Environmental Science & Technology LETTERS

Editors' Choice

Open Access



pubs.acs.org/journal/estlcu

Letter

# Legacies of Pre-1960s Municipal Waste Incineration in the Pb of City Soils

Enikoe Bihari, Garrett Grewal, and Daniel D. Richter*

Cite This: *Environ. Sci. Technol. Lett.* 2023, 10, 897−902

Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

**ABSTRACT:** A 1937 street map of Durham, North Carolina, located four city-run waste incinerators that we recognized to be sites of contemporary city parks. We obtained city permission to sample three park's soils, developed a sampling design for geospatial mapping of hypothetical incinerator-ash contamination of park soils, and queried online Durham newspapers to understand histories of incinerator operations, ash disposal, and incinerator-to-park conversions. In 2021−2022, seven decades after parks were created, two parks had soil-Pb > 400 mgPb/kg, EPA's threshold for safe soil in play areas. At Walltown Park, six of 97 surface samples ranged from 416 to 1338 mg Pb/kg within meters of a basketball court and a park path. East Durham Park had a hectare-sized area where 12 samples averaged 1294 mgPb/kg (median 1335 mg/kg). Engineering surveys of United States and Canadian cities in 1941 and 1958 suggest that half incinerated solid wastes. Many records describe how incinerator ash was dumped with little regard for health or environmental hazards. Legacy soil contaminations of incinerator ash can be identified, as we have done in Durham, from historical records of city-waste incinerator operations, online access to newspaper archives that describe incinerator-to-park conversions, and a XRF to screen for soil-Pb contamination.


**KEYWORDS:** *city parks, urban-soil pedogenesis, American Public Works Association (APWA), United States Public Health Service, sanitary engineering, XRF, online newspaper archives, pre-1960s city-waste incineration*

## INTRODUCTION

"*The past is a foreign country: they do things differently there.*" Hartley 1953

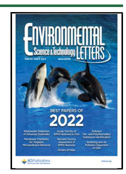
Lead (Pb) has long been used in ceramics, paints, cosmetics, pipes, solders, batteries, and gasoline. Because Pb is relatively insoluble, Pb accumulates in city soils to concentrations in the 100s to 10,000s of mg/kg.[1] In contrast, Pb is but ∼14 mg/kg in Earth's crust and <30 mg/kg in uncontaminated soils.[2,3] City-soil Pb contamination is an international problem.[4]

Human exposure to Pb causes chronic disease, cognitive and behavioral impairment, and other problems.[5] Primary prevention policies have dramatically decreased human exposure to Pb, given the removal of Pb from solder in canned foods and from fresh paint and gasoline.[6] At the same time, however, toxicologists have grown increasingly concerned about adverse effects of low-level Pb exposure.[7−11] Many studies link Pb exposure to contaminated soil, including via tracking soil particles into homes, playing outdoors, and gardening.[12−16] Environmental Pb indoors and outdoors will pose health risks for many years to come.

In 1994, the United States Environmental Protection Agency (USEPA) set 400 mg/kg total soil Pb to be the concentration considered hazardous for residential play areas.[17] This concentration was based on 1990s risk models that predicted probabilities that children's blood Pb would exceed 10 $\mu$g/dL, the United States (US) child-blood Pb action level at that time.[18] Since then, the Centers for Disease Control and Prevention (CDC) has reduced the blood action level to 5 ug/dL in 2012 and 3.5 ug/dL in 2021,[19,20] yet the USEPA's 1994 soil-Pb threshold for safe play areas (400 mg/kg) remains unaltered.[21] In 2012, a USEPA technical workgroup recommended 100 mg/kg as the maximum soil Pb to minimize gardening-related exposure.[22]

Recent city-soils research demonstrates that *median* surface-soil Pb concentrations are decreasing following the removal of Pb from gasoline and fresh paint by the 1980s in the US. In New Orleans, median acid-extractable soil Pb (a fraction of total Pb) statistically decreased from 99 to 54 mg/kg between 2002 and 2016.[23] Median soil Pb in Detroit decreased from 183 to 92 mg/kg in acid-extractable Pb from 2000 to 2019,

**Received:** July 10, 2023
**Revised:** August 23, 2023
**Accepted:** August 23, 2023
**Published:** September 11, 2023



while remaining much lower in suburbs at 33 and 35 mg/kg, respectively.[24] Wade et al.[25] proposed that such decreases are attributable to "urban-soil pedogenesis," a new concept about how city soils change with time. In recent decades, for example, *with the greatly diminished new Pb inputs to city environments*, water and wind erosion has been mixing and redepositing Pb-contaminated and uncontaminated particles. Meanwhile, earthworms mix Pb-contaminated soil with less-contaminated soil in a process known as pedoturbation, and construction and horticultural activities (anthro-pedoturbation) mix and bury soil Pb as well, all of which may diminish median surface-soil Pb concentrations over time.[25]

