RESEARCH ARTICLE

Curtailing Lead Aerosols: Effects of Primary Prevention on Soil Lead, Pediatric Exposures, and Community Health.

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Abstract:
Five decades after the US approval of the commercial use of leaded petrol, the US EPA began a phasedown of leaded petrol to prevent spoiling catalytic converters, mandatory on all new US cars in 1975. With prompting by citizens and the Minnesota legislature, the US Congress required the US EPA to enforce a rapid phasedown on 1 January 1986 until the final ban of leaded petrol for highway vehicles on 1 January 1996. This article reviews the outcomes of curtailing leaded petrol on the temporal and spatial changes of pediatric blood Pb and soil lead (Pb) in metropolitan New Orleans and beyond. In 2001, a soil Pb survey was completed for all census tracts of metropolitan New Orleans. In 2006, after major flooding by Hurricane Katrina, a preliminary survey of 44 census tracts showed that the median soil Pb and children's median blood Pb decreased across flooded *and* unflooded communities. In June 2017 a second survey was completed in all census tracts. Evaluation of pediatric blood Pb and soil Pb in matching census tracts (N=274) confirmed that curtailing leaded petrol diminished children's exposure and concurrently reduced soil Pb. The concurrent temporal and spatial declines of children's exposure and soil Pb were also observed in the Detroit Tri-County Area of Michigan. Curtailing leaded petrol was gradually accepted, and on 30 August 2021, 35 years after the US EPA phasedown, leaded petrol was banned by all nations. Eliminating leaded petrol was an essential step for primary Pb prevention of pediatric exposure and improving community health. Continuing efforts are required to reduce legacy-soil Pb that persists disproportionately in traffic congested, older, inner-city, urban areas, and other communities subjected to large inputs of Pb aerosols.

Keywords: blood lead decline; Cochrane collaboration; soil lead decline; mapping soil lead and blood lead; pediatric and community health; tetraethyl lead; leaded petrol lead aerosol

Prologue. *If a community is safe for children, then it is safe for everyone.* Anonymous public health professional, working to replace play area soil at a childcare center in Stockholm, Sweden.

1. Introduction

The World Health Organization reported in 2014, that over half, 54.6%, of the world population lived in cities, up from 34% in 1960[1]. Urban environments require systematic, longitudinal research to ensure human safety and environmental sustainability. Long-term studies are often conducted to comprehend the impact of cities on ecosystems. However, analyses of governmental policy on the resilience and sustainability of cities as human habitats are less common[2]. Lead (Pb) is an imperceptible and persistent toxicant. Lead aerosols, because of their small particle size (< 2.5 µm), when inhaled are a major risk factor to all cells and the cause of many ailments, including chronic neurological and cardio-vascular diseases in every age group[3-8].

In 1980, the National Academy of Sciences published a report, *Lead in the Human Environment*, that included a chapter by Clair Patterson that began, “Sometime in the near future it probably will be shown that the older urban areas of the United States have been rendered more or less uninhabitable by the millions of tons of poisonous industrial lead residues that have accumulated in cities during the past century. Babies are more susceptible…than are adults[9]”.

Patterson’s forebodings about Pb contamination were partly confirmed a few years later by an urban soil study which found an extreme disparity between the soil lead (SPb) in the inner-city compared to outer communities of metropolitan Baltimore, Maryland[10]. Subsequent studies in residential communities of Minnesota advanced the science by demonstrating a strong association between SPb and children’s blood Pb (BPb) in the context of city size and community location of within cities[11]. The studies of SPb and BPb by community confirmed Patterson’s premonitions.

The petrol additive tetraethyllead (TEL) was an especially potent source of Pb contamination in cities. TEL was introduced into commerce in the mid-1920s[12]. Its use became almost universal by 1950. Figure 1 shows the tonnages of Pb from vehicle use in North America and Europe grew exponentially through the 1950s, ‘60s, ‘70s, and peaked in 1975[13]. An estimate of quantities of aerosol Pb from TEL in the U.S. was 6 million tonnes with about 10,000 tonnes deposited in New Orleans[14]. The aerosol inputs of Pb-dust varied according to traffic flow and congestion with the automobile acting as a toxic substance delivery system. Traffic-associated TEL emissions caused a public health disaster that became international in scope[15,16].

In 1975 catalytic converters became mandatory on all new cars. TEL usage declined substantially after the introduction of catalytic converters, a pollution control device, necessitated the removal of Pb additives to prevent catalyst damage[17]. Realizing slow progress in the 1980s, the EPA implemented the rapid phase-down on 1 January 1986 which continued until the final ban of most leaded petrol for highway use (see Figure 1). This advanced primary prevention.

