Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2023, 11, 21-31
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Relationships among Environmental Lead in Playground Soils and Dust and Blood Lead of Children in Muncie, Indiana, USA

Abdulgadir Elnajdi*, Adam Berland, Carolyn Dowling, Jessi Haeft

Department of Environment, Geology and Natural Resources, Ball State University, Muncie, IN, USA
Email: *aaelnajdi@bsu.edu

How to cite this paper: Elnajdi, A., Berland, A., Dowling, C., & Haeft, J. (2023). Relationships among Environmental Lead in Playground Soils and Dust and Blood Lead of Children in Muncie, Indiana, USA. *Journal of Geoscience and Environment Protection, 11,* 21-31.
https://doi.org/10.4236/gep.2023.1110003

Received: September 19, 2023
Accepted: October 10, 2023
Published: October 13, 2023

Abstract

The present study was designed to assess lead levels in playground soil and accumulated dust on playground equipment and then correlate those environmental lead measurements with children's blood lead in the surrounding neighborhoods. Soil lead and surface dust were collected from 14 playgrounds in Muncie, Indiana, and blood lead levels were calculated for nearby children. Correlation analyses revealed a moderate positive association between dust Pb and soil Pb with a correlation coefficient $r = 0.46$ ($p = 0.099$). The relationship between settled dust on playground equipment and composite blood lead level also showed a medium positive correlation, indicated by $r = 0.36$ ($p = 0.202$). A positive correlation was also observed between soil Pb and composite blood lead values, as evidenced by $r = 0.51$ ($p = 0.061$). Furthermore, the assessment of spatial autocorrelation using Moran's I index indicated no significant spatial clustering for the variables studied (dust Pb, soil Pb, and blood Pb). Correlation analysis showed a connection between lead levels in soil and dust, but no significant links were found between soil lead and blood lead and between dust lead and blood lead. These results suggest that environmental lead in parks has a limited impact on children's blood lead levels nearby. Spatial autocorrelation analysis also revealed no significant spatial patterns among variables—dust, soil, and blood lead. Given these findings, it is recommended to seek expertise from qualified professionals and further perform comprehensive testing and analysis to investigate potential lead sources in children's blood. The outcomes of this study offer valuable insights into assessing playground environmental lead contamination, contributing to future research priorities in this area. Specifically, future studies could focus on collecting larger sample sizes and characterizing blood lead in children who frequently use playgrounds rather than those who live nearby but may or may not use the playgrounds.

Keywords

Heavy Metals, Public Health, Soil Contamination, Urban Parks, Health Risk Assessment

1. Introduction

The problem of lead contamination in urban playgrounds and parks is becoming increasingly recognized as a significant public health concern (Penteado et al., 2021), with studies continuously reporting on its prevalence and impact. A recent study by Azar (2021) noted the connection between lead in the blood and the increased concentration of soil lead in Muncie, Indiana, highlighting a lack of attention given to Pb contamination in areas where children play.

In recent years, investigations have revealed links between lead concentrations in dust and elevated blood lead levels (BLLs) in children. Taylor (2015) focused on the hazardous metals in environmental dust associated with bulk mineral transport in public playgrounds, revealing consistent contamination. A similar study by Peng et al. (2019) showed that the risk of elevated BLLs was six times higher due to dust exposure than playground soil exposure in Beijing.

Further back, studies such as Taylor et al. (2013) detailed the risks associated with lead smelter emissions, revealing a high rate of childhood lead poisoning linked to playground dust exposure. The focus on playgrounds as a significant source of exposure was also underlined by Gredilla et al. (2017), emphasizing the ingestion of dust particles through hand-to-mouth activity by children in publicly accessible playgrounds.

Earlier works by Bi et al. (2015), Caravanos et al. (2006), Papanikolaou et al. (2005) and Sánchez-Nazario et al. (2011) highlighted the dynamic nature of lead-contaminated dust in indoor and outdoor environments, suggesting a critical role in children's Pb exposure. The significance of dust as a lead source was also emphasized by studies from the early 2000s and late 1990s, including those by Charlesworth et al. (2011), Ng et al. (2003) and Wong and Mak (1997), respectively, which focused on urban dust and its inevitable contact with humans.

This evolving understanding of lead exposure builds on foundational research from the late 20th century, with scholars like Duggan et al. (1985) and Duggan (1980) revealing correlations between environmental Pb measurements and blood Pb in children in proximity to Pb smelting plants and earlier investigations by Thornton et al. (1994) and Rice (1992) detailing the heightened sensitivity of children to adverse health effects due to lead exposures.