We suggest that as median city-soil Pb decreases,[23−25] city-Pb hot-spot prediction and intervention are becoming increasingly important for reducing Pb exposure. This study examines a source of soil-Pb contamination that we assert is far more common than is currently understood and potentially an underappreciated route of lead exposure, surface-soil Pb derived from ash from pre-1960s municipal waste incinerators. We characterize these incinerators as "pre-1960s", because they operated when solid waste management was almost entirely a local practice with few state and federal programs and regulations, prior to the US Solid Waste Disposal Act of 1965.[26,27]

Municipal waste collection and disposal was first organized in the late 19th century, and from the start, incineration was strongly supported by public health officials, sanitary engineers, and municipal leaders.[28−31] Incineration reduced city-waste volumes by more than 5-fold and transformed an overwhelming garbage problem to an ash, a material traditionally used as fertilizer. Household garbage, manure, street sweepings, construction debris, animal bodies, and miscellaneous city detrata were incinerated.[31] The resulting ash was widely dumped on land and in water, and remarkably, little attention was paid to the potential health and environmental hazards.[31]

There has been longstanding interest in landfills repurposed as public parks,[32] an iconic example of which is New York City's Flushing Meadow Park, home of the 1939 and 1964 World's Fairs and the New York Mets' Shea Stadium and Citi Field. Our work here focuses on the ash from pre-1960s city incinerators that was not confined to landfills, but was disposed in areas where it may have resided in city soils for >50 to 100 years.

We hypothesize that pre-1960s municipal waste incineration was a major source of soil Pb proximate to former incinerators and where the resulting ash was dumped. Our objectives were to (1) quantify spatial distributions of surface-soil Pb in three Durham parks, 70 years after city-run neighborhood incinerators were converted to parks, and (2) based on the Durham data, review engineering, scientific, and historical records including newspaper archives for insights about pre-1960s waste incineration and ash disposal across the US and Canada, and about conversions of city-run incinerator sites to other land uses, including public parks.

## ■ METHODS

**Study Sites.** Durham, North Carolina, is a rapidly growing Southern Piedmont city of 285,000 people in 2020. Incorporated in 1869, the city grew from <7000 to >70,000 people between 1900 to 1950, the decades during which the city operated neighborhood waste incinerators several of which became parks in the 1950s.

Our research began with a 1937 street map of Durham's Department of Public Works that located four city-run waste incinerators (Figure S1) that we recognized to be sites of contemporary city parks. As we planned a sampling design and obtained permission for sampling from the Department of Parks and Recreation, we reviewed archives of online city newspapers (*Durham Herald*, *Durham Sun*, and *The Carolina Times*) for historical details of incinerator operations and conversions to parks. Aerial photography from 1940 to 2020 illustrated incinerator to park conversions as well as city-landscape change (Figure S2).

**Sampling and Analysis.** At each of the three Durham parks, surface soil (0 to 2.5 cm depth) was collected at GPS points using a stratified randomized design, with park-strata being grassy areas, secondary post-1940s forests, and revegetated stream corridors (sampling strata identified by capital letters in Figure S2). Arc-GIS Pro generated random sampling points weighted by the strata area. Sampling density averaged ∼1 sample per 250 $m^{-2}$. Each soil sample totaled 100−200 g and was composed of four subsamples taken from the corners of a 30 cm sampling square. A total of 269 composite samples were collected and archived.

In Walltown and East Durham Parks, we also sampled soils and sediments from within incised channels of streams that flow through the parks. In Walltown Park, we selected five streambank sites along Ellerbe Creek for soil-profile sampling (Figure S3). Vertical areas of the channel walls, each 40 cm wide and up to 3 m deep, were exposed with a mattock from the soil surface to the water line and sampled from bottom-to-top from horizons identified by color, texture, and artifacts (molten glass and metal and furnace clinkers). In East Durham Park, we collected 13 samples from what we interpreted to be ash layers that we exposed from the channel walls of a tributary to Goose Creek.

Mineral soil samples were air-dried and passed through a 2 mm screen. We measured samples for Pb in the laboratory with an Olympus (Evident) Vanta-M XRF, standardized with NIST-certified standards 1646a and 2711a, and in-lab standards estimated with HF digestion and ICP-OES analyses[33] (Figure S4).