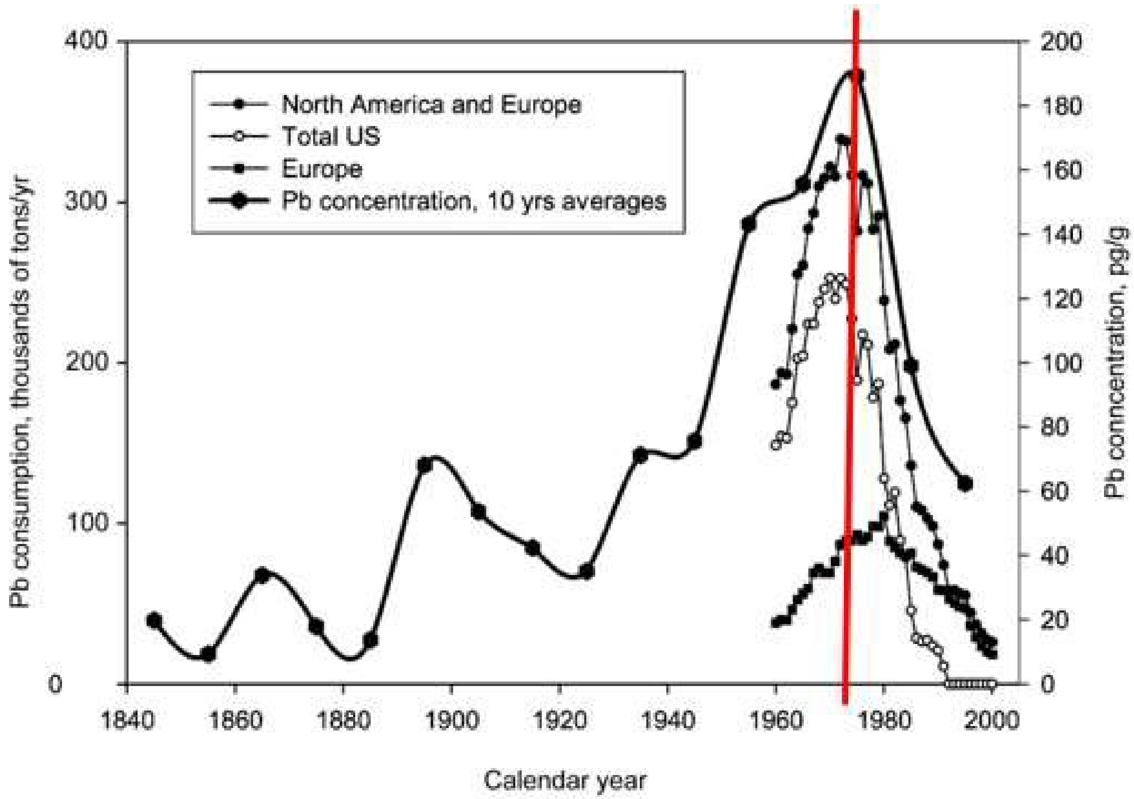

Figure 1. Rise and fall of lead aerosol deposition in Arctic ice before and after the 1975 introduction (red line) of unleaded petrol to protect the catalytic converter, modified from Krachler et al[13]. The stall in reduction in the US occurred in around 1982. Note that in Europe declines followed the US.

In the US, TEL is a legal product and still used in aviation gas or LL100 avgas (containing 0.56 g Pb per L) for piston engine aircraft. The US EPA estimates that avgas accounts for over 60% of the current Pb aerosol in the US[18,19]. An outcome of avgas is that BPb is higher for children living within 0.5–1 km of airports where avgas is used compared with children living 1 km beyond these airports[20]. Particularly concerning is the fact that all grades of leaded and unleaded petrol are transported through the same pipelines. To protect petroleum industry from liability due to Pb contamination of unleaded fuel, an allowable amount of TEL is permitted in unleaded petrol.

Current US CDC intervention efforts take place after individual children are identified with elevated BPb. This approach is secondary, and while it was important for this study, testing BPb is not primary prevention[21]. Cochrane Collaboration is an internationally recognized organization for evaluating the effectiveness of medical interventions[22]. Cochrane Collaboration reviewed the outcomes of US intervention methods which involve education and housecleaning after children are identified as Pb exposed. The review indicated that education and household cleanup methods are *ineffective* for treating Pb exposed children. The review also noted that the effect of SPb remediation and/or a combination of actions on children's exposure were not reviewed because not enough data exists[22]. We take exception to the lack of data. The studies in Minnesota and New Orleans are data-rich with community-by-community matching of SPb and pediatric BPb results. A preliminary study on 44 representative New Orleans communities showed positive effects of curtailing leaded petrol by reducing SPb and pediatric BPb[23,24].

The primary objectives of this manuscript are to update the preliminary study with up-to-date data about SPb and pediatric BPb results, to review changes in SPb and children's BPb in metropolitan New Orleans after the cessation of Pb aerosols from TEL additives in petrol for highway use, and report on a test of the concurrent SPb and BPb hypothesis beyond New Orleans.

2. Methods

Early New Orleans research was conducted at Xavier University of Louisiana from 1990 through April 2006. The research was then transferred to Tulane University. An initial SPb survey of 287 census tracts was first completed for metropolitan New Orleans in 1992, and it is not used in this study. The first survey used in this study was conducted in 1998 – 2001 for metropolitan New Orleans[25]. After Hurricanes Katrina and Rita, an abbreviated survey of 44 census tracts, illustrated in Fig. 2, performed as a preliminary study[23,24]. The second metropolitan New Orleans survey used in this study was of 285 census tracts was completed in 2017[26]. Two uncollected census tracts were fenced off after Hurricane Katrina by the US Department of Housing and Urban Development (HUD) accounts for the reduction from 287 to 285 census tracts. All surveys were conducted using the 1990 census tract boundaries[27]. Sections 2.1 – 2.6 describe protocols for the soil collection, soil extraction and analysis, and quality assurance and quality control procedures, along with the blood Pb surveys, and statistical analyses. The word "community" is used interchangeably with "census tracts."