Given the development of research in this field, this study aims to build upon these findings, focusing on the lead levels in playground soil and accumulated dust and their correlation to children's blood lead levels in the parks' vicinity, particularly in urban areas like Muncie, where there has been limited attention to Pb contamination. This study aims to 1) assess lead levels in playground soil and accumulated dust on playground equipment, 2) identify the correlation between environmental lead in soil and lead in dust, and 3) ascertain the relationship between environmental lead loadings and blood lead levels in children residing near parks. We hypothesize a tangible relationship between soil lead and dust lead, positing that lead-contaminated dust on playground equipment will result in elevated blood lead levels in children living near the parks.

2. Materials and Methods

2.1. Data Collection and Preparation

The study collected data components from three sources: dust, soil, and blood. Dust samples were obtained from 14 public playgrounds in Muncie (40.19˚N, 85.39˚W) during the Summer of 2021 using the wipe sampling method (**Figure 1**). This method commonly measures dust lead loading and indicates lead dust contamination. Dust loading, expressed in grams per unit area (g/m^2 or g/ft^2), represents the amount of dust on a surface. Multiplying the Pb concentration by the dust loading gives a Pb loading value, expressed in micrograms of Pb per unit area (μg/m^2 or μg/ft^2).

The dust samples were collected by sweeping the surfaces of playground equipment using surface wipes. The selected surfaces were exposed to the surroundings and not disturbed by playground users. Surface areas were marked with masking tape, and their dimensions were measured before sampling. Multiple points on the playground equipment were sampled, with at least five

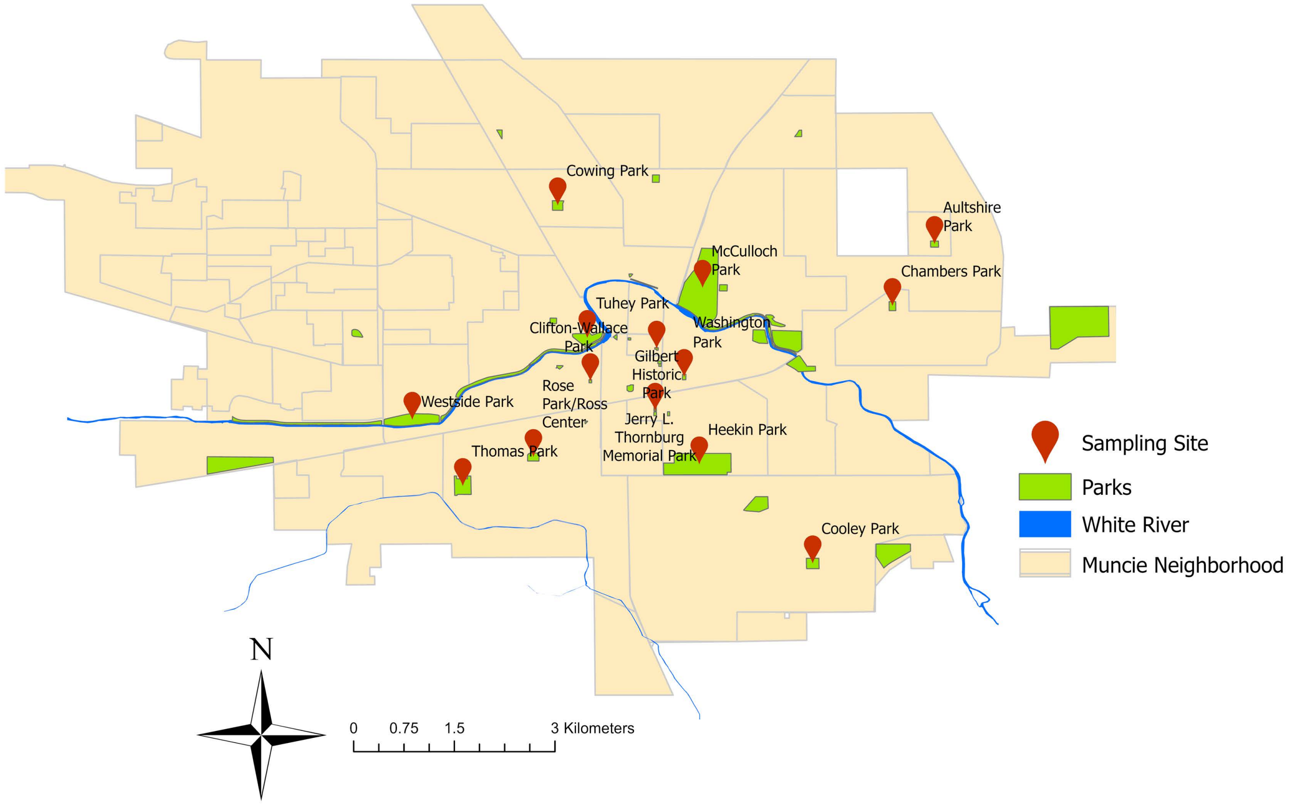

Figure 1. Sampling sites in Muncie parks.

subsamples combined to create one sample. Criterion Laboratories, Inc. analyzed the dust samples using Method CLI 442, adapted from EPA Method 3050 A and NIOSH 9100. Lead surface wipes were analyzed using Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES).