To map surface-soil Pb, we interpolated concentrations in ArcGIS Pro using a local polynomial function to create a soil-Pb map for each park (2nd order exponential kernel function). This interpolation is parsimonious and allowed for the mapping of the entire park while also retaining some of the inherent spatial heterogeneity in surficial Pb concentrations. Local polynomial functions are used in similar soil contamination and soil property studies and can interpolate between soil samples with moderate to high accuracy.[34−36]

To examine the association of surface-soil Pb with other potentially hazardous ash elements, we selected 12 samples (four per park from surface-soil samples with low to high Pb), for digestion at 200 °C in 15.8 M $HNO_3$ and analysis by ICP (EPA Method 3052).[37]

**Historical Analysis of Pre-1960s Incinerators and Their Conversions to City Parks.** To better understand what we were uncovering in the soils of the Durham parks, we investigated the history of municipal incineration in Durham and across the US and Canada in a variety of records, books, and papers[28,29,31,38−45] and by analyzing American Public Works Association (APWA) data from their 1941 and 1958 city surveys of waste management. These city-survey data are from appendices of the first two editions of APWA's *Refuse*


https://doi.org/10.1021/acs.estlett.3c00488
Environ. Sci. Technol. Lett. 2023, 10, 897−902

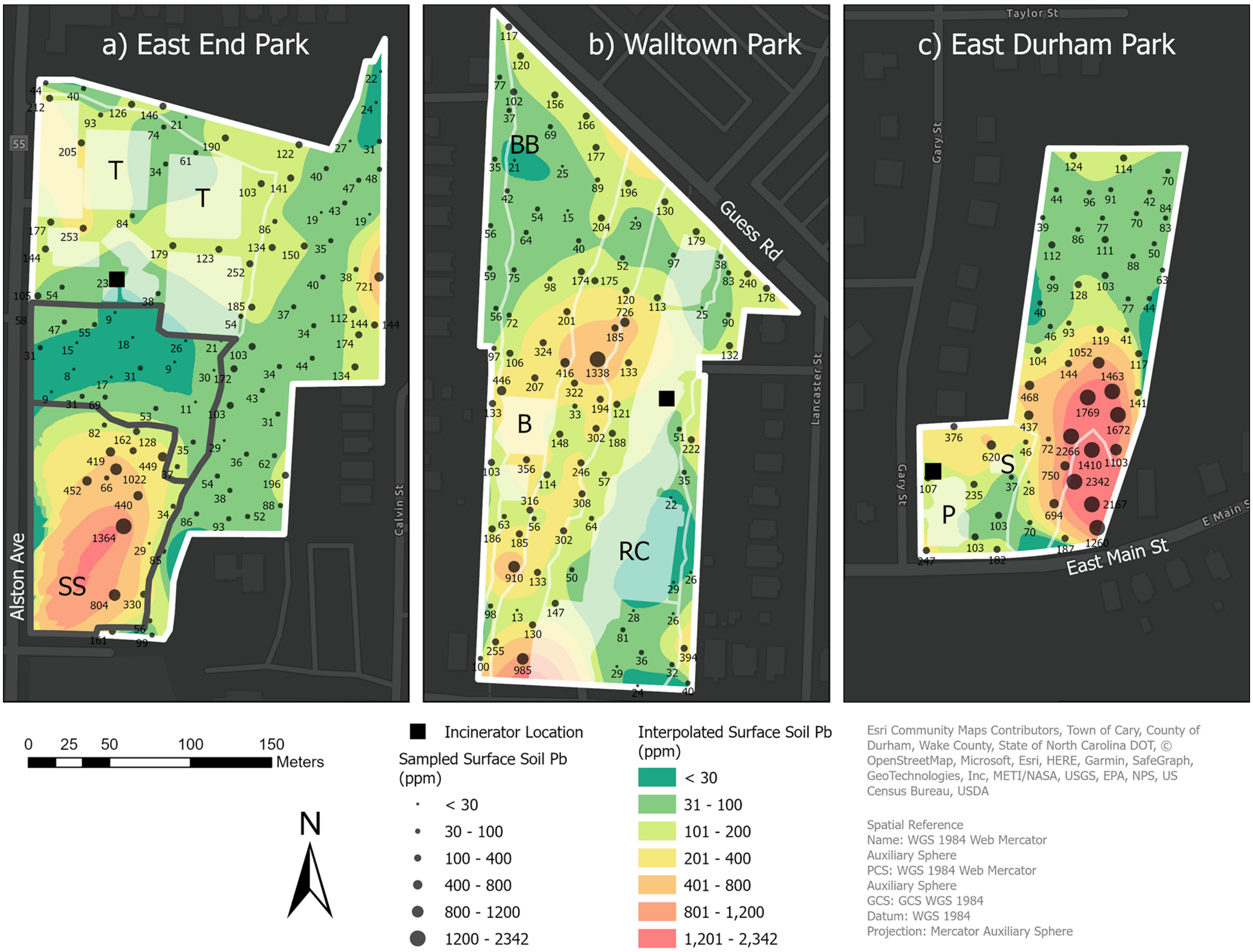



**Figure 1.** Surface-soil Pb heat maps of (a) East End Park, (b) Walltown Park, and (c) East Durham Park in Durham, North Carolina. In (a) East End Park, "T" marks hard-surface tennis courts, and "SS" is the city's abandoned Sign and Signal Shop, the latter surrounded by fencing with locked gates indicated by black lines. In (b) Walltown Park, "B", "BB", and "RC" are outdoor basketball courts, old baseball field, and community recreation center, respectively. In (c) East Durham Park, "P" and "S" are playgrounds with a jungle gym and picnic shelter, respectively.