2.1. Census tract map of metropolitan New Orleans.

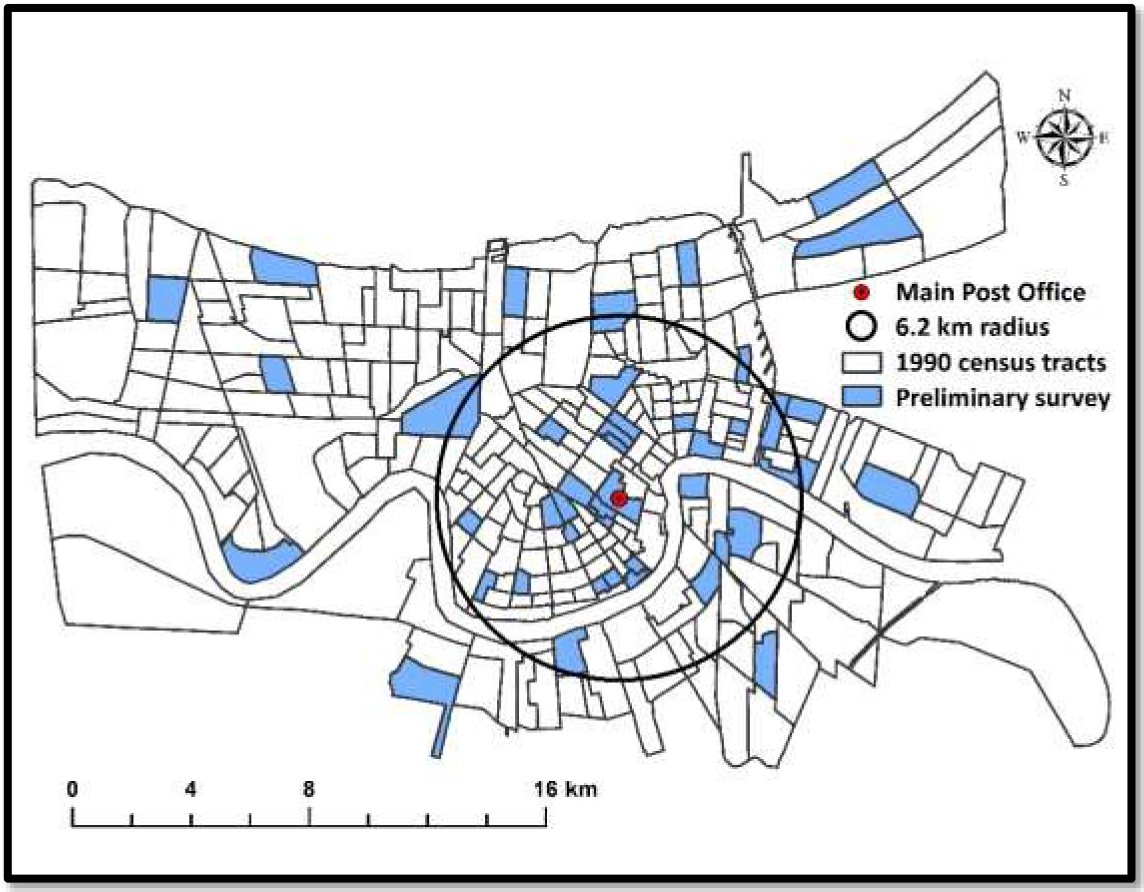

Figure 2 shows with a red dot the location of the Main Post Office (MPO) and the 1990 census tract boundary map used for the soil surveys. The 1998 – 2001 survey was completed on all 287 census tracts. An abbreviated sampling of 44 census tracts was done after the 2005 Hurricane Katrina/Rita flooding of New Orleans[23,24]. There were only 285 census tracts available for sampling in the 2013 – 2017 survey as described above[26].

2.2. Soil Collection

The soil samples were collected from the top 2–3 cm. For each census tract, 19 soil samples from 4 residential locations were systematically collected as follows: Within 1 m of residential roadsides (9 samples), within 1 m of busy streets (4 samples), within 1 m of homes (3 samples), and from open spaces away from homes and streets (3 samples)[25].

2.3. Soil Pb Extraction and Analysis

The collected soils were air-dried and sieved through a 2 mm mesh sieve (ASTM#10 stainless steel sieve). The protocol for extraction was tailored to manage large numbers of samples with maximum efficiency using minimum dilution and sample re-analysis in the following manner: To overcome the alkalinity and dilution issues, soil samples were extracted with 1 M nitric acid at a 1/50 ratio (400 mg soil plus 20 mL of 1M nitric acid) and shaken for two hours[25]. The soil to acid ratio maintained a low pH for extraction and decreased the need for multiple sample dilutions and reanalysis. The soil sample extracts were analyzed by Inductively

Coupled-Atomic Emissions Spectrometry (ICP-AES).

2.4. Soil Analysis Quality Assurance Quality Control (QAQC)

National Institute of Standards and Technology (NIST) traceable standards were used for ICP-AES calibration verification. Duplicate soil samples at a rate of 1 per census tract (N=287 or 285 as described above) were prepared and analyzed. In-house reference soil samples were included during analysis, and the SPb results for these were consistent across the surveys. All soil survey samples are archived at Tulane University.

2.5. Children's Blood-lead Data

Blood Pb monitoring data were managed by the Louisiana Office of Public Health's Louisiana Healthy Homes and Childhood Lead Poisoning Prevention Program (LHHCLPPP). The children's BPb monitoring program follows the protocols of the US Centers for Disease Control and Prevention (CDC) for collection, preparation, and analysis of pediatric BPb[28,29]. For each survey ≤ 6-year-old children's blood samples were collected by clinics throughout metropolitan New Orleans and analyzed for Pb. The BPb results were transferred to the LHHCLPPP. Our lab obtained the BPb data (unidentifiable as to individual children) from LHHCLPPP and coded by census tract. Of the 285 census tracts with matching SPb in the two surveys, 274 census tracts had five or more children with BPb results in the 2 surveys available for study. An elevated BPb is defined as equal to or above the 2012 reference value of ≥ 5 µg/dL[30]. The pre-Katrina BPb are from January 2000–August 2005 and the post-Katrina BPb are from 2011–2016. The BPb data for metropolitan New Orleans consists of 54,695 and 27,249, respectively, for the two surveys[26].

2.6. Statistical Analysis

The Multi-Response Permutation Procedures (MRPP) are a group of distance-based statistical tests that evolved from the early work of R.A. Fisher[31,32]. The model does not assume any specific data distribution, and the statistical model focuses on the actual data (without transformations, truncation, or other manipulation to "normalize" the data). Furthermore, the model treats data using ordinary Euclidian geometric spaces[33]. The probability value (*P*-value) associated with the MRPP is the proportion of all possible test statistic values under the null hypothesis that are less than or equal to the observed test statistic of the actual observations[34]. Table 1 lists various community characteristics and MRPP P-values of the differences between near and far distances for each characteristic. The Berry-Mielke universal $\mathfrak{R}$ (or Mielke's $\mathfrak{R}$) was calculated for the effect size between near and far distances. In addition, Table 2 lists Fisher's exact test results of the probability that SPb and BPb are associated for near vs. far communities. Cramér's V demonstrate the strength of the effect size for Fishers exact test [31].

