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A study on the implications of redlining, greenspace density, housing age, and income on heavy metal soil contamination

Werbach P

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Abstract
Correlations between heavy metal contamination of soil, greenspace density, age of housing, redlining, and income in San Francisco were determined. The original hypothesis was that a strong, direct relationship existed between low-income neighborhoods and high heavy metal concentrations in soil. Twenty-five soil samples were collected from each of four neighborhoods– two above the citywide median income level and two below– making up 100 samples. Soil samples were collected with a focus on high-contact areas, such as parks. Neighborhoods were determined based on median household income, racial makeup, percent below the poverty level, history with redlining, and average education levels. The two low-income communities included were Bayview-Hunters Point (HP) and Chinatown (CT), while the high-income neighborhoods were Presidio Heights/the Presidio (PH) and Potrero Hill (PoH). The major heavy metals tested for were lead (Pb), arsenic (As), uranium (U), and thorium (Th) with an X-Ray Fluorescence Analyzer. Results indicated that PoH had the largest average Pb level at 287 ppm, with PH having the second largest at 211 ppm. The maximum recommended Pb soil contamination level in California is 80 ppm. CT and HP mean Pb levels were found to be at 78 and 125 ppm. These results suggest that heavy metal soil contamination had a stronger, positive correlation to older housing and high greenspace density than income, as neighborhoods with both older housing and higher greenspace density were found to be the most contaminated. Although a clear correlation was not found between redlining and soil contamination, the study produced positive results about the soil safety of two industrial or high-density neighborhoods, HP and CT, while drawing attention to the unsafe heavy metal levels in PH and PoH soil and highlighting a previously unconsidered pattern.

Keywords
Greenspace density, Redlining, San Fransisco, Heavy metal contamination, Soil, High density neighborhood, Presidio Heights, Potrero Hill, Bayview-Hunters point, Chinatown

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Pearl Werbach, Lawrence Hall of Science, 1 Centennial Dr, Berkeley, CA 94720, USA.
pearlwerbach@gmail.com

Introduction

In the 1930s, the Home Owners' Loan Corporation composed maps of San Francisco that ranked each neighborhood from most to least desirable, or from first to fourth grade (1). These maps were made to assist banks in determining which neighborhoods were safer to invest in but discriminated against neighborhoods with higher numbers of people of color, Black people primarily (1). Although today the 20th-century American practice of excluding people of color from home ownership is illegal, it has lasting detrimental implications on the people in historically redlined communities through their respiratory and cognitive health, access to resources, expected lifespan, and other facets of life (2, 3). Redlined communities are exposed to higher levels of air contaminants such as $PM_{2.5}$ and NO_2 as a result of the preferential industrial development in these communities, making residents of redlined areas 2.4 times more likely to go to the hospital for asthma (1, 4, 5). Within San Francisco, African Americans suffer a disproportionately extreme gap in premature deaths compared to other racial groups (6, 7). The interaction between race, socioeconomic status, historical redlining, and health is extremely relevant to San Francisco. Past studies have made it clear that living in a historically redlined or low-income neighborhood can have detrimental effects on one's health (8). Historic redlining, a high Black population, and low socioeconomic status areas are all largely connected within San Francisco. This research takes previous studies on these interactions a step further by looking at soil contamination, which has a direct effect on health, and its correlations with redlining within San Francisco.

The four heavy metals tested for were arsenic (As), lead (Pb), uranium (U), and thorium (Th). Exposure to these heavy metals can have devastating effects, especially on developmental health (9). Arsenic is known to cause cancer of the skin, bladder, liver, lungs, and kidneys (9). Lead exposure, especially during childhood development, obstructs neural connections and increases the likelihood of the development of behavioral and learning disabilities (10, 11). California's threshold for safe soil is 80 ppm Pb, not to be exceeded. The Environmental Protection Agency recommends keeping children out of gardens exceeding 200 ppm Pb, and not growing root vegetables at those numbers or higher (12). No level of lead in blood is safe (13). Uranium and thorium can be carcinogenic when inhaled, ingested, or absorbed through the skin (14, 15). Lifelong issues follow high exposure to heavy metals, many of which can be introduced into neighborhoods through industrial development, something more likely to occur in fourth-grade redlined communities (16). This study adds to existing research on heavy metal exposure, put into the perspective of other neighborhood demographics. In researching soil contamination across neighborhoods, we evaluated an important facet of environmental injustice within San Francisco. Our original hypothesis was that low-income communities would experience higher levels of heavy metal soil contamination than high-income neighborhoods.

Materials & Methods

Neighborhoods were selected based on education levels, percentage Black population, median household income, and history with redlining, as presented in Table 1.

Table 1. Table presenting the median household income as well as other characteristics of each selected neighborhood (1-5).