*Collection Practice*,[31,39] and data from the 1941 survey are summarized in Table S1. We queried online archives of >10 newspapers for information about conversions of incinerator sites to other land uses, including to city parks, and summarized results in Table S2 for New York City; Baltimore; Charleston, South Carolina; Spokane, Washington; Los Angeles; and Jacksonville, Florida. We use these cities to propose an approach to investigating historical soil contamination from pre-1960s city-waste incineration.

## ■ RESULTS

Seventy years after the three Durham parks were created, the parks have markedly different spatial distributions in soil Pb (Figure 1).

**East End Park.** In surface soils between the hard-surfaced tennis courts (T) and soccer fields and adjacent to two park buildings and an amphitheater, Pb concentrations were all <253 mg/kg (Figure 1a, Figure S2). In this small but popular park area, soil Pb averaged 120 mg/kg ($n$ = 18) and ranged from 23 to 253, all below USEPA's 400 mg/kg threshold for safe play-area soil. A 1940 aerial photograph shows the old incinerator (Figure S2), the legacies of which seem to be erased from the contemporary park's surface soils, especially compared with the other two parks.

However, to the south of the publicly accessible East End Park with its tennis and soccer facilities, behind a fence with locked gates, we encountered a one ha soil-Pb hotspot, not from incinerator ash but from paint from the city's abandoned Sign and Signal Shop (SS in Figure 1). Sand-sized paint chips are visible in the surface soils and sediments, and surface-soil Pb concentrations in this largely unvegetated area averaged 409 mg/kg ($n$ = 13) and ranged from 29 to 1364 mg/kg. Road paint has long been enriched in Pb for pigmentation and durability.[46]

**Walltown Park.** Legacies of Pb from incinerator ash are evident in surface soils of Walltown Park (Figure 1b, Figure S2). While the median across the park was relatively low (103 mg/kg), six of the 97 samples collected ranged from 416 to 1338 mg/kg, and eight others exceeded 300 mg/kg. Three samples adjacent to basketball courts (B in Figure 1b) were 316, 356, and 446 mg/kg. The highest Pb concentration in Walltown surface soils, 1338 mg/kg, was located within meters of a high-traffic foot bridge across Ellerbe Creek.

Within the deeply incised streambanks of Ellerbe Creek, each of the five soil profiles (SB1 to SB5 in Figure S3) had ~1 to >2 m thick layers of buried ash with molten glass and metal, furnace clinkers, low (dark) Munsell color values, and high soil Pb. The highest Pb concentrations in each of the five profiles



https://doi.org/10.1021/acs.estlett.3c00488
Environ. Sci. Technol. Lett. 2023, 10, 897−902

ranged from 2457 to 5038 mg/kg. Coring could determine these buried ash layers' extent and stratigraphy.

**East Durham Park.** In the southeastern part of East Durham Park, north of East Main Street, is a nearly one ha area in which 12 surface-soil samples average 1294 mg Pb/kg and have a median of 1335 (Figure 1c, Figure S2). Every sample in this area except one exceeds 437 mg/kg, and the highest is 2342 mg/kg.

In the southwest of the park, again north of East Main Street, two samples that are 376 and 620 mg/kg soil Pb are <10 to 20 m from a children's jungle gym (P) and a picnic shelter (S). A multiunit apartment house constructed before 1972 is directly adjacent to the highest soil-Pb concentrations we observed in East Durham Park (Figure 1c, Figure S2).

As in Walltown Park, we sampled stream channel walls, these of a tributary to Goose Creek that drains East Durham Park. In 13 samples from what we interpreted to be ash-derived strata, Pb concentrations averaged 3171 mg/kg with three of the samples having Pb concentrations of 7498, 8906, and 12,781 mg/kg.

**Soil Pb and Other Contaminants.** Soil-Pb contamination can be associated with other potentially hazardous ash elements and organics. In 12 Durham surface-soil samples (four from each park), concentrations of soil Pb were highly correlated with soil As, Cd, Cr, Cu, and Zn. Correlation coefficients between Pb and these five metals ranged between 0.94 to 0.99, all highly significant with very low p-values. A correlation matrix is illustrated in Figure S5.

## DISCUSSION

**Durham Parks' Soil Pb.** We attribute the contrasting patterns in soil Pb in the three Durham parks to legacies of incinerator operations, to practices used to convert incinerator sites to parks, and to 70 years of urban-soil pedogenesis.[25]

East End Park may have relatively low Pb concentrations due to efficient ash removal prior to the park's opening and to additions of low-Pb soil during park construction and maintenance. In contrast, surface soils >400 mgPb/kg in Walltown Park indicate ineffective topsoil coverage of incinerator ash.

Even still, low-Pb surface soils on the old baseball field and adjacent to the Walltown Recreation Center (in Figure 1, BB and RC, respectively) are likely due to low-Pb soil imported to build the ballfield, the garden beds, and embankments around the recreation center building. Such patterns give credence to the potential effectiveness of soil remediation.