For soil analysis, samples were obtained from accessible locations without hard standing or vegetation cover using a soil sampler probe. The probe was rinsed with deionized water before and after use. Five subsamples were collected from each site and combined to create a ~150 g aggregate soil sample for each playground. The soil samples were air-dried, sieved (2 mm), and homogenized. They were then sent to a Geochemical Testing lab in Pennsylvania. The samples were microwave digested following EPA 3050B, and the concentrations of Pb in the digestion solutions were quantified using EPA 6010D Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES).

This study utilized blood data from the Regenstrief Institute in Indiana, covering a period from 2014 to 2018 for children aged 0 to 5. A total of 1060 blood samples were collected and analyzed. For children aged 6 to 17, the study utilized data from 1992 to 2017, consisting of 87 samples. The study adhered to the protocols outlined in BSU's IRB Protocol #1181099-2 to ensure patient protection. The collected data included date, age, race, location, and blood test results.

2.2. Inverse Distance Weighting (IDW)

This study implemented Geographic Information System (GIS) techniques to assess each site's composite blood lead levels. The focus was to glean insights into the spatial variability of blood lead levels and discern patterns that may be relevant for public health interventions. Blood lead levels were interpolated using Inverse Distance Weighting (IDW) with a 10-meter output cell size. IDW was selected for its capacity to generate a smooth surface over the entire study area based on the known values from blood test sample points. It is particularly apt for this study as it assumes that the influence of blood lead levels decreases with distance, allowing for a nuanced interpolation between sample points.

We set the IDW power to 2 to emphasize the influence of nearer points more than the distant ones, reflecting the assumption that closer locations will have more similar blood lead levels due to the localized nature of lead contamination and its effects. To account for varying sample densities across the study area, a variable search radius was applied to incorporate the twelve nearest sample points. Subsequently, the interpolated value at each playground location was extracted to serve as that park's composite blood lead level. This approach aligns cohesively with the study's objective to effectively assess and portray the spatial distribution of blood lead levels, offering insights into potential areas of concern and aiding in developing targeted intervention strategies.

2.3. Global Spatial Autocorrelation Analysis

Global spatial autocorrelation analysis was implemented using the Moran's I index (Griffith, 1987) to quantify the extent of spatial clustering in attribute variables across the study area. Moran's I was calculated separately for soil Pb, dust Pb, and blood Pb. We used inverse distance weighting with no distance threshold to implement the analysis. This analysis indicates whether values at sample points exhibit a clustered vs random spatial pattern. Moran's I value ranges from approximately 1 to −1. A positive index indicates spatial clustering of similar sample values, index values near zero indicate a random pattern and negative index values indicate spatial dispersion of similar sample values.

2.4. Correlation Analysis

The data was analyzed statistically utilizing SPSS Statistics software (IBM, USA). This involved conducting Pearson product-moment correlation analysis and calculating the linear relationship between three variables, namely soil Pb, dust Pb, and blood Pb.

3. Results and Discussion

3.1. Lead Concentrations in Soil, Dust, and Blood

Table 1 summarizes the results of the lead analysis of soil and dust samples in the Muncie parks. Lead concentrations are between 19 and 205 mg/kg-dry of soil and between 1.78 and 7.36 μ/ft^2 of dust samples. The spatial distributions of dust, soil, and blood lead levels across Muncie are shown in **Figures 2-4**, respectively.

Table 1. Summary of blood lead levels (BLLs), dust lead, and soil lead results.

No.	Park Names	Composite BLL (mg/dL)	Dust Pb (μ/ft^2)	Soil Pb (mg/kg-dry)
1	Rose Park	3.01	5.7	78.16
2	Tuhey Park	2.25	3.2	100.16
3	Thomas Park	2.82	7.3	61.5
4	Cowing Park	2.95	1.5	35.72
5	McCulloch Park	3.26	1.9	78.9
6	Washington Park	4.6	4.1	37.1
7	Chambers Park	1.78	2.1	19.6
8	Cooley Park	3.25	1.1	29.5
9	Heekin Park	7.36	2.8	77.7
10	Clif Walla Park	4.14	6.5	190.63
11	Westside Park	5	2.8	174.22
12	Aultshire Park	3.2	1.6	31.88
13	Jerry Me Park	4.44	3.3	36.4
14	GilbHis Park	2.28	4.8	205