	San Francisco	Chinatown	Hunter's Point	Presidio Heights	Potrero Hill
Median Household Income	$126,187	$24,656	$52,431	$161,615	$147,671
% Less Than High School Educated	12.93%	52.25%	26.08%	0%	4.58%
% Black Population	5.70%	0.75%	27.66%	0%	5.59%
History with Redlining	N/A	"Fourth Grade"	Not redlined	"First/Second"	Not redlined

Although parts of Hunters Point were not redlined because of its sparse settlement during those years, two of its districts were given a fourth-grade rating, the lowest rating (17, 18). Given their low median household income and high percentage of the less-than-high-school-educated population, Hunters Point and Chinatown were selected as the two low socioeconomic status communities for this study.

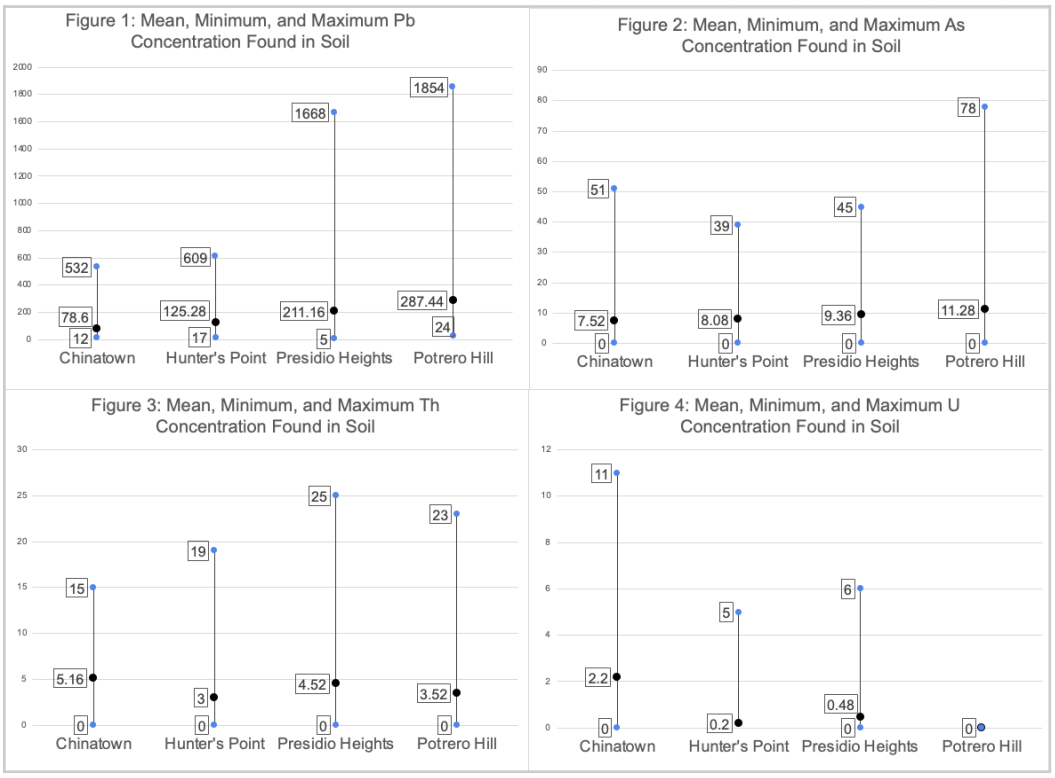
Presidio Heights and Potrero Hill both have considerably high median household incomes and numbers of high school-educated people, as well as positive (or neutral) histories with redlining. Earlier in the Presidio's history, only White people were allowed to move and live there (19). The neighborhoods of Potrero Hill and the Presidio were selected as the two high-socioeconomic status communities for the purposes of this study.

All 100 of the samples collected were taken with a focus on high-traffic areas of the neighborhoods, reflecting as accurately as possible a representation of exposure rates. Playgrounds were emphasized for the greater possibility of contact with soil and the disproportionately large effect lead and other heavy metals have on childhood development. Samples were also collected from community parks and dirt plots on sidewalks. Sidewalk dirt plots may have high crossover exposure on humans through pet dogs tracking that dirt into a house. Proximity to the ocean does not affect heavy metal concentration unless samples are collected from the direct shoreline, which causes soil erosion (20). This was not the case for any sample. The ground does not freeze in San Francisco, nor would that affect the samples. Samples were all obtained from topsoil and dug up using a trowel. Samples were taken from topsoil and not deeper in the ground because topsoil most accurately represents exposure to people. Pebbles and rocks were manually sifted out of the soil, then samples were air-dried and crushed to a finer particle size, all to increase analysis efficacy.