3. Results and Discussion

3.1. Spatiotemporal changes in soil Pb in Metropolitan New Orleans.

Figure 3 shows the kriged census tract median soil SPb for the two surveys census during intervals of 13 – 18.8 years with a median of 15.5 years (N = 274).

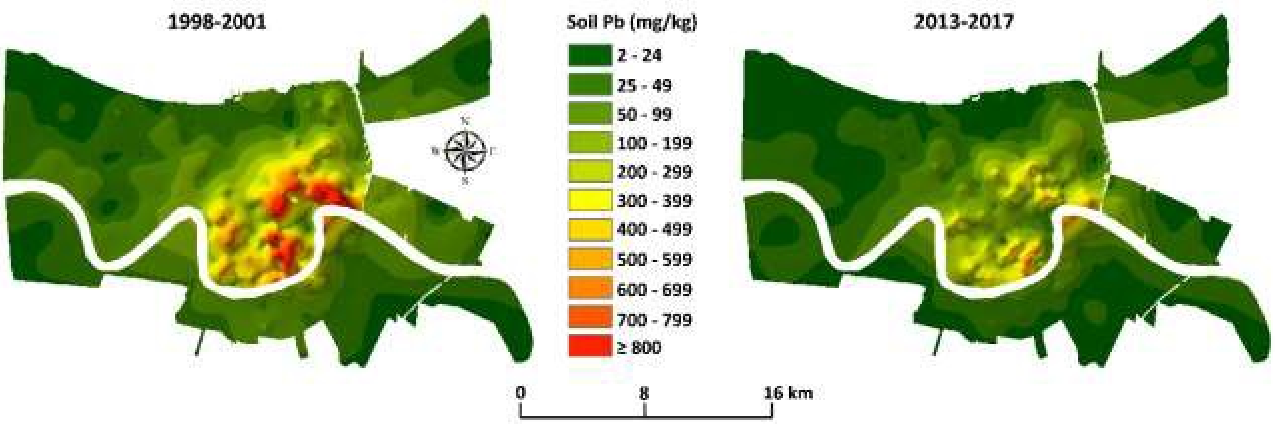

Figure 3. Maps of the Kriged soil Pb for 285 census tracts in this study illustrate the spatial-temporal 1998 – 2001 vs. 2013 – 2017 SPb spatiotemporal decrease between surveys[26].

3.2. Blood Pb relationship to soil Pb for two surveys in Metropolitan New Orleans

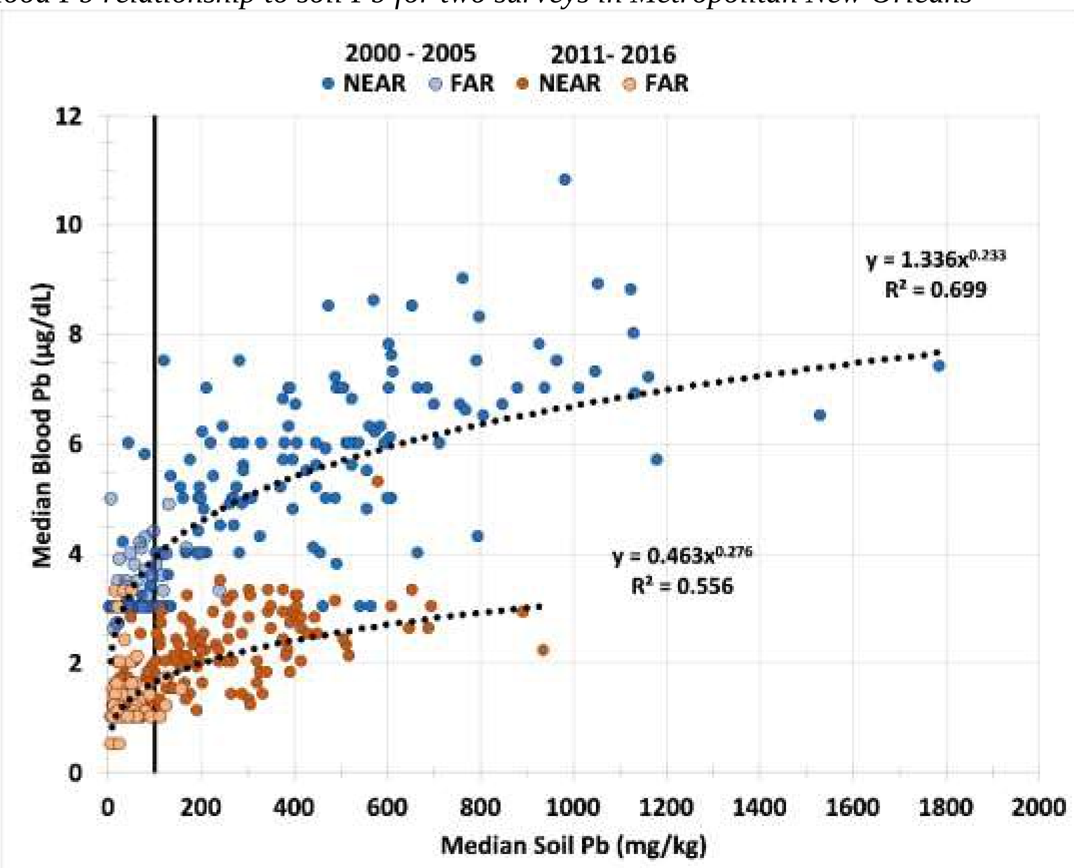

Figure 4 is redrawn from the PNAS study[26] and illustrates that BPb of children residing in the communities surveyed in 2000–2005 (blue) were substantially higher than children's BPb surveyed in the same communities in 2011–2016 (red)[26]. The dark blue and dark red dots represent the near communities, and the light blue and light red dots represent the far communities.

As described in section 2.5, BPb was collected by the Louisiana Office of Public Health in cooperation with the CDC. The children's BPb results are a critical component in the New Orleans studies because they are matched with SPb results by community in both surveys as shown in Figure 4. The Y axis shows the median children's blood Pb in communities for 2000 – 2005 (blue) compared with communities surveyed in 2011 – 2016 (red). The children's median BPb (Y axis) is paired with the corresponding median SPb (X axis)[26]. The New Orleans's children, through their BPb results are providing important information about their response to SPb in their immediate communities in the city.