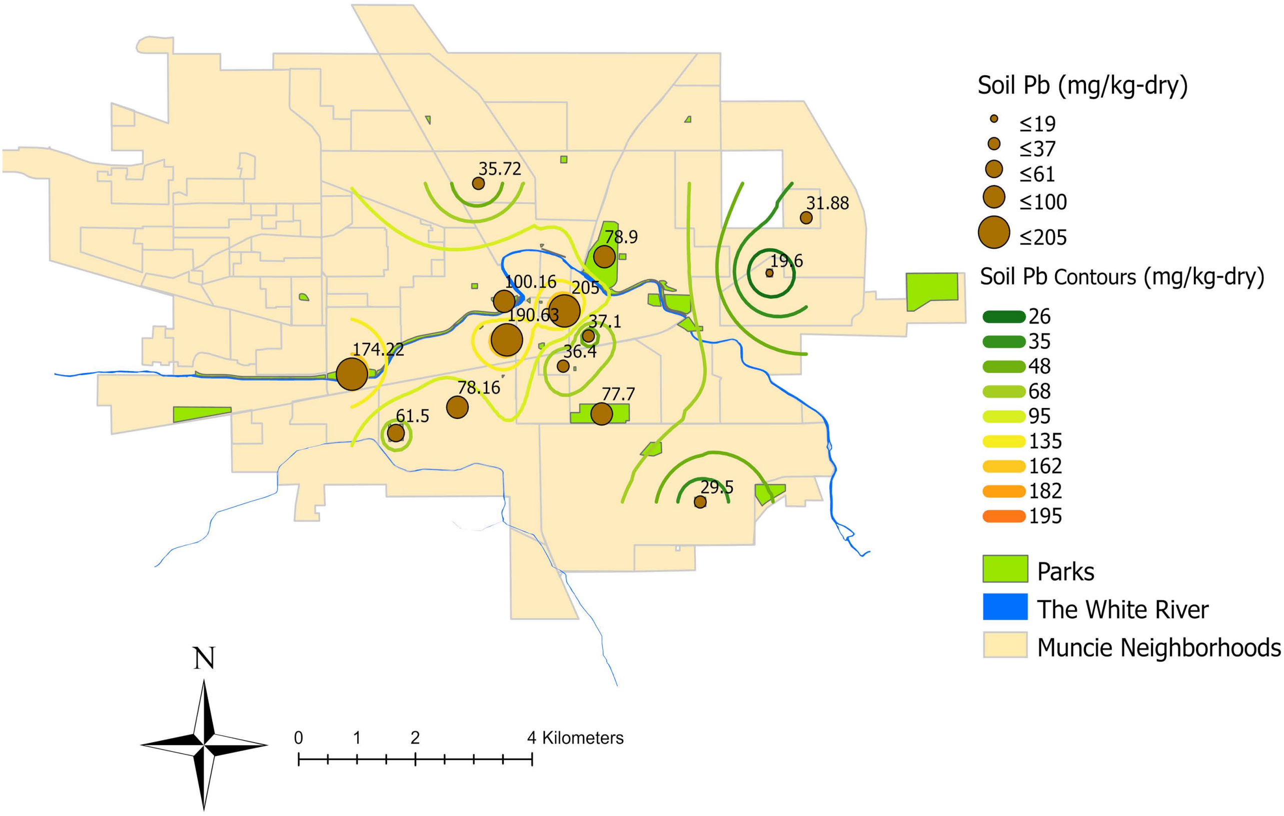

Figure 2. The spatial distributions of soil lead concentration across Muncie parks.