In East Durham Park, the cluster of 12 samples with a median of 1335 mg/kg soil Pb (Figure 1c), indicates that this area may never have been covered with topsoil (as reported in newspapers) or may have been covered with too little topsoil. Accelerated erosion over 70 years at ~0.5 mm/y (equivalent to 7.5 Mg/ha/y, a moderate rate of accelerated soil erosion[47]) could remove much of a 5 cm thick layer of topsoil.

**Durham's Incinerator-to-Park Conversions.** Starting in 1915 and continuing for 50 years, a series of Durham incinerators combusted garbage and other refuse from homes, businesses, and city streets.[48,49] Durham's first incinerator was built by the Nye Odorless Crematory Company, similar to those already in operation in Raleigh, North Carolina, and Florence, South Carolina.[50] Its location on Durham's Morris Street was not one of the four sites illustrated on Durham's 1937 street map (Figure S1). By the 1920s, five incinerators were operating likely including the four neighborhood incinerators on the 1937 Public Works map,[51,52] each combusting up to 15 to 20 tons of waste per day (Figure S1). The four neighborhood incinerators were closed in 1942, when Durham opened a large central incinerator outside the city, a facility that operated until 1965.[49,53] Assuming the four neighborhood incinerators operated for 15 years, each produced on the order of 10,000 tons of ash (15 y, 15 ton/day, 300 d/y, 0.15 ash/solid waste ratio).

By the late-1940s, public pressure had mounted to convert abandoned incinerator sites to parks and playgrounds,[54] and by the mid-1950s, three of the incinerator sites had become East Durham, East End, and Walltown Parks[55,56] with playgrounds, grass fields, picnic shelters, sports fields, paths, streams, and urban trees. By then, thousands of truckloads of ash had been removed from the former incinerator sites, with 500 truckloads of Walltown ash reportedly dumped in nearby Northgate Park in low-lying areas.[57] The incinerator ash in the new parks and in Northgate Park was reported to be covered with "topsoil."[57]

**National Implications for Pre-1960s Municipal Incineration.** Durham's story has important implications for many communities that are currently unaware of this potential soil contamination. By 1902, over 15% of the American cities were reported to be operating waste incinerators. By the 1930s through 1950s, city surveys by the APWA indicated that half of US and Canadian cities, small and large, were incinerating solid waste (Table 1, Table S1), all while incineration was widely promoted by sanitary engineers, public health professionals, and municipal leaders, both in Durham[58] and across the US and Canada.[28,29,31,38]

**Table 1. Three surveys of US and Canadian cities from 1902 to 1956 that document a half-century of widespread city-waste incineration**

| Year city survey | Cities in survey (#) | Pre-1960s incineration (%) | Sanitary landfill (%) | Hog farming (%) | Open dumping (%) |
|---|---|---|---|---|---|
| 1902[38] | 161 | 16.8 | – | 25.5 | 59.6 |
| 1941[26] | 187 | 49.7[a] | 1.6 | 35.8 | 81.3 |
| 1956[39] | 89 | 49.4 | 73.0 | 22.5 | 24.7 |

[a]Some details of ash disposal practices in the 93 cities with incinerators in 1941 are found in Table S1.

By midcentury, however, city-waste incinerators began to close due to high operational and replacement costs, the advent of the "sanitary landfill", and the entry of the federal government into solid-waste management.[27,40,59−61] Between 1965 and 1976, the US Solid Waste Disposal Act, Clean Air Act, and Resource and Conservation Recovery Act transformed city solid-waste management from being a local activity into one that was increasingly regulated by state and federal authority.[27] Today, less than 3% of US cities operate city-waste incinerators, nearly all of which are major engineering facilities with advanced pollution controls and energy recovery systems.[62]

The ash produced by pre-1960s city-waste incinerators in the US and Canada was enormous, and it was disposed with remarkably little appreciation for health and environmental risks. Hering and Greeley[29] chemically analyzed city refuse (even for Pb), but made few if any comments about the potential hazards of ash, despite the fact that the authors were deeply committed sanitary engineers. Many reports describe in detail how city-waste ash was dumped on land to fill in low-


https://doi.org/10.1021/acs.estlett.3c00488
Environ. Sci. Technol. Lett. 2023, 10, 897−902

lying areas, wetlands, ditches, gullies, ravines, and canyons, and dumped into rivers, lakes, lakefronts, waterfronts, harbors, and the ocean.[29,31,39]

Given the poor to nonexistent documentation of this dumping, contemporary construction engineers, developers, and regulators should be well aware of these potentially hazardous materials in the belowground environment and take advantage of rapid, accurate, and portable XRF instrumentation. While we do not yet have quantitative estimates of toxicological risks of soil Pb in city parks, our experience in Durham[63] clearly demonstrates that such soil contamination risks the public's trust in city parks that are fundamental to the wellbeing, happiness, and upbringing of urban children and families. Such invisible contaminations need practical and effective remedy.