Note that if pediatric BPb is below 100 mg/kg, then the curvilinear regression in both 2000-2005 (blue dots) and 2011 – 2016 (red dots) show a steep increase of blood Pb. The curvilinear relationship was first noted in an earlier study[36]. This result has bearing on the safe amount of SPb for children living in New Orleans. Most children are Pb safer when they live in communities with < 40 mg/kg Pb. Multiple characteristics are listed in Table 1 for New Orleans communities.

Table 1 lists data sorted by two distances, near and far, from the Main Post Office (MPO) for two different time periods. See Fig. 2. The table lists community characteristics for area, population density, SPb, children's BPb, race, and income associated with each distance[37]. The P-value indicates differences while Mielke's R is a measure of the effect size.

		Dist. MPO	Area	Pop.	White	Black	Other	SPb	BPb	Household
2000		km	km^2	km^2	%	%	%	mg/kg	µg/dL	Income US$
N	**Tracts (N)**	147	147	147	147	147	147	147	147	147
E	**Min.**	0.0	0.1	294	0.0	0.9	0.3	35	3.0	4,621
A	**Med.**	**3.8**	**0.6**	**3,892**	**23.0**	**72.7**	**3.1**	**410**	**5.7**	**21,981**
R	**Max.**	6.2	6.4	15,527	97.4	99.5	24.8	1774	10.6	109,721
2015										
	Tracts (N)	147	147	147	147	147	147	147	147	146
F	**Minimum**	6.2	0.5	22	0.0	0.0	0.0	6	2.1	16,250
A	**Med.**	**10.2**	**1.6**	**2,388**	**78.1**	**12.7**	**4.2**	**44**	**3.0**	**37,919**
R	**Max.**	20.9	18.8	6,476	98.7	100.0	21.5	237	5.0	146,158
	P-value	2.5×10^{-53}	1.7×10^{-26}	1.4×10^{-19}	5.2×10^{-14}	1.8×10^{-14}	4.3×10^{-5}	4.8×10^{-40}	2.1×10^{-42}	2.4×10^{-22}
	Mielke's ℜ	*0.425*	*0.143*	*0.127*	*0.130*	*0.138*	*0.028*	*0.349*	*0.411*	*0.149*
2000										
N	**Tracts (N)**	143	143	143	143	143	143	143	143	141
E	**Min.**	0.4	0.16	307	0.0	0.4	0.0	16	1.0	8,738
A	**Med.**	**3.9**	**0.64**	**2,813**	**40.8**	**51.5**	**4.4**	**187**	**2.1**	**30,917**
R	**Max.**	6.7	5.05	7,702	97.0	100.0	21.1	910	4.9	155,714
2015										
	Tracts (N)	143	143	143	143	143	143	143	143	143
F	**Min.**	6.7	0.46	98	0.0	0.0	0.0	6	0.5	18,114
A	**Med.**	**10.6**	**1.44**	**2,170**	**71.5**	**17.0**	**5.5**	**25**	**1.0**	**44,357**
R	**Max.**	20.9	18.65	6,900	99.4	100.0	24.9	127	3.3	161,250
	P-Value	4.2×10^{-53}	8.7×10^{-22}	1.2×10^{-9}	5.8×10^{-5}	2.0×10^{-5}	*0.016*	1.4×10^{-34}	2.6×10^{-35}	5.1×10^{-6}
	Mielke's ℜ	*0.437*	*0.115*	*0.062*	*0.036*	*0.042*	*0.010*	*0.301*	*0.335*	*0.035*

The relationships observed in two surveys of SPb and pediatric BPb, near and far distance from the Main Post Office in the center of Metropolitan New Orleans, and socioeconomic variables are listed in Table 1. The Mielke's ℜ effect size is strongest for distance in the case of SPb and BPb. The effect sizes are weaker for the other variables listed, as described in the following sections. To illustrate the data listed in Table 1, the raw data is treated as described in published research[37]. The graphs transparently exhibit the data and provides an opportunity for independent evaluation. Section 3.3 displays the effect of distance on SPb and BPb. Section 3.4 illustrates the distribution by race in near and far communities. The purpose of the graphs is to visualize the raw data along with statistical summaries for the 95% confidence interval of the median.

