The contribution of lead contamination sites to childhood lead poisoning in the Hawaiian Islands

A REPORT SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAIʻI AT HILO IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
IN
TROPICAL CONSERVATION BIOLOGY AND ENVIRONMENTAL SCIENCE
PROFESSIONAL INTERNSHIP TRACK

By
Geoffrey M. Grimmett

Internship Committee:
Diana Felton, Mentor[1]
Kacey Ingalls, Mentor[2]
Kelly Hoffman Mentor[3]
Lisa K. Canale, TCBES Professional Internship Program Coordinator[4]

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[1] *Hazard Evaluation and Emergency Response Office, Hawaiʻi State Department of Health, Pearl City, Hawaiʻi 96782, USA*

[2] *Hazard Evaluation and Emergency Response Office, Hawaiʻi State Department of Health, Pearl City, Hawaiʻi 96782, USA*

[3] *Hazard Evaluation and Emergency Response Office, Hawaiʻi State Department of Health, Pearl City, Hawaiʻi 96782, USA*

[4] *Tropical Conservation Biology and Environmental Science Graduate Program, University of Hawaiʻi at Hilo, Hilo, Hawaiʻi 96720, USA*

Acknowledgements

I would like to thank Dr. Diana Felton, Kacey Ingalls, Kelly Hoffman, the Hawaiʻi State Department of Health's (HDOH) Hazard Evaluation and Emergency Response (HEER) Office, and the Hawaiʻi Childhood Lead Poisoning Prevention Program (HI-CLPPP) for providing this internship opportunity to me and for their guidance and support throughout this entire process. I would also like to thank my advisor, Lisa Canale, for her assistance in obtaining this internship and for her support over the course of these past two years in the Tropical Conservation Biology and Environmental Science (TCBES) Program. Finally, I would like to thank the University of Hawaiʻi at Hilo, the TCBES graduate program, and my cohort for making these past two years of graduate school a very special and fulfilling experience.

Abstract

This internship was in conjunction with the Hawaiʻi State Department of Health's (HDOH) Hazard Evaluation and Emergency Response (HEER) Office with the overall goal of the project being to improve the understanding of the geographic distribution of childhood lead poisoning in Hawaiʻi to inform childhood lead poisoning prevention efforts. The internship included the collection and mapping of blood lead data from the years 2015-2019 and environmental pollution data, such as lead contaminated sites, to help identify potential sources of lead exposure. These data were then analyzed to identify relationships between elevated blood lead levels (EBLLs) and factors such as distance from nearest site, lead concentration value at nearest site, and their interaction. The results of this analysis support the idea that most childhood exposures to lead in Hawaiʻi occur in the household. This report goes into more detail about the work described above and reflects on how this internship has benefitted both my mentor agency and myself.

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List of Abbreviations

TCBES - Tropical Conservation Biology and Environmental Science

UH- University of Hawaiʻi

HDOH – Hawaiʻi Department of Health

HEER – Hazard Evaluation and Emergency Response

HI-CLPPP- Hawaiʻi Childhood Lead Poisoning Prevention Program

BLL- Blood lead level

EBLL- elevated blood lead level

IQ- intelligence quotient

LCR- Lead and Copper Rule

SVI- Social Vulnerability Index

EPA- Environmental Protection Agency

GIS- Geographic Information System

EAL- Environmental Action Level

FIPS- Federal Information Processing Standards

PO – post office

HDOT- Hawaiʻi Department of Transportation

DLNR- Department of Land and Natural Resources

Introduction

Background

Project Description

Environmental contaminants, such as lead, have severe effects on the environment and public health. An example of this is lead exposure being responsible for cognitive and behavioral deficits in young children (Lanphear 2005; Hauptman 2017; Felton et al. 2019). I will address studies on environmental lead exposure and its effects on children and provide background information on my mentor agency. This area of study caught my interest and was the basis of my internship project that I worked on in the Summer of 2020.