An X-ray Fluorescence Analyzer (XRF) was used to analyze the samples' compositions. Each sample's arsenic (As), lead (Pb), uranium (U), and thorium (Th) contents were recorded. Heavy metal concentrations did not come close to the limit of detection of the XRF (21).

Results

It was found that the overall mean contaminant concentrations across the four neighborhoods were 175.6 ppm Pb, 9.1 ppm As, 4.1 ppm Th, and 0.7 ppm U. The most notable among those was the Pb level– the state of California recommends avoiding soil that has over 80 ppm lead, and this average is more than double that number. It was found that PoH had the largest mean sample Pb levels, as presented in Figures 1 and 5.



Figures 1-4. Graphs depicting the mean soil contaminant levels found in each of the four neighborhoods, along with error bars and the minimum and maximum levels found.

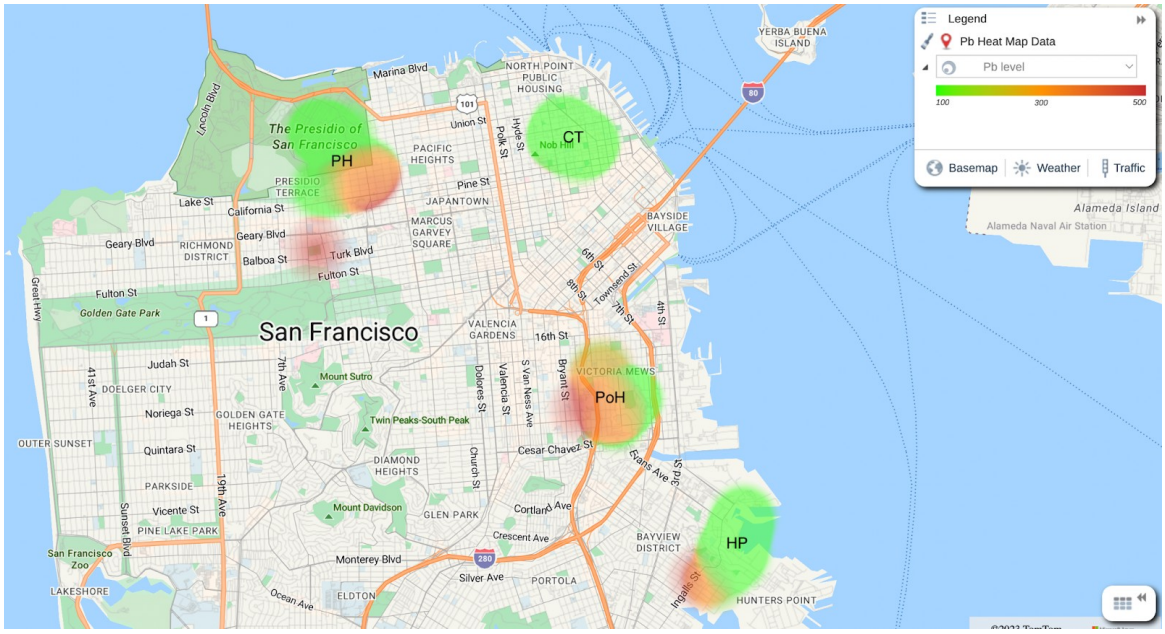


Figure 5. Heatmap of San Francisco overlaid with colors according to the amount and frequency of high Pb levels found, made using the mapping tool in eSpatial (6).

A total of four samples from PoH and PH had Pb levels exceeding 1000 ppm. Running a paired student t-test that compared our mean Pb level data between the low and high-socioeconomic-status neighborhoods, we found that the data were statistically significant (P= 0.0025) at an alpha value of 0.05. PoH and PH also had the highest average As concentrations, at 11.3 ppm and 9.4 ppm, presented in Figure 2. This is generally considered a safe average, although some site-specific numbers were at ranges up to 78 ppm, which is not recommended (22). Chinatown had the highest average U and Th levels at 2.2 and 5.2 ppm, respectively, as presented in Figures 3 and 4. Although the CT average U concentration was considerably higher than the average of the three other neighborhoods (0.2 ppm), the presence of the Th beside it was evidence of a natural U decomposition process, not due to recently placed radioactive material. Figures 1-4 depict a large range in heavy metal levels found, a range to be expected. The nature of heavy metals is that they are resistant to moving. It is not uncommon to find a site with a large amount of one heavy metal and then a few feet away find no trace of heavy metal contamination. What is more relevant is the frequency and intensity of the high heavy metal concentrations found, as those numbers represent the risk for heavy metal poisoning.

Discussion

Table 2. Graph demonstrating the relationship between housing age, income, and average heavy metal contamination (5, 7, 8).