3.3. Soil Pb and blood Pb and near and far distance from the center of the city.

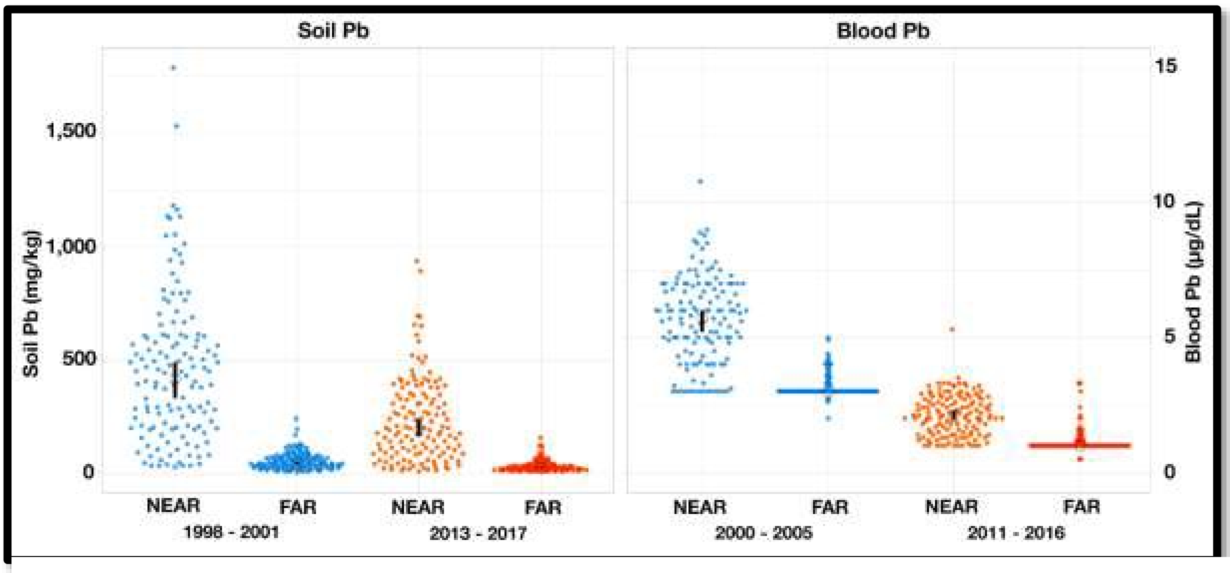

Figure 5. This graph summarizes median SPb (left panel) and median BPb (right panel) results for the two surveys as a function of near and far distance from the center of New Orleans (defined as the Main Post Office or MPO). The left scale is SPb in mg/kg and the right scale is children's BPb in µg/dL The black bars show the 95% confidence interval of the median[37,38].

Note the persistently higher quantities of SPb in the near communities of the city compared with far communities of the city. Observe the extraordinarily high pediatric Pb exposure in near communities in the 2000-2005 compared to 2011 – 2016. During 2000 – 2005 the 95% confidence interval exceeded the CDC reference value of 5 µg/dL. In 2011 – 2016, the 95% confidence interval of the median was about 3 µg/dL and below the CDC reference value. In both surveys the differences between the near and far communities remain consistent. In New Orleans, SPb and BPb are a function of distance from the center of the city. For BPb, the analytical sensitivity increased between 2000 – 2005 and 2011 – 2016[26].

3.4. Race, soil Pb, and blood Pb as a function of distance from the center of the city.

In addition to the associations between SPb and BPb living at near and far distances, there is also detailed public information about the racial makeup of the residents living in the near and far communities of Metropolitan New Orleans[37]. Descriptive statistics include medians and ranges for near and far communities are listed along with the

MRPP P-values and Mielke's R effect size results in Table 1.

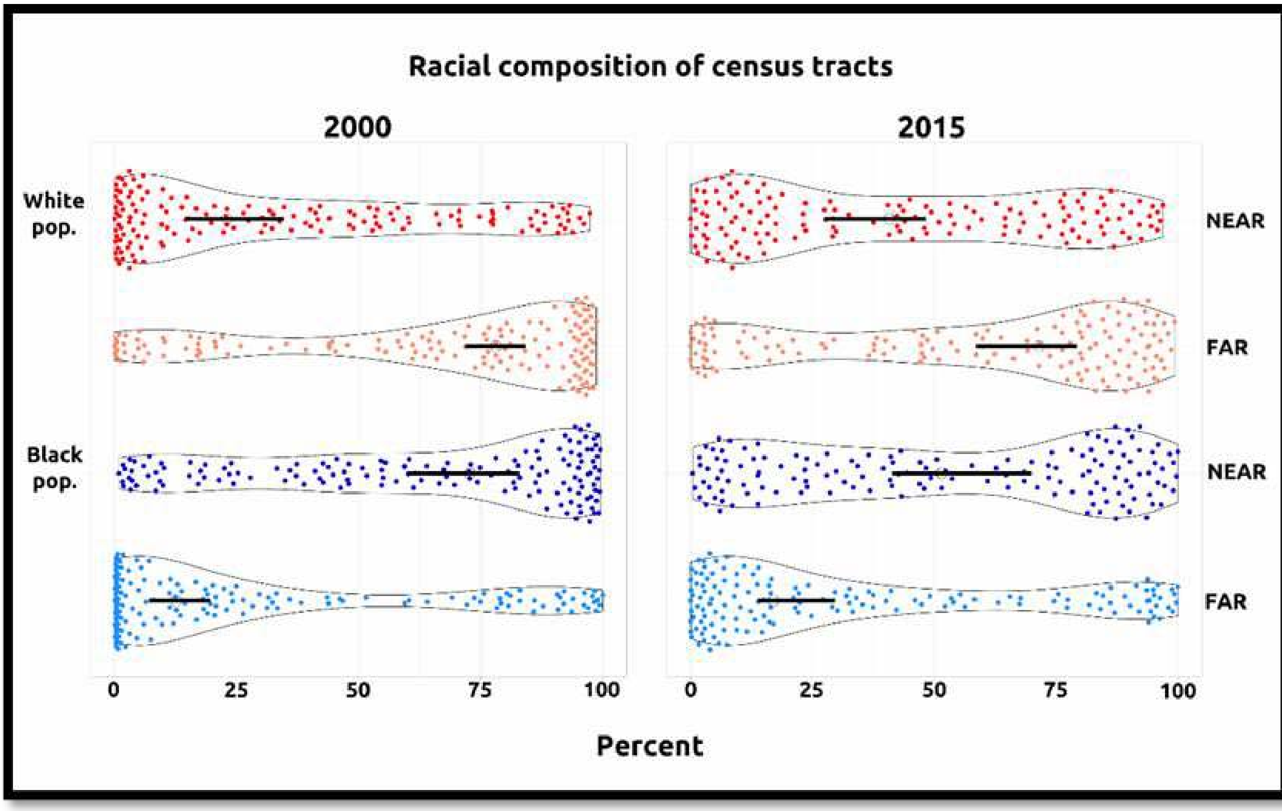

Figure 6 illustrates the data distribution for the White and Black populations living in near and far census tracts by race in Metropolitan New Orleans. The x-axis is percent, and the y-axis is race (left side) and near and far (right side) of the panels. The left panel is for 2000 and the right panel is for 2015. Each dot represents the median percent for race by census tract[37]. The graphs also include black bars for the 95% confidence interval of the median as calculated from the raw data[38].

Note that in the case of the White population, the percent is lowest in the near census tracts of the city and becomes clustered at high percentages for the far census tracts of the city. The percent Black population is clustered in the near census tracts of the city and only sparsely represented in the far census tracts of the city.