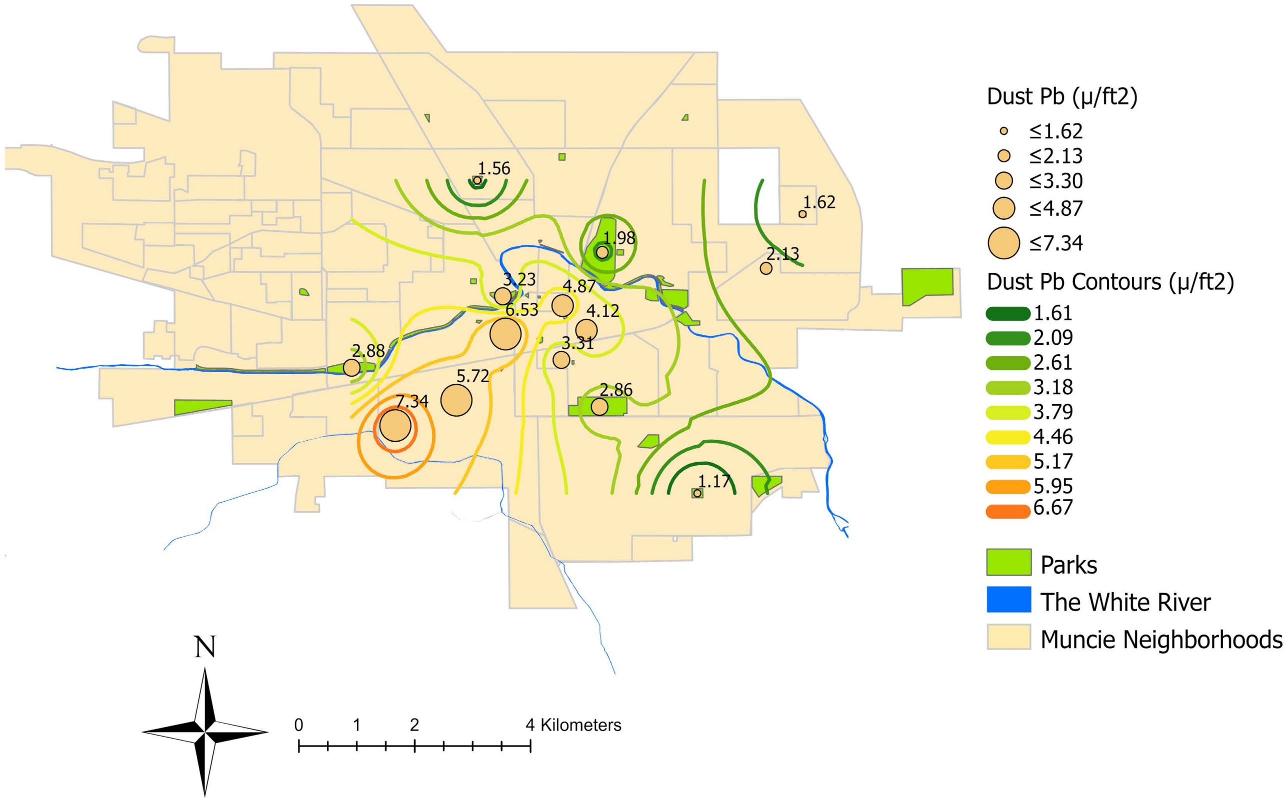

Figure 3. The spatial distributions of dust lead concentration across Muncie parks.