Lead and Its Toxic Effects on Children

The threat of lead toxicity is well known and has been documented for years. The earliest account of lead poisoning dates back to Egypt, where it was used for homicide, and the first written account of disease or ailment caused by lead was in 370 BC by Hippocrates, who described lead colic (Hernberg 2000). Lead poisoning in children was first discovered in Australia in 1894, while the first cases reported in the United States were in the 1910s (Needleman 1994; Hernberg 2000). The conventional knowledge at the time was that lead poisoning that did not result in the death of the child meant that the dilemma was over and that the child would not experience any future problems or health disparities (Needleman 1994). This was disproven in 1943, which led to a new standard being established where cases were classified and treated as lead poisoning only when victims had symptoms such as vomiting or abdominal pain (Needleman 1994). However, this new classification did not account for the possibility of asymptomatic, chronic lead poisoning which occurs at lower lead doses. (Needleman et al. 1979). The debate over lead's toxic properties at low levels prompted researchers to conduct studies to determine if these lower lead levels caused neuropsychiatric problems in young children (Needleman et al. 1979).

The study done by Needleman et al. (1979) provided conclusive evidence that these lower lead levels did result in neuropsychiatric deficits in children despite a lack of acute symptoms. Earlier studies provided inconclusive results or were challenged due to these studies not observing a representative population and mostly relying on blood lead levels (BLLs) to diagnose subjects, which were very inaccurate at the time due to laboratories being unaccustomed to analyzing blood for lead (Needleman et al. 1979; Hernberg 2000). These studies were also criticized for not controlling for confounding factors such as perinatal exposure, nutritional intake, or socioeconomic status (Needleman et al. 1979). Results also suffered from the use of mass screenings that failed at identifying subtle impairments (Needleman et al. 1979). The findings made by this study prompted the definition of lead toxicity to be revised and also resulted in the prioritization of policy change to direct the removal of lead sources from the environment, such as the use of leaded gasoline (Needleman 1994).

Low Testing Rates and Some Forms of Lead Source Removal Presenting Constraints and Confounding Factors for Researchers

Since the publishing of the Needleman et al. (1979) paper, the methodologies employed to study and monitor lead poisoning have continued to evolve and develop. One such development is the refinement of blood lead testing that now yields more accurate results due to blood lead testing being more common in modern laboratories and improvement in laboratory techniques that prevent contamination of blood samples. However, this monitoring method is still constrained by a few factors. One factor is low testing rates in some communities. For example, in Hawaiʻi, less than 16% of children were tested in 2017 and 2018 (Felton et al. 2019). This is problematic because there has been a slight rise in blood levels recently in the state of Hawaiʻi, where elevated blood lead levels have ranged from 0.8-1.4%, but since testing rates are so low the possibility of some lead poisoning cases going undocumented remains high (Felton et al. 2019). A similar problem exists in China where lead poisoning screening is not required as part of a yearly checkup and is only done at the behest of the child's parents (Yan et al. 2013). Pediatricians also lack training in identifying and preventing lead poisoning, which may lead to misdiagnosis (Yan et al. 2013). Another constraint experienced by researchers in this field is that the removal of lead sources often requires a child to have elevated blood lead levels, which means they have already been poisoned (Potash et al. 2015). The removal of lead-based paint or lead contaminated soil abatement can also present problems due to the respective removal processes resulting in the dispersal of lead particulates in the air (Potash et al. 2015).

Current Knowledge

Although current methodological constraints present hurdles to childhood lead poisoning researchers, there have been many strides made when it comes to understanding childhood lead poisoning. It is known that children whose blood is contaminated with lead are at risk of experiencing neuropsychiatric problems due to lead being a neurotoxin that targets mitochondria and negatively affects its structure and function (Wiebe et al 1991; Felton et al. 2019). Dosage level has also been recognized as a huge factor during diagnosis. Children who have low-moderate blood lead levels are usually asymptomatic and experience neuropsychiatric problems as they age (Lanphear 2005; Hauptman 2017; Felton et al. 2019). Some of these deficits include difficulty paying attention, decreased intelligence quotient (IQ), and poor academic performance (Lanphear 2005; Calello and Henretig 2015; Hauptman 2017; US EPA 2018; Felton et al. 2019). However, children with very high blood lead levels may have acute symptoms that consist of abdominal pain, vomiting, constipation, anemia, lethargy, irritability, and loss of appetite (Lanphear 2005; Calello & Henretig 2015; Hauptman 2017; Felton et al. 2019).