We suggest the following approach: (1) Compile a list of the hundreds or probably >1000 US and Canadian cities that operated pre-1960s waste incinerators from records in many authoritative books, professional reports, and papers.[28,29,31,38,39] Table S1 starts such a list with 93 cities that had waste incinerators based on APWA's 1941 survey of waste management of 187 US and Canadian cities.[31] (2) In these cities, query online archives of newspapers and other historical records to document timing and locations of incinerator operations and details about incinerator site conversions to other land uses, including to parks. (3) Deploy XRF instrumentation to efficiently screen contemporary soils for potential contamination. Table S2 illustrates the feasibility of this proposed approach for six US cities.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.estlett.3c00488.

Figures S1−S7: Durham's 1937 Department of Public Works street map, aerial photographs of incinerators and parks from 1940 and ∼2020, regression of total Pb analyzed by XRF and ICP, correlation matrix of soil Pb and six heavy metals, and photographs of a neighborhood incinerator in 1940 and of Walltown Park in 1953 and 2023 (PDF)

Tables S1 and S2: Lists of 93 US and Canadian cities that incinerated solid waste, and summary histories of six cities that converted pre-1960s incinerator sites to city parks and other land uses (PDF)

## ■ AUTHOR INFORMATION

### Corresponding Author

**Daniel D. Richter** − *Nicholas School of the Environment, Duke University, Durham, North Carolina 27708, United States*; orcid.org/0000-0003-3547-433X; Email: drichter@duke.edu

### Authors

**Enikoe Bihari** − *Nicholas School of the Environment, Duke University, Durham, North Carolina 27708, United States*

**Garrett Grewal** − *Nicholas School of the Environment, Duke University, Durham, North Carolina 27708, United States*

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.estlett.3c00488

### Notes

The authors declare no competing financial interest.

## ■ ACKNOWLEDGMENTS

We thank Gary Smith, Bruce Fredrickson, Carson Holloway, Gabe Filippelli, Emmanuel Obeng-Gyasi, Anna Wade, Howard Mielke, Susan Richter, Ben Richter, Ram Oren, Bill Schlesinger, Heather Stapleton, Dean Urban, Paul Heine, Will Cook, Louis Lu, Julia Kagiliery, Adam Skinner, Carson Lambert, Delphine Sellars, Lucille Patterson, Toddi Steelman, Stelfanie Williams, Olympus Scientific (Evident) technical staff, and Durham Department of Parks and Recreation. We credit Duke Physics Instrument Shop and Bernard Jelinek for Pb-free solder repair of a mill screen, Duke University for partial support for the Olympus XRF, and Duke Libraries for bringing Durham's historical newspapers online. Research reported in this publication was supported by Duke University and the National Institute of Environmental Health Sciences of the National Institutes of Health under Award Number P42ES010356. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

## ■ REFERENCES

(1) Datko-Williams, L.; Wilkie, A.; Richmond-Bryant, J. Analysis of U.S. soil lead (Pb) studies from 1970 to 2012. *Sci. Total Environ.* **2014**, *468−469*, 854−863.

(2) Rudnick, R.; Gao, S. Composition of the continental crust. In *Treatise on Geochemistry*; 2014; Vol. *4*, pp 1−51. .

(3) Smith, D. B.; Cannon, W. F.; Woodruff, L. G.; Solano, F.; Kilburn, J. E.; Fey, D. L. *Geochemical and mineralogical data for soils of the conterminous United States*; U.S. Geological Survey Data Series 801; U.S. Geological Survey Data Series, 2013. https://pubs.usgs.gov/ds/801/.

(4) Global Assessment of Soil Pollution, 2021. *FAO*.http://www.fao.org/3/cb4894en/online/cb4894en.html (accessed July 30, 2023).

(5) Lead Poisoning. *Mayo Clinic*. https://www.mayoclinic.org/diseases-conditions/lead-poisoning/symptoms-causes/syc-20354717 (accessed 30 July 2023).

(6) Pirkle, J. L.; Brody, D. J.; Gunter, E. W.; Kramer, R. A.; Paschal, D. C.; Flegal, K. M.; Matte, T. D. The decline in blood lead levels in the United States: the National Health and Nutrition Examination Surveys (NHANES). *Jama* **1994**, *272* (4), 284−291.

(7) *Center for Health Statistics*, CDC, 2022.

(8) Lanphear, B. P.; Lowry, J. A.; Ahdoot, S.; Baum, C. R.; Bernstein, A. S.; Bole, A.; Brumberg, H. L.; Campbell, C. C.; Lanphear, B. P.; Pacheco, S. E.; Spanier, A. J.; Trasande, L. Prevention of childhood lead toxicity. *Pediatrics* **2016**, *138* (1), No. e20161493.