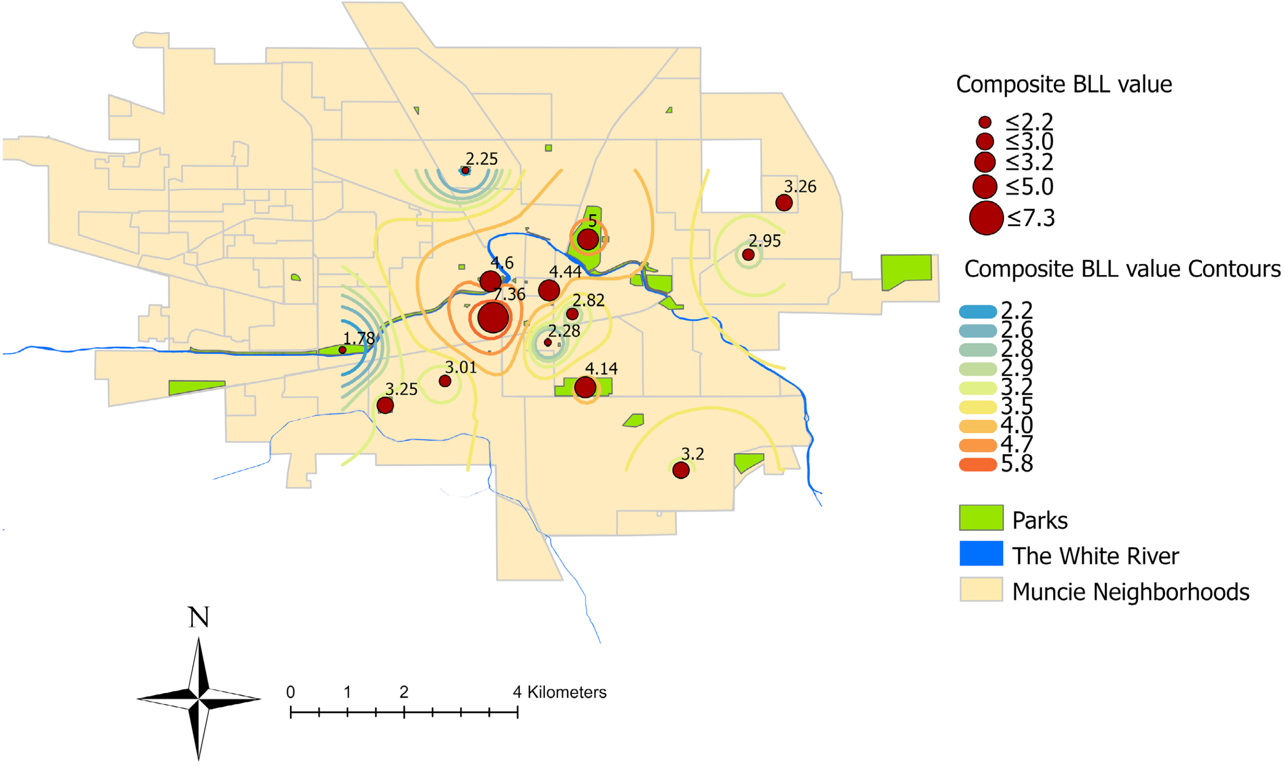

Figure 4. The spatial distributions of blood lead concentrations for children living near Muncie parks.

3.2. The Correlation Results

We calculated the correlation coefficient between soil lead, dust lead, and blood lead data for children ages 0 to 17 who live near the parks. The results revealed modest, positive correlations among dust, soil, and blood lead levels suggesting that the soil of the park and the settled dust on playground equipment may influence the blood lead levels of neighborhood children (**Table 2**). In detail, we observed a moderate, positive correlation between the variables dust Pb and soil Pb (r = 0.46, p = 0.099). There was a positive correlation coefficient between dust on playground equipment and composite blood lead level (r = 0.36). Still, the p-value (0.202) indicated this correlation was insignificant, presumably due to the small sample size. Furthermore, there is a positive correlation between the variables soil Pb and composite blood lead values with (r = 0.51, p = 0.061).

3.3. Spatial Autocorrelation (Global Moran's I) Results

The Moran's I index of dust Pb, soil Pb, and blood lead were 0.12, −0.048, and 0.046, respectively. The corresponding p-values were 0.84, 0.15, and 0.35 indicating that none of the variables exhibit statistically significant spatial clustering. Therefore, we cannot conclude with certainty that there are significant spatial clustering or dispersion patterns in the distribution of these variables. It is unclear whether patterns would be observed if larger sample sizes could be obtained to increase statistical power.

Table 2. Pearson correlation coefficients (r) between environmental lead measures and blood lead Levels.

		Dust Pb	Soil Pb	Composite BLL value
Dust Pb	Correlation	1	0.46	0.36
	p (2-tailed)		0.099	0.202
Soil Pb	Correlation	0.46	1	0.51
	p (2-tailed)	0.099		0.061
Composite BLL value	Correlation	0.36	0.51	1
	p (2-tailed)	0.202	0.061	

3.4. Discussion

In this study, there were associations between environmental lead and blood lead, but there was no clear evidence that Pb in playground dust or soil were contributors to blood levels for children living near the parks. This conclusion challenges the hypothesis that dust lead concentrations directly contribute to blood lead levels in children. There are several possible reasons why lead dust did not contribute significantly to blood lead levels in this study.

First, while public parks were sampled broadly across Muncie (**Figure 1**), relatively small sample sizes likely inhibited the ability to detect significant patterns in the data.

Second, we observed relatively low lead levels in dust and soil. EPA has reduced the standard for lead in dust from 40 (μg/ft^2) to 10 μg/ft^2 for floors and from 250 μg/ft^2 to 100 μg/ft^2 for windowsills (EPA, 2021). The EPA's reduction of the lead standard in dust has important implications. It reflects an increased awareness of the health risks associated with lead exposure, particularly for children. Lowering the acceptable levels aims to protect the public from developmental delays and other adverse effects. The revised standards also improve indoor environmental quality by minimizing lead hazards on floors and windowsills. Establishing stricter limits makes identifying and addressing areas with elevated lead levels easier, promoting safer living conditions and demonstrating a commitment to reducing lead exposure (EPA, 2021).

Third, soil lead can contaminate a larger surface area compared to dust lead. As noted by Laidlaw et al. (2012), lead contamination in soil can extend beyond the immediate vicinity of the park or playground, spreading into surrounding areas. This broader contamination increases the likelihood of exposure to lead through multiple pathways, such as direct soil ingestion, inhalation of soil particles, or transfer of soil to hands and subsequent hand-to-mouth contact (Laidlaw et al., 2012).