	SF	Chinatown	Hunter's Point	Presidio	Potrero Hill
Mean Year House Built	1952	1951	1965	1945	1987
Median Year House Built	1940 to 1949	1939 or earlier	1960 to 1969	1939 or earlier	1980 to 1989
Percentage Greenspace	14%	5%	6.7%	32.8%	8.7%
Average Income	$80,383	$24,656	$52,431	$161,615	$147,671
	Average Pb	79 ppm	125 ppm	211 ppm	287 ppm
	Average As	8 ppm	8 ppm	9 ppm	11 ppm

Our results suggest that the combination of both older housing and higher greenspace density may be conducive to higher contamination levels. This may be a result of the older housing stock providing higher levels of heavy metals and the greenspace acting as a container for them. The two neighborhoods in this study found with the most As and Pb had high greenspace density and older housing, as presented in Table 2. Old housing provides more opportunities for exposure to Pb through the use of pre-1970s leaded paint. Copper-chromated arsenic (CCA) was once used as a preservative for wood within building construction, and although regulations stopped its usage in 2002, much of the older housing in PoH and PH was likely contaminated by As as a result of the use of CCA (22). The PH and PoH high As concentrations could be a result of older homes, coupled with high greenspace percentages where the As could be contained in the soil and where certain fertilizers that contain As may be used. PoH and PH are both high-income neighborhoods with high access to nature– together having an average of 15.4% tree cover (23). On the other hand, CT has a tree cover of 5% and the Bayview (a larger neighborhood that includes Hunter's Point) has an overall tree cover of 6.7% (23). A multitude of studies have shown the link between high urban greenspace and heavy metal contamination, which this study corroborates (24-26). The presence of soil in urban environments raises the likelihood of contact with soil-contained heavy metals, with one study specifically finding soil in urban systems to be an especially efficacious container for heavy metals (26). Communities with older housing have a larger source of Pb and As to be contained within surrounding greenspace, which can result in higher exposure rates, as found in this study.

Furthermore, due to a lack of greenspace, one sample collection run in CT took us 45 minutes to collect 5 samples. We were regularly able to collect about 5 samples per 15 minutes in PoH and PH because of the large soil presence. This may be the reason behind the lower heavy metal concentrations in CT, despite the older housing in CT (27). The infrequent dirt plots may inhibit lead paint from leaching into soil

that may be easily accessible, potentially protecting CT residents from exposure to Pb, As, U, and Th. Nonetheless, a lack of interaction with nature can have significant negative effects on resident health. Lack of greenspace is linked to more frequent depression, higher mental distress, obesity, as well higher mortality rates (28, 29). Studies have suggested adverse effects on public health as a result of lower nature density within CT. Although CT does have many older housing units, it does not have the access to soil that would have enabled the finding of Pb and As. Thus, the combination of older housing and high canopy cover density may create an opportunity for higher heavy metal soil contamination.

It is important to acknowledge the fact that this lower access to greenspace in low-income neighborhoods is not uncommon. There is a clear trend between access to nature and wealth (29). In this case, that access to nature may have increased the probability of heavy metal exposure, but it also reserves the benefits of greenspace interaction for high-income individuals.

Hunters Point has been contaminated with radioactive materials for generations due to the shipyard, which was used during World War II to handle hazardous waste and maintain warships and was later closed in 1974 (31). After the ensuing thirty-year cleanup by the EPA, Hunter's Point was officially deemed safe for residential use (31, 32). Still, there are conflicting arguments on the efficacy of these cleanup efforts, and the site still exposed its nearby residents to high levels of uranium for many years before it was deemed clean (33). The low U concentrations we found, at an average of 0.2 ppm, suggest that these cleanup efforts have been successful in the areas we studied. This is optimistic news for the future of this neighborhood.

Future studies should further explore the interactions between income, neighborhood greenspace exposure, older housing, and lead poisoning. Going the extra step of testing individuals for lead poisoning could provide better insight into the realized effects of what this study found, especially when put in perspective with greenspace density and housing age.

Conclusion

Our study found that lead, arsenic, uranium, and thorium soil contamination was more directly correlated with the combination of both high greenspace density and older housing than it was with low-income neighborhoods within San Francisco. It also found that cleanup efforts at the Hunter's Point shipyard may have been successful. Through higher nature exposure and older housing, our results suggested that high-income communities may be more susceptible to heavy metal contamination; a new finding. These results spread awareness of the widespread dangers of heavy metal exposure and its presence within all neighborhoods. Past studies have found data on the high exposure rates of low-income, typically more industrialized, neighborhoods, and our results did not negate that. Instead, they built on previous studies by expanding collective awareness of the different means by which heavy metal contamination can occur,

i.e. living in a particularly industrial neighborhood or a neighborhood with both older housing and high greenspace percentage. This information should enable the design and implementation of policies that decrease the susceptibility of residents to heavy metal exposure.

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