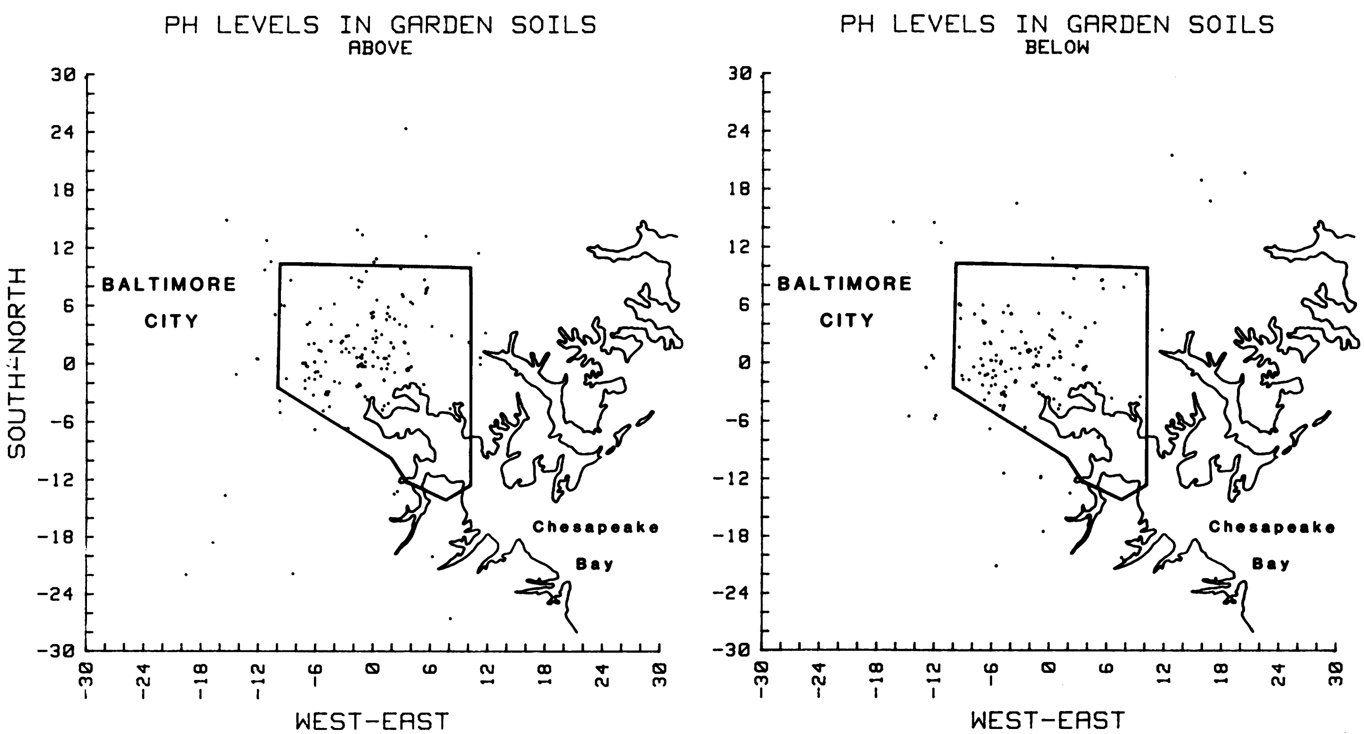

FIGURE 2—Comparison of locations of garden soils having pH values greater than or equal to the median value (left) with locations of garden soils having pH values less than the median value (right). Note the lack of any obvious clustering of locations for either the higher or lower pH values.

been proposed that the maximum daily permissible intake of lead from all sources should be less than 100 micrograms for infants under the age of six months and should not exceed 150 microgram for children between six months and two years of age.[23] Children in the infant-crawling-creeping-toddler stages of development are particularly vulnerable to soil lead because of their small body size, greater lead absorption and retention rate (approximately 50 per cent compared to 8 per cent for adults),[24] and their developmental need to explore and learn through hand-to-mouth behavior.[25-27] The median garden soil (100 ppm) of this study would contribute 100 micrograms of lead per gram of dry soil to the lead intake of a child deliberately or inadvertently ingesting soil during play, mouthing, thumb-sucking, and similar activities. Thus, the high lead soils in this study have the potential of contributing at least 100 per cent and more of the permissible daily lead intake per gram of soil ingested by an infant under six months old, and the majority of the high lead soils would exceed the daily permissible intake by several fold (see Table 1). Lead ingestion is implicated in a variety of learning disabilities and behavioral disturbances among children.[28,29]

While the manner in which the concentration of lead and the other metals occurred, and the environmental and public health problems related to these findings need further investigation, there is no reasonable doubt that lead and the other metals studied are excessively concentrated in the inner-city of Baltimore relative to surrounding areas. Given the extraordinary probability value (10^{-23}) for lead concentration in the center of Baltimore, and the fact that Baltimore is fundamentally similar to other large urban centers, we expect the distribution pattern of soil lead of all large cities to be similar to Baltimore. Thus, the inner-city is a location where, in the course of everyday activities, children face a higher possibility of being exposed to lead than children living in other urban locations. We conclude that soil lead levels are an important measure in accounting for the fact that degree of urbanization correlates with the magnitude of the child lead problem.

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