Since lead has no biological role in the human body, any lead detected must come from environmental exposure (Wiebe et al. 1991; Felton et al. 2019). The majority of exposure in the United States is due to deteriorating lead-based paint on the interior and exterior of buildings (Wiebe et al. 1991; Felton et al. 2019). Children are at particular risk of exposure when it comes to lead-based paint due to them participating in exploratory hand to mouth behaviors, which can result in the ingestion of lead-contaminated dust and paint chips (Wiebe et al 1991; Etzal & Balk 2019; Felton et al. 2019). Soil may also be contaminated due to exterior lead-based paint, historic use of leaded gasoline, welding, and auto repair (Wiebe et al. 1991; Lin et al. 2010; Angelon-Gaetz et al. 2018; Felton et al. 2019). Some other risk factors that are specific or more common in Hawai‘i are the smelting of lead fishing weights, the use of certain religious and cultural products, and volcanic emissions creating acidic conditions that cause home water catchment systems to leach lead from roofing and plumbing materials (Wiebe et al. 1991; Thomas & Macomber 2010; Lin et al. 2010; Angelon-Gaetz et al. 2018; IVHHN 2018; Felton et al. 2019).

Treatment of lead poisoning includes the identification and removal of the lead source, providing the afflicted child with optimal nutrition, referral to early intervention services, and chelation therapy for very high blood lead level cases (Committee on Environmental Health 2005; Woolf et al. 2007; Hauptman 2017; Felton et al. 2019). Even though population studies in the United States have shown a steady decrease in lead levels since the 1970s, there has been a slight rise in the 95th percentile blood lead levels for children ages 1-5 (CDC 2019; Felton et al. 2019). This rise has also been seen in Hawai‘i where elevated blood lead levels have ranged from 0.7-1.8% (Felton et al. 2019). As mentioned above, testing rates in Hawai‘i are very low, where less than 16% of children were tested in the years 2017 and 2018, so some cases may have gone undocumented (Felton et al. 2019). This is relevant to treatment since not only are these undocoumented cases not recieving the aid that they need but also the sources of lead that they were exposed to are going undiscovered as well (Felton et al. 2019).

Knowledge Gaps and Future Studies

One of the major knowledge gaps concerning childhood lead poisoning is how mixtures of lead with other metals may influence lead’s already harmful neurobehavioral effects. Some studies have been conducted to test how interactions between lead and other metals such as manganese, cadmium, arsenic, and mercury affect cognition (Kim et al. 2009; McDermott et al. 2011; Yorifuji et al. 2011; Claus Henn et al. 2012; Sanders et al. 2015). It has been observed that young children exposed to mixtures of manganese and lead have scored lower on the BSID-II, which is used to monitor neurodevelopment, and older children exposed to the mixture scored lower on IQ tests when compared to children exposed solely to lead (Kim et al. 2009; Claus Henn et al. 2012; Sanders et al. 2015). Studies concerning exposure to mixtures of lead and mercury and lead and arsenic have also shown higher occurrences of intellectual disabilities and deficits when it comes to memory, verbal learning, and attention (McDermott et al. 2011; Yorifuji et al. 2011; Sanders et al. 2015). Although these studies have shown a greater increase in the understanding of how these metal mixtures affect children's cognitive ability, there remains a lack of research when it comes to understanding how these mixtures affect behavior in children (Sanders et al. 2015).

Another potential area of future study would be evaluating the compliance of utilities to the Environmental Protection Agency's (EPA) Lead and Copper Rule (LCR), which requires utilities to implement remedial actions when more than 10% of tap water sources exceed the lead action level of 15 ppb (Katner et al 2016). Non-compliance to this rule resulted in the Flint Water Crisis, which lead to Flint's community suffering from prolonged exposure to lead-contaminated water. Reasons for this non-compliance were due to poorly designed compliance monitoring protocols and biased sampling methods (Triantafyllidou & Edwards 2012; Katner et al. 2016). Future studies should revisit Flint and observe other communities nationwide to see if utilities have begun to comply with the LCR and if sampling methods have improved.