The results show that predominantly African-American communities, and presumably their children, are located nearer the center of the city where soil Pb is highest. Also, the predominantly White population, and their children, live in the far communities of New Orleans where the SPb is lowest. Table 1 and Figure 6 shows that the pattern of SPb and BPb exposure in 2015 underwent some moderation compared to the results observed in 2000

In the 2000 survey the disparity was largest between the high SPb communities and percentage of Black residents compared low SPb of communities with the highest percentages of White residents. Although the trend is attenuated in 2015 compared with 2000, the multiple pediatric and community health issues associated with Pb exposure are present[5-8]. The racial disparity is alarming for civil society[38]. For example, the collective personalities of adults are negatively influenced by the Pb exposures that occur during childhood[3].

Environmental justice is an important issue in urban settings. The accumulations and distribution of Pb in urban communities is a systemic and structural part of environmental justice and racism in cities. The disparity of SPb and BPb by socioeconomic characteristics must be acknowledged before there are possibilities of developing actions to address environmental justice

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3.5 Fishers exact test P-values and effect size of the association between BPb and SPb.

Table 2 shows the results for Fisher's exact test P-values of the associations between the explanatory variable, soil Pb, and the dependent variable, blood Pb, for two surveys. There were 274 census tracts with matching SPb and BPb results for the 2001 and the 2017. This Table is revised from Table 1 of the original publication[26]. The P-values are extremely small, and the Cramér's V demonstrates the high degree of strength of the effect size.

1998 - 2001		**BPb Census Tracts (N)**			
Med. 99 mg/kg	N	**< 3.6 µg/dL**	**≥ 3.6 µg/dL**	**P-value**	**Cramér's V**
HIGH SPb (~NEAR)	137	13	124		
LOW SPb (~FAR)	137	124	13	$4.0x10^{-46}$	0.810
2013 - 2017		**BPb Census Tracts (N)**			
Med. 54 mg/kg	N	**< 1.3 µg/dL**	**≥ 1.3 µg/dL**	**P-value**	**Cramér's V**
HIGH SPb (~NEAR)	137	24	113		
LOW SPb (~FAR)	137	110	27	$1.6x10^{-26}$	0.628

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The median SPb decreased from 99 mg/kg in 1998 – 2001 to 54 mg/kg in 2013 – 2017. Also, the median BPb declined from 3.5 µg/dL to 1.3 µg/dL during the interval between the two surveys. The Fisher exact test P-values are small ($< 10^{-26}$) and the Cramér's V value indicates a strong effect size between SPb and pediatric BPb especially for 1998 – 2001 and smaller but still a strong effect size for 2013 – 2017. Soil Pb and pediatric blood Pb are concurrently coupled. Also, the floods of metropolitan New Orleans by Hurricanes in August and September 2005, previously believed to a major event that decreased SPb and BPb in metropolitan New Orleans, is not as important as suggested[39]. Community SPb and BPb in both flooded and unflooded underwent the same concurrent decline of SPb and pediatric BPb[26].

If the extremely strong associations between BPb and SPb described in Table 1 and 2, and observations displayed in Figures 3 – 6 are valid, then all larger cities are expected to have a similar concurrent spatiotemporal decline in SPb and pediatric BPb. Fortuitously, a previous small 2001 survey provided an opportunity for a 2019 follow-up survey in the Detroit Tri-County Area[40]. The results for the Detroit Tri-County Area yielded the same of decline trends in SPb and pediatric BPb as observed in metropolitan New Orleans. As a result, we conclude that curtailing Pb aerosols is strongly related to declines of SPb and the continuing decreases of pediatric BPb [26.40].

3.6. The US EPA January 1, 1986, rapid phasedown of leaded petrol for highway use.

Figure 1 illustrates the rise and fall of Pb aerosols in Arctic ice which are directly related to lead aerosols from the use of leaded petrol[13]. The rapid decline of leaded petrol stalled around 1982 when the US EPA regulations were being relaxed. Based on early SPb and BPb studies in Minneapolis[41], a small group of citizens formed the Minnesota Lead Coalition and brought the Pb issue to the attention of state legislators. The group persuaded the Minnesota legislature to study the relationship between SPb and BPb across the state. The results indicated that pediatric Pb exposure depended on city size and community where children lived[11]. The legislature vote to ban leaded petrol in Minnesota, but that proved to be legally impossible. The federal government has jurisdiction over the formulation of petrol. It was illegal for the legislature to ban leaded petrol in Minnesota. The next action by the Minnesota Legislature was to petition Congress and the US EPA to ban leaded petrol. A hearing was arranged by David Durenberger US Senator of Minnesota for a 22 June 1984 hearing at the Capitol, Washington D.C. The first author, HWM, was invited to make the case for banning leaded petrol on behalf of the Minnesota Lead Coalition and the citizens of Minnesota. A copy of the Hearing and testimony is included in the references[42]. Figure 7 is a photograph taken at the hearing during the testimony.

Supporting the testimony were comments submitted to the US EPA from the Minnesota Lead Coalition. The comments were drafted by the late Patrick L. Reagan who undertook the writing task[43]. In response to the Senate hearing and comments, the US EPA promulgated the regulations for the rapid phasedown of leaded petrol to begin on January 1, 1986. The rapid phase-down regulation advanced the original 1996 date for the US EPA ban on leaded petrol by ten years.

Figure 7. Professor Howard W Mielke testifying on behalf of the Minnesota Lead Coalition on 22 June 1984 at the Airborne lead reduction act of 1984 hearing before the committee on environment and public works, United States Senate[42]. Note the soil samples near the base of the microphone.

To recapitulate, it may be audacious to suggest that early SPb and BPb studies in Minnesota sparked the global ban of leaded petrol. However, the attention of the Minnesota Legislature, under the leadership of Representative Ann Wynia, set in motion a study of SPb and BPb which demonstrated that leaded petrol was an issue for Minnesota. When the elected state lawmakers and officials realized they could not legislate on behalf of their own pediatric population to protect them from Pb aerosols and accumulated SPb in the Minnesota cities, they petitioned Congress and the US EPA to regulate on behalf of Minnesota citizens.