(9) Lanphear, B. P.; Rauch, S.; Auinger, P.; Allen, R. W.; Hornung, R. W. Low-level lead exposure and mortality in US adults: a population-based cohort study. *Lancet Public Health* **2018**, *3*, e177−e184.

(10) Koller, K.; Brown, T.; Spurgeon, A.; Levy, L. Recent developments in low-level lead exposure and intellectual impairment in children. *Environ. Health Perspect.* **2004**, *112* (9), 987−994.

(11) Banks, E. C.; Ferretti, L. E.; Shucard, D. W. Effects of low level lead exposure on cognitive function in children: a review of behavioral, neuropsychological and biological evidence. *Neurotoxicology* **1997**, *18* (1), 237−281.

(12) Schachter, A. E.; Gailey, A.; Egendorf, S. P.; Mielke, H. W. Mechanisms of children's soil exposure. *Current Problems in Pediatric and Adolescent Health Care* **2020**, *50* (1), 100742.

(13) Laidlaw, M. A. S.; Taylor, M. P. Potential for childhood lead poisoning in the inner cities of Australia due to exposure to lead in soil dust. *Environ. Pollut.* **2011**, *159* (1), 1−9.

(14) Spliethoff, H. M.; Mitchell, R. G.; Shayler, H.; Marquez-Bravo, L. G.; Russell-Anelli, J.; Ferenz, G.; McBride, M. Estimated lead (Pb) exposures for a population of urban community gardeners. *Environmental Geochemistry and Health* **2016**, *38* (4), 955−971.

(15) Zahran, S.; Laidlaw, M. A. S.; McElmurry, S. P.; Filippelli, G. M.; Taylor, M. Linking Source and Effect: Resuspended Soil Lead, Air Lead, and Children's Blood Lead Levels in Detroit, Michigan. *Environ. Sci. Technol.* **2013**, *47* (6), 2839−2845.

(16) Hunt, A.; Johnson, D. L.; Griffith, D. A. Mass transfer of soil indoors by track-in on footwear. *Science of The Total Environment* **2006**, *370* (2), 360−371.

(17) *Lead: Identification of Dangerous Levels of Lead (Final Rule)*, 40 CFR Part 745; USEPA, 2001; pp 1206−1240.

(18) White, P. D.; Van Leeuwen, P.; Davis, B. D.; Maddaloni, M.; Hogan, K. A.; Marcus, A. H.; Elias, R. W. The conceptual structure of the integrated exposure uptake biokinetic model for lead in children. *Environ. Health Perspect.* **1998**, *106*, 1513−1530.

(19) Low Level Lead Exposure Harms Children: A Renewed Call for Primary Prevention: Report of the Advisory Committee on Childhood Lead Poisoning Prevention of the Centers for Disease Control and Prevention. *CDC*. http://www.cdc.gov/nceh/lead/ACCLPP/Final_Document_030712.pdf (accessed July 4, 2023).

(20) CDC Updates Blood Lead Reference Value for Children. *CDC*. https://www.cdc.gov/media/releases/2021/p1028-blood-lead.html (accessed July 4, 2023).

(21) Gailey, A. D.; Schachter, A. E.; Egendorf, S. P.; Mielke, H. W. Quantifying soil contamination and identifying interventions to limit health risks. *Current Problems in Pediatric and Adolescent Health Care* **2020**, *50* (1), 100740.

(22) *Technical Review Workgroup Recommendations Regarding Gardening and Reducing Exposure to Lead-Contaminated Soils*; US Environmental Protection Agency: Augusta, GA, USA, 2014.

(23) Mielke, H. W.; Gonzales, C. R.; Powell, E. T.; Laidlaw, M. A. S.; Berry, K. J.; Mielke, P. W.; Egendorf, S. P. The concurrent decline of soil lead and children's blood lead in New Orleans. *Proc. Natl. Acad. Sci. U.S.A.* **2019**, *116*, 22058−22064.

(24) Mielke, H. W.; Gonzales, C. R.; Powell, E. T.; Shah, A.; Berry, K. J.; Richter, D. D. Spatial-temporal association of soil Pb and children's blood Pb in the Detroit Tri-County Area of Michigan (USA). *Environmental Research* **2020**, *191*, 110112.

(25) Wade, A. M.; Richter, D. D.; Craft, C. B.; Bao, N. Y.; Heine, P. R.; Osteen, M. C.; Tan, K. G. Urban-soil pedogenesis drives contrasting legacies of lead from paint and gasoline in city soil. *Environ. Sci. Technol.* **2021**, *55*, 7981−7989.

(26) Melosi, M. V. *Garbage in the Cities*; University of Pittsburgh Press, 2004.

(27) Hickman, H. L.*American Alchemy: The History of Solid Waste Management in the United States*; ForesterPress, 2003.

(28) Venable, W. M. *Garbage Crematories in America*; J. Wiley and Sons: NY, 1906.