Although the lead levels in the dust and soil of playground parks may be relatively low, they still present a significant risk to children. This is because there is no safe level of lead in the environment where kids play and can be exposed to lead (Vorvolakos et al., 2016). It is important to note that the low lead levels observed in these parks may be attributed to various factors, such as practical remediation efforts, regular maintenance, or low lead levels in the surrounding environment. Second, children may have limited exposure to these pollutants, even if lead-containing dust and soil are present in park playground. For example, if dust and soil are not easily accessible to children or if children do not frequently swallow or inhale dust or soil while playing, lead exposure may be minimal. Also, the age and behavior of children can affect their exposure to lead. Younger children who are more likely to engage in hand-to-mouth conduct and spend more time crawling or playing on the ground may have more exposure to lead than older children who are less likely to engage in these behaviors. Furthermore, lead ingestion can be reduced when children and guardians exercise good hygiene habits, such as regular hand washing before eating, drinking, and playing (Rhoads et al., 1999).

Other environmental sources of lead could influence blood lead levels in children. Our study focused on outdoor dust and soil lead concentrations, but indoor dust lead concentrations could also significantly contribute to blood lead levels in children (Lanphear & Roghmann, 1997). These could include lead-based paint in nearby buildings, lead-contaminated water from old plumbing systems, or consumer products that contain lead. Other environmental factors can impact the bioavailability and mobility of lead in dust and soil, such as soil characteristics, climate, weather conditions, and geographical location, which can, in turn, influence the potential for lead exposure in children.

However, we must know that the absence of a significant contribution of dust lead from park playgrounds to blood lead levels in children may not imply that these sources are completely safe. It is still important to regularly monitor and control possible lead exposure risks in playgrounds and other environments where children play to ensure their health and safety.

4. Conclusion

Lead was sampled in soil and dust from 14 parks in Muncie to understand whether environmental lead exposure is correlated with blood lead levels from children living near parks. Correlation analysis showed an association between the soil and dust lead concentrations, and we observed no statistical relationship between soil lead and blood lead or between dust lead and blood lead. The correlation results suggest that environmental lead in parks did not contribute significantly to blood lead levels for children living nearby. Also, based on the spatial autocorrelation analysis, none of the variables (dust Pb, soil Pb, and blood Pb) show statistically significant spatial clustering or dispersion patterns. While this study did not show clear connections between environmental lead and blood lead levels, local regulations and guidelines should be followed to minimize health risks. If there are concerns about lead exposure, consulting with qualified experts and conducting thorough testing and analysis is recommended for additional investigation to explore possible lead sources in children's blood.

Fund

This study received support from Ball State University's Department of Environment, Geology, and Natural Resources and a Geology & Health Scientific Division Student Research Grant from The Geological Society of America.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Azar, B. (2021). *An Analysis of Soil and Blood Lead Samples in Delaware County, East Central, Indiana*. MS Thesis, Ball State University.

Bi, X., Li, Z., Sun, G., Liu, J., & Han, Z. (2015). *In Vitro* Bioaccessibility of Lead in Surface Dust and Implications for Human Exposure: A Comparative Study between Industrial Area and Urban District. *Journal of Hazardous Materials, 297,* 191-197. https://doi.org/10.1016/j.jhazmat.2015.04.074

Caravanos, J., Weiss, A. L., & Jaeger, R. J. (2006). An Exterior and Interior Leaded Dust Deposition Survey in New York City: Results of a 2-Year Study. *Environmental Research, 100,* 159-164. https://doi.org/10.1016/j.envres.2005.08.005

Charlesworth, S., De Miguel, E., & Ordóñez, A. (2011). A Review of the Distribution of Particulate Trace Elements in Urban Terrestrial Environments and Its Application to Considerations of Risk. *Environmental Geochemistry and Health, 33,* 103-123. https://doi.org/10.1007/s10653-010-9325-7

Duggan, M. (1980). Lead in Urban Dust: An Assessment. *Water, Air, and Soil Pollution, 14,* 309-321. https://doi.org/10.1007/BF00291844

Duggan, M., Inskip, M., Rundle, S., & Moorcroft, J. (1985). Lead in Playground Dust and on the Hands of Schoolchildren. *Science of the Total Environment, 44,* 65-79. https://doi.org/10.1016/0048-9697(85)90051-8

EPA (2021). *Hazard Standards and Clearance Levels for Lead in Paint, Dust and Soil.* TSCA Sections 402 and 403, Volume 86 FR 983.

Gredilla, A., Fdez-Ortiz de Vallejuelo, S., Gomez-Nubla, L., Carrero, J. A., de Leão, F. B., Madariaga, J. M., & Silva, L. F. (2017). Are Children Playgrounds Safe Play Areas? Inorganic Analysis and Lead Isotope Ratios for Contamination Assessment in Recreational (Brazilian) Parks. *Environmental Science and Pollution Research, 24,* 24333-24345. https://doi.org/10.1007/s11356-017-9831-6

Griffith, D. (1987). *Spatial Autocorrelation: A Primer.* Association of American Geographers: Resource Publications in Geography.