After the US EPA banned leaded petrol, and with leadership from the UN, other nations gradually acted to protect citizens from leaded petrol. The process of banning of leaded petrol took 35 years from the US EPA rapid phasedown in 1986 to the final ban by all nations in 2021[45].

For example, China banned leaded petrol in 2000 and pediatric Pb decreased in cities across the nation[44]. Algeria was the last nation to end the use of leaded petrol and on 30 August 2021, and the United Nations Environmental Programme hailed the global ban of leaded petrol for highway use in all nations[45].

The removal of TEL from highway vehicle petrol curtailed most of the Pb-dust inputs into cities. The sharp decrease of Pb aerosols had the immediate effect of reducing children's inhalation of Pb particles, with the effect of rapid reduction BPb[13,46-48]. When Pb aerosols declined, Pb deposition or Pb loading of the topsoil also decreased. Contaminated soil remains in residential communities as a source of continuing Pb exposure. The resuspension of soil sourced Pb aerosols is supported by a Pb isotope study conducted in London which found that Pb isotopes in aerosols in the 21st Century are the Pb isotopes found in petrol during the 20th Century[49]. On a seasonal basis, especially during late summer and fall, soil moisture becomes depleted and Pb particles become prone to resuspension into the air, accounting for BPb seasonality[50,51]. During winter months, BPb trends are lower and during late summer and fall BPb trends are higher[52-53].

After Pb aerosol deposition ceased, soils had a reprieve. Pb particles infiltrate to deeper soil horizons, accounting for a portion of the decrease of Pb in topsoil of metropolitan New Orleans communities. Support for this process is found in a study of Israel sandy soils along roadsides, and the three-decades of research in the Vienna Woods of declining atmospheric deposition of metals and decreases in soil Pb and foliage Pb at the study sites[54,55].

Topsoil ecosystems are teaming with lifeforms and biological processes such as bioturbation may explain topsoil Pb decreases in flooded as well as unflooded New Orleans communities[56-58]. The influences of physical and biological processes in urban topsoil require additional research to understand the ecological role by organisms to the resilience and sustainability of urban soils[2].

3.7. Legacy lead exposure and primary pediatric lead prevention.

In New Orleans near-city communities remain excessively contaminated from previous Pb uses. Children continue to experience excessive exposure to SPb as shown in the data illustrated in Figures 3 – 6. Lead exposure of children has dire long-term societal effects after exposure[59-61]. These studies support Patterson's prediction because of excessive residues from industrial use of Pb, cities have become too contaminated for safe human habitation. Grounded by the persistence of leaded petrol and its remobilization as atmospheric aerosols as shown in London[44], active cleanup of environmental sources such as

SPb is needed to prevent continued exposure of children, especially in older inner-city communities. In Norway, Rolf T. Ottesen was a strong advocate for mapping SPb and cleanup to prevent children's Pb exposure[62]. Soil intervention projects are underway in many cities to diminish urban Pb with proactive, primary prevention processes to reduce exposure to environmental sources and benefits to community health[63-65].

Epilogue. The pediatric blood Pb and soil Pb interventions support the prologue that *if a community is safe for children, then it is safe for everyone*. Conversely, *if communities are unsafe for children, then they are unsafe for everyone.*

5. Conclusions

Early urban soil Pb studies in Baltimore and pediatric blood Pb linked with soil Pb in Minnesota and New Orleans provide consistent evidence that leaded petrol accumulation in urban residential communities is fraught by a severe, invisible, public health issue that unequally affects the most susceptible citizens living in the most vulnerable communities. The amounts of Pb in soils of each community are associated with city size and community location near or far from the interior of the city. Children are the most vulnerable to Pb exposure, especially within communities near the center city soil Pb and pediatric Pb are highest. In New Orleans, the amount of lead in communities is declining concurrently in children's blood and in topsoils. The small P-values and large effect size of the concurrent declines of pediatric blood Pb and environmental soil Pb, indicates that the observations in New Orleans soils probably occur in other cities. This hypothesis was test in a follow-up study in the Detroit Tri-County Area where a similar pattern of decline was observed. Lead isotope evidence in London demonstrate that current Pb isotopes found in the air are linked to the environment that became contaminated with leaded petrol use during the 20th century. The use of leaded petrol for highway use was completely banned globally as of 30 August 2021.

The global response to leaded petrol shows that humanity can learn and fix mistakes that were made in the past. But the pace of the response was slow. It took 35 years from a formal US EPA response regarding the connection between leaded petrol and excessive pediatric exposure to globally ban of leaded petrol. The health of millions of children living in urban communities around the globe was tainted. Many communities contain excessively Pb contaminated soils, and these communities are frequently home to the most vulnerable, the poor, minority, and pediatric residents. Primary prevention cleanup is required to reduce population Pb exposure and thwart the disproportionately high Pb exposure of the most vulnerable populations. In addition, there are many invisible issues that affect the pediatric population. These include water fluoridation, lead in drinking water, multiple exotic organic substances and plastics, endocrine disrupting chemicals, loss of biodiversity, soil erosion, water degradation, and an accelerating rise in carbon dioxide (a monstrous issue), along with a catalogue of other issues that affect children's health. The existential question is whether humanity can learn and fix the litany of mistakes from the past that require more rapid responses than demonstrated by the 35-year global response to leaded petrol?

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Dedicated to the citizens of New Orleans who cooperated with the soil sampling surveys. The photo, Figure 7, was provided by David Durenberger, US Senator from Minnesota (1978 – 1994).

Author Contributions: H.W.M. conceived the revised project and drafted the manuscript. E.T.P. collected and extracted all soil samples for both surveys, and C.R.G. analyzed, organized, and mapped matching SPb and BPb in the 1998 – 2001 and 2013 – 2017 soil and blood lead surveys of New Orleans (Tables 1 and 2 and Figures 2 – 6).

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