(29) Hering, R.; Greeley, S. A. *Collection and Disposal of Municipal Refuse*; McGraw Hill Book Co.: NY, 1921.

(30) To talk about incinerator. *Durham Morning Herald*, April 28, 1913.

(31) *Refuse Collection Practice*; Committee on Refuse Collection and Disposal, American Public Works Association: Chicago, 1941.

(32) Aplet, J. A. H.; Conn, W. D. The uses of completed landfills. *Conservation and Recycling* **1977**, *1*, 237−246.

(33) Wang, Z.; Wade, A. M.; Richter, D. D.; Stapleton, H. M.; Kaste, J. M.; Vengosh, A. (2022). Legacy of anthropogenic lead in urban soils: Co-occurrence with metal (loids) and fallout radionuclides, isotopic fingerprinting, and in vitro bioaccessibility. *Science of The Total Environment* **2022**, *806*, 151276.

(34) Abdulmanov, R.; Miftakhov, I.; Ishbulatov, M.; Galeev, E.; Shafeeva, E. Comparison of the effectiveness of GIS-based interpolation methods for estimating the spatial distribution of agrochemical soil properties. *Environmental Technology and Innovation* **2021**, *24*, 101970.

(35) Ma, X.; Longley, I.; Gao, J.; Kachhara, A.; Salmond, J. A site-optimized multi-scale GIS based land use regression model for simulating local scale patterns in air pollution. *Sci. Total Environ.* **2019**, *685*, 134−149.

(36) Saha, A.; Gupta, B. S.; Patidar, S.; Martínez-Villegas, N. Optimal GIS interpolation techniques and multivariate statistical approach to study the soil-trace metal(loid)s distribution patterns in the agricultural surface soil of Matehuala, Mexico. *Journal of Hazardous Materials Advances* **2023**, *9*, 100243.

(37) USEPA Method 3052. Microwave assisted acid digestion of siliceous and organically based matrices, 1996. *USEPA*. www.epa.gov/sites/default/files/2015-12/documents/3052.pdf (accessed July 30, 2023).

(38) Morse, W. F. *The Collection and Disposal of Municipal Waste*; Municipal Journal and Engineer, 1908.

(39) *Committee on Refuse Collection. Refuse Collection Practice*, 2nd ed.; American Public Works Association, 1958.

(40) *Institute for Solid Wastes. Solid Waste Collection Practice*, 4th ed.; American Public Works Association: Chicago, 1975.

(41) *Waste Incineration and Public Health*; National Research Council: Washington, DC, 2000.

(42) de Berkeley Parsons, H. *The Disposal of Municipal Refuse*; John Wiley; NY, 1906.

(43) Steinberg, T. *Gotham Unbound*; Simon-Schuster: NY, 2014.

(44) Butler, C. R. *Lowcountry at High Tide: A History of Flooding, Drainage, and Reclamation in Charleston*; University of South Carolina Press, Columbia, SC, 2020.

(45) Kaiser-Schatzlein, R. *The History of New York, Told through Its Trash*; The New Yorker, 2021.

(46) Gooch, J. W. *Lead-Based Paint Handbook*; Plenum Press: NY, 1993.

(47) Brady, N.; Weil, R. *Nature and Properties of Soils*; Prentice Hall, 2016.

(48) A final Test Today at 4:30. *Durham Morning Herald*, February 9,1915.

(49) Council Oks downtown renewal step. *Durham Morning Herald*, April 21, 1965.

(50) Sites Were Inspected. *Durham Morning Herald*, July 29, 1914.

(51) City Aldermen Reelect School Board Members. *Durham Morning Herald*, April 21,1925.

(52) Incinerators Clogged by Trash. *Durham Morning Herald*, September 5, 1928.

(53) Inside Durham's Incinerator. *Durham Morning Herald*, December 18, 1951.

(54) Progress on Playground for Walltown Section. *Durham Morning Herald*, December 12, 1949.

(55) From Incinerator Site to Playground. *Durham Morning Herald*, September 16, 1950.

(56) Playground Dedication Program Set. *Durham Morning Herald*, June, 25, 1953.

(57) City Parks Have Undergone Thorough Face Lifting during Past Few Years. *Durham Morning Herald*, April 9, 1955.

(58) Health Board Heard Report. *Durham Morning Herald*, October 7, 1913.

(59) Hume, N. B. History of efforts at incineration in the Los Angeles area. *Journal of the Air Pollution Control Association* **1967**, *17*, 308−309.

(60) Melosi, M. V. Historic development of sanitary landfills and Subtitle D. *Energy Laboratory Newsletter* **1994**, *31*, 20−24.

(61) *Refuse Collection Practice*, 3rd ed.; Committee on Solid Wastes, Public Administration Service: Chicago, 1966.

(62) Energy Recovery from the Combustion of Municipal Solid Waste. *USEPA*. https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw (accessed July 30, 2023.

(63) Lead in our park. *Walltown Community Association*. https://www.walltown.net/ (accessed July 30, 2023).