Laidlaw, M. A. S., Zahran, S., Mielke, H. W., Taylor, M. P., & Filippelli, G. M. (2012). Re-Suspension of Lead Contaminated Urban Soil as a Dominant Source of Atmospheric Lead in Birmingham, Chicago, Detroit and Pittsburgh, USA. *Atmospheric Environment, 49,* 302-310. https://doi.org/10.1016/j.atmosenv.2011.11.030

Lanphear, B. P., & Roghmann, K. J. (1997). Pathways of Lead Exposure in Urban Children. *Environmental Research, 74,* 67-73. https://doi.org/10.1006/enrs.1997.3726

Ng, S. L., Chan, L. S., Lam, K. C., & Chan, W. K. (2003). Heavy Metal Contents and Magnetic Properties of Playground Dust in Hong Kong. *Environmental Monitoring and Assessment, 89,* 221-232. https://doi.org/10.1023/A:1026103318778

Papanikolaou, N. C., Hatzidaki, E. G., Belivanis, S., Tzanakakis, G. N., & Tsatsakis, A. M.

(2005). Lead Toxicity Update. A Brief Review. *Medical Science Monitor, 11,* RA329-336. https://pubmed.ncbi.nlm.nih.gov/16192916/

Peng, T., O'Connor, D., Zhao, B., Jin, Y., Zhang, Y., Tian, L., Zheng, N., Li, X., & Hou, D. (2019). Spatial Distribution of Lead Contamination in Soil and Equipment Dust at Children's Playgrounds in Beijing, China. *Environmental Pollution, 245,* 363-370. https://doi.org/10.1016/j.envpol.2018.11.011

Penteado, J. O., de Lima Brum, R., Ramires, P. F., Garcia, E. M., dos Santos, M., & da Silva Júnior, F. M. R. (2021). Health Risk Assessment in Urban Parks Soils Contaminated by Metals, Rio Grande City (Brazil) Case Study. *Ecotoxicology and Environmental Safety, 208,* 111737. https://doi.org/10.1016/j.ecoenv.2020.111737

Rhoads, G. G., Ettinger, A. S., Weisel, C. P., Buckley, T. J., Goldman, K. D., Adgate, J., & Lioy, P. J. (1999). The Effect of Dust Lead Control on Blood Lead in Toddlers: A Randomized Trial. *Pediatrics, 103,* 551-555. https://doi.org/10.1542/peds.103.3.551

Rice, D. (1992). Behavioral Impairment Produced by Developmental Lead Exposure: Evidence from Primate Research. *Human Lead Exposure,* 138-152.

Sánchez-Nazario, E. E., Mansilla-Rivera, I., Derieux-Cortés, J.-C., Pérez, C. M., & Rodríguez-Sierra, C. J. (2011). The Association of Lead-Contaminated House Dust and Blood Lead Levels of Children Living on a Former Landfill in Puerto Rico. *Puerto Rico Health Sciences Journal, 22,* 153-159. https://pubmed.ncbi.nlm.nih.gov/12866140/

Taylor, M. P. (2015). Atmospherically Deposited Trace Metals from Bulk Mineral Concentrate Port Operations. *Science of the Total Environment, 515,* 143-152. https://doi.org/10.1016/j.scitotenv.2015.02.010

Taylor, M. P., Camenzuli, D., Kristensen, L. J., Forbes, M., & Zahran, S. (2013). Environmental Lead Exposure Risks Associated with Children's Outdoor Playgrounds. *Environmental Pollution, 178,* 447-454. https://doi.org/10.1016/j.envpol.2013.03.054

Thornton, I., Watt, J. M., Davies, D. J. A., Hunt, A., Cotter-Howells, J., & Johnson, D. L. (1994). Lead Contamination of UK Dusts and Soils and Implications for Childhood Exposure: An Overview of the Work of the Environmental Geochemistry Research Group, Imperial College, London, England 1981-1992. *Environmental Geochemistry and Health, 16,* 113-122. https://doi.org/10.1007/BF01747907

Vorvolakos, T., Arseniou, S., & Samakouri, M. (2016). There Is No Safe Threshold for Lead Exposure: A Literature Review. *Psychiatriki, 27,* 204-214. https://doi.org/10.22365/jpsych.2016.273.204

Wong, J., & Mak, N. (1997). Heavy Metal Pollution in Children Playgrounds in Hong Kong and Its Health Implications. *Environmental Technology, 18,* 109-115. https://doi.org/10.1080/09593331808616518