My internship project at the Hawai‘i State Department of Health's HEER office also addressed childhood lead poisoning in communities across the state of Hawai‘i. The HEER Office is specifically equipped to address this issue since their mission statement is "to protect health and the environment by providing leadership, support, and partnership in preventing, planning for, responding to, and enforcing laws relating to releases or threats of releases of hazardous substances to the environment (HEER Office 2020A)." The HEER Office fulfills this mission statement by documenting blood lead test results, following up with a child's physician to coordinate treatment, providing lead site investigations at a child's residence in order to identify the source of exposure, and by conducting special studies related to chemical hazards (HEER Office 2020B). The project at the Department of Health's HEER Office was exemplary of the final responsibility listed above. It involved analyzing children's blood levels statewide and assessing how environmental factors may be contributing to lead exposure. The work done during this project helped with the monitoring and prevention of childhood lead poisoning in the state which may also benefit the office's collaborators to help address issues related to lead poisoning in the future.

Purpose

The purpose of my project was to assess how environmental factors, specifically lead contaminated sites, may be contributing to childhood lead exposure in Hawaiʻi.

Learning Objectives

Graduate School Learning Objectives

- Learn about Geographic Information Systems (GIS)
- Learn R programming language
- Outreach and event planning
- Learn more about toxicology
- Improve my knowledge in environmental health
- Learn the principles of epidemiology
- Improve my knowledge in statistics
- Learn more about social science research methods
- Learn more about organizational management and logistics
- Learn how to communicate my work and scientific interests using social media
- Improve presentation skills
- Improve writing skills

Professional Development Objectives

- Test skills in GIS
- Test skills in R

- Continue learning about toxicology
- Learn more about lead contamination
- Become familiar with the HEER Office's culture
- Inter-agency collaboration (to inform me how other agencies handle and prioritize data)
- Learn more about the Center for Disease Control's Social Vulnerability Index (SVI)
- Create an SVI high risk map and compare it to the Hawaiʻi Childhood Lead Poisoning Prevention Program's (HI-CLPPP) current high risk map
- Learn how to navigate and use the state's iHEER and Access databases
- Be able to identify confirmed and potential lead contamination sites
- Learn how to use the Maven database
- Learn more about environmental health policy and how our data influences policy
- Learn about what protected health information is and how to protect it under the HIPPAA law
- Learn more about lead site investigations
- Get experience being a part of residential site investigations
- Get experience in writing a report for the HEER Office and HI-CLPPP
- Get experience presenting my work to the HEER Office and HI-CLPPP

Professional Internship

Roles and Responsibilities

My role and responsibilities as an intern at the Department of Health's HEER Office were to assist my mentors with their respective projects. I assisted my mentors at the Department of Health with a project that was concerned with analyzing children's blood lead levels statewide and assessing how environmental factors may be contributing to lead exposure. This primarily involved me using the state's iHEER and Access databases to pull environmental pollution data, the state's Maven database to obtain blood lead levels and their respective addresses, GIS to map the environmental pollution data and blood lead levels, and R to analyze my datasets.

Expectations

The internship that I completed at the Department of Health's HEER Office fulfills the expectations of the TCBES internship program. Having the opportunity to accomplish work that will help aid childhood lead poisoning prevention in Hawaiʻi has made this internship incredibly meaningful both to myself and to the community as a whole. The internship also constantly provided new and exciting challenges every step of the way, such as learning GIS, using analytical skills that I had previously acquired, and the process of compiling all of my work in order to present it to the HEER Office and the HI-CLPPP team. Additionally, the welcoming demeanor and tutelage of my mentors allowed me to be seamlessly integrated into the agency. The results of this easy transition can be seen in my work, where I was able to collaborate with a multitude of my colleagues which undoubtedly benefitted the project as a whole. Finally, the experiences described above have culminated in the expansion of my knowledge on and my ability to contribute to the field of lead contamination, poisoning, and prevention.

Timeline

Table 1. Internship Timeline.

Task	**Date Accomplished**
Training	May 2020
SVI Map	June 2020
SVI Map Presentation at HI-CLPPP Coalition Meeting	July 2020
Site Investigation	July 2020
Data Gathering, Mapping, and Analysis for Project	July 2020
Final Presentation for HEER Office	August 2020

Approach

Strategies and Methods

The project at the Department of Health that was concerned with analyzing children's blood levels statewide and assessing how environmental factors may be contributing to lead exposure included a number of strategies and methods. Some of my methods included obtaining residential addresses of children who received a blood lead test between the years 2014-2019 from the Hawai'i Electronic Disease Surveillance system, using GIS to map residential addresses with their corresponding blood lead level, and pulling environmental pollution data from the iHEER database, which is a map-based database that catalogs known sites of environmental contamination across Hawai'i. It is managed by the HEER Office and contains geographic data, history of remediation work, and pertinent documents. The pollution data that I pulled from the database helped me create a layer of iHEER lead contamination sites in GIS. I then imported these data into R Studio where I ran several multiple linear regression models in order to analyze both the relationship between blood lead levels and their nearest contamination site and the relationship between elevated blood lead level rates and the number of sites within a census tract at the state and county level. At the end of the internship, I completed a formal write up in the form of a paper containing methods and analysis for the HEER Office. I also presented my work to the Hawai'i Childhood Lead Poisoning Prevention Program team and other involved parties.

Assessment Method to Evaluate Achievement

Appreciative Inquiry

Define:

- How do we flesh out this project even more to include other factors such as housing information?

Discovery:

- I really enjoyed working with my mentors and colleagues everyday

- I enjoyed expanding my knowledge on lead contamination and poisoning
- I enjoyed learning more about my agency's role in mitigation and abatement when it comes to lead contamination and poisoning
- I enjoyed learning more about the history of the Hawaiian Islands while I was researching possible contamination sites
- I enjoyed navigating the state's databases in order to pull relevant blood lead data and site data
- I really enjoyed constructing the maps in GIS
- I really enjoyed putting my R Studio skills that I learned at UH Hilo to the test
- I really enjoyed participating in a site investigation
- I really enjoyed seeing all my work come together at the end especially being able to present it to my peers, colleagues, and classmates

Dream

- There was always a positive vibe when I was in the office
- I am really happy and proud of the fact that I was able to learn GIS and how to use the state's databases in the short amount of time that I had
- I am really happy that I was able to get comfortable with the culture of the HEER Office
- I got really positive feedback from my mentors
- The work I did was very satisfying
- I'm really happy and proud that my work can in some way give back to the environment and the community
- Excited for how this project may be expanded upon in the future

Design

- Now that I'm more comfortable with GIS and the state's databases I can focus more time into other areas of the project
- Reach out to more people to get their input on improving the project

- Add factors such as housing information in my mapping and analysis
- Continue getting feedback from my mentors and colleagues
- Take a moment for myself to appreciate the work that I've done

Destiny

- Implement the above ideas

Outcomes

Deliverables

I have attached the final report that I submitted to the HEER Office at the end of my internship in the Appendices section.

Note: Private Information such as addresses have been jittered (i.e., the addition of random noise) in the maps below and no protected health information has been included in this report.

Additional Achievements

I also created a map based on Hawai'i's social vulnerability index (SVI) in order to highlight possible high-risk areas for lead poisoning in the state. This map will be compared to the current high-risk map that HI-CLPPP uses. I've attached the map below in the Appendices section.

Note: No protected health information has been included in these maps

Discussion

Now that my internship has concluded, I am confident in saying that the work that I was able to accomplish over the summer will be very beneficial to my host organization. My analysis of the blood lead data and environmental pollution data across the state helped us determine if there are correlations between areas with elevated blood lead levels and lead contaminated sites in those areas. Specifically, the analysis yielded positive relationships at the state level between BLLs and distance from nearest potential sites and lead concentration values at nearest confirmed site where median BLLs increased by 0.81% and 0.27%, respectively, as distance and lead concentration value doubled (Table 1 in HDOH Final Report). The statewide analysis also yielded a positive relationship between EBLL rates and the number of well sites within a census tract where median EBLL rates increased by 27.59% as number of well sites doubled (Table 6 in HDOH Final Report). At the county level, Honolulu County showed an inverse relationship between BLLs and distance from nearest confirmed site where median BLLs decreased by 1.32% as distance doubled (Table 2 in HDOH Final Report). This county also showed positive relationships between BLLs and distance from nearest potential site and lead concentration values at nearest confirmed site where median BLLs increased by 0.88% and 0.38%, respectively, as distance and value doubled (Table 2 in HDOH Final Report). For Hawaiʻi County, a positive relationship was observed between BLLs and lead concentration value at nearest confirmed site where median BLLs increased by 2.2% as concentrations doubled (Table 3 in HDOH Final Report). Both Maui and Kauaʻi counties did not show any dependencies between BLLs and the explanatory variables (Tables 4 and 5 in HDOH Final Report). In summary, the results of the project supported the idea that most childhood exposures to lead in the state of Hawaiʻi are due to lead hazards in the home. Also, the list that I compiled of every confirmed and potential lead contaminated site in the state may help with future investigations where the source of exposure is unknown. Additionally, both the results of the project and the list may help inform potential toxic lead removal efforts in the future. Overall, I expect our work to support the ongoing cause to monitor and prevent childhood lead poisoning in Hawaiʻi.

Auxiliary tasks such as the creation of a high-risk map and my participation in a residential lead site investigation were also of direct benefit to the HEER Office. The high risk map based off of census data such as sociodemographic and housing risk factors allowed us to identify areas where children may be at highest risk for lead exposure. Another important purpose for this map was to compare it to the HEER Office's previous high risk map, which was based on zip codes, in order to potentially construct a more comprehensive high risk system. My participation in the lead site investigation contributed to the HEER Office's ability to identify possible sources of exposure that were the likely cause of a child's elevated blood lead level.

Finally, it should be noted that this was the HEER Office's first time taking on a TCBES Professional Masters Internship Student. Hopefully the relationship established here with my internship will continue to grow with more TCBES students interning at the HEER Office in the future or other possible collaborations.

Conclusion

My TCBES journey has been incredibly invaluable to me and my future endeavors. The program was very accomodating and supportive when it came to my interests in environmental health and epidemiology. My professors and colleagues have also taught me so much about the conservation and environmental science fields in general, which has expanded my knowledge and awareness of subjects in which I had no prior experience in. My colleagues have especially been very important to me. They are one of my largest sources of inspiration and have been a great support system throughout my time in the program. These friendships will be something that I will always cherish.

My internship was also an incredibly fulfilling experience that allowed me to gain deeper insight into the environmental health field while also being able to participate in work that will make a difference in Hawaiʻi. This internship allowed me to gain new skills in areas such as GIS and improved my aptitude with software such as R Studio. I am particularly grateful to my mentors who were extremely kind, informative, and supportive of me and my goals. They made a constant effort to make sure that I had an opportunity to be involved with as many different facets of their work as possible. I am really hopeful that I will be able to work with them in the future and possibly expand upon this project. Overall, my time in this program has been really special and will continue to be influential in my future development.

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Appendices

Sample Deliverables

HEER Office Final Report

Note: Private Information such as addresses have been jittered in the maps below and no protected health information has been included in this report.

Assessment of Lead Contaminated Sites and How They Contribute to Childhood Lead Exposure in Hawai‘i

By

Geoffrey M. Grimmett

Overview

Blood lead levels (BLLs) in the United States have steadily decreased since the 1970s due to increasing knowledge of lead toxicity and policies such as the banning of lead based paint for home use in 1978 and the Clean Air Act of 1970 which began the phase out of leaded gasoline. However, there has recently, between the years of 2015-2016, been a rise in the 95th percentile of BLLs for children aged 1-5 (CDC 2019; Felton et al. 2019). This rise was also observed in Hawaiʻi where the percentage of children with elevated blood lead levels (EBLLs) ranged from 0.7-1.8% throughout the state (Felton et al. 2019). It is also important to point out that even though public policy has regulated the use of lead, lead is still used in some processes and present in some products such as the smelting of fishing weights, vehicle repair, and certain religious and cultural products (Wiebe et al. 1991; Thomas & Macomber 2010; Lin et al. 2010; Angelon-Gaetz et al. 2018; Felton et al. 2019). In addition, lead as a chemical element does not breakdown in the environment, so both current and historical sources of lead will persist through the environment. It is generally accepted that the majority of childhood lead exposures in Hawaiʻi occur at home, with the primary sources of lead being deteriorated lead-based paint and contaminated soil from leaded gasoline or deteriorated exterior lead-based paint. Other potential sources are shown in Table 1. Taking this into consideration, it is safe to assume that these sources may be contributing to lead exposure in Hawaiʻi. The overarching goal of the study was to assess how environmental factors and environmental contamination may be contributing to childhood lead exposure in Hawaiʻi. This involved five main steps. The first step was to obtain the residential addresses of children who received a blood lead test between the years 2015-2019 from the Hawaiʻi Electronic Disease Surveillance System. The second step was to use Geographic Information System (GIS) mapping to map the residential addresses of these cases with their corresponding blood lead level. Then the third step was to pull environmental pollution data from the iHEER and Access databases utilized by the Department of Health Hazard Evaluation and Emergency Response (HEER) Office. The fourth step was to create a layer of iHEER and Access lead contaminated sites in GIS. The final step was to assess how these environmental factors may be contributing to lead exposure in Hawaiʻi through statistical analysis. The results of this study may indicate new priority sites for cleanup and may also give an explanation as to why some areas may have higher incidence and risk of lead exposure. This study was performed from July 1st, 2020 to August 20th, 2020.

Table 1. Possible Sources of Lead (from HI-CLPPP website)

Source	Description
Paint and Dust	Homes built before 1978 may contain lead paint. The older the home, the higher the risk. Dangerous lead dust can be spread around the home from peeling paint, paint chips, painted windows and doors that rub together, and recent repairs/renovations.
Bare Soil	Soil around buildings and near busy roads may be contaminated with lead. Soil can be carried into your home on hands, shoes and clothing, or by the wind. Once inside your home, soil gets on floors, furniture, toys, or other objects that your child touches or puts in his or her mouth.
Household Items, Toys, and Jewelry	Things in your home may have lead in them. Watch out for anything bought from garage/yard sales, thrift stores, or passed down from family and friends. These items may include old or brightly decorated dishware, old metal items, furniture that looks old or has metal pieces, antique toys, older imported toys, costume jewelry, toy jewelry with rhinestones, and jewelry from vending machines. Toys made before 2010 were not required to be independently tested for lead and may have higher lead levels.
Foreign Products	Traditional remedies (Chinese or Ayurvedic remedies), traditional make-up, and imported spices/food bought in other countries and specialty grocery stores may contain lead. Brightly colored powders (red, orange, yellow) usually contain the highest amount of lead. Examples include turmeric, curry powder, kohl, surma, sindoor, greta, azarcon, ba-baw-san, and ghasard.
Jobs and Hobbies	People exposed to lead at work or through jobs and hobbies like construction, welding,

	painting, plumbing, fishing, making stained glass, visiting firing ranges, or working on cars can bring harmful levels of lead dust home to their families. You cannot see lead dust, but it can be carried home in your car or on your clothes, shoes, skin, and hair.
Water	If your home has an older plumbing system or a poorly designed/maintained rainwater catchment system, your water may contain lead.

Methods

Environmental Contamination Sites

Confirmed Sites

Confirmed sites were identified using the Hawai‘i State Department of Health's (HHDOH) iHEER and Access databases. Sites were categorized as "confirmed" sites if they had analytical results documenting the presence of lead at concentrations greater than or equal to the HDOH Environmental Action Level (EAL) for lead in soil of 200 ppm. There were 145 confirmed sites identified in total.

Potential Sites

Sites were categorized as "potential" sites if they were suspected to have some form of lead contamination based on historical use and were also identified using HDOH's iHEER and Access databases. In addition, some bridge and airport sites were identified using the Historic Hawai‘i Foundations 2013 bridge inventory and the Hawai‘i Department of Transportation's (HDOT) list of abandoned and forgotten airports located on the HDOT website. There were 148 potential sites identified in total.

Well Sites

Water well sites were identified by using a layer that was provided by the Department of Land and Natural Resources' (DLNR) Commission on Water Resource Management which initially included 5,244 wells. Since this study was only concerned with wells used for domestic drinking purposes, wells that did not fit this criterion were not included in mapping or analysis. This resulted in 899 wells being eligible for mapping and analysis.

Address and Blood Lead Data

Blood lead test results were obtained from HDOH's Electronic Disease Surveillance System. Test results that occurred between the years 2015 and 2019 were used for mapping and analysis. This initially consisted of 81,204 cases. Test results that were not from Hawaiʻi, did not have a residential address recorded, possessed an incomplete address, or only included a medical provider's address were excluded, which resulted in 41,436 cases for mapping and analysis. Test results were paired down again with the removal of cases that only provided a post office (PO) box as an address. Post office boxes were removed due to prior studies stating that exact locations were better for statistical analysis since they are more representative of a child's immediate environment (Rytkönen 2004; Kaplowitzc et al. 2010; Vivier et al. 2010; Hanna-Attisha et al. 2016). Test results were then filtered to only include children < 6 years old which left 28,372 cases eligible for mapping and analysis. The remaining test results were then geocoded to latitude and longitude coordinates using the United States Census Bureau's geocoding tool.

Mapping

Features were mapped using ArcGIS Online. The confirmed and potential lead contaminated sites and the geocoded test results were then mapped using the software (Figures 1-5). Confirmed sites were represented as black dots on the map that increased in size as lead concentration values increased. Potential sites were represented as pink dots on the map. Pop-up information for confirmed and potential sites on the map included the site's name, street address, state, and zip-code information while confirmed sites also included the concentration of lead at the site. Domestic wells were represented with a blue dot on the map. Pop-up information for wells included the name of the well and its use. Elevated blood lead test results (EBLL) were identified as a blood lead test result of ≥ 5 µg/dL and were represented as orange dots on the map that increased in size as BLL increased. Pop-ups for the EBLLs included child ID, the type of sample taken, and the test result value. Strong efforts were made to protect privacy and no personal identifying information was included. EBLL rates per census tract were represented on a color gradient from beige to red where increasing EBLL rates corresponded to increasingly darker colors (Figures 6-10). Pop-ups for the EBLL rates included the Federal Information Processing standards (FIPS), county, number of elevated results, average value of results, and percentage of elevated cases vs non-elevated cases.

Analysis

Analysis was performed using the analysis tools provided by ArcGIS Online and R Studio. This included ArcGIS Online's aggregation tool that allowed for EBLL rates to be calculated by census tract and a nearest location tool that calculated the distance between elevated test results and the nearest confirmed site, potential site, and well site.

Results

BLLs and Their Relationship to Nearest Site Distance and Lead Concentration at Nearest Confirmed Site

As described above, the distance between elevated blood test results and the nearest confirmed site, potential site, and well site was calculated using ArcGIS Online's nearest location tool. After these distances were determined, a multiple linear regression model (MLR) was run in R Studio to determine whether there was a dependency between BLLs and:

A. Distance from nearest confirmed site, potential site, well site,

B. Lead concentration value at nearest confirmed site,

C. Multiplicative effect of distance from nearest confirmed site and lead concentration value at nearest confirmed site (confirmed*release).

This MLR model was ran at both the state level and county level.

Statewide

The MLR run for the entire state showed a dependency between BLLs and distance from nearest potential site ($p = 1.73 * 10^{-6}$; 95% CI: 1.0047672, 1.011423) where median BLL increased by 0.81% as distance from nearest potential site doubled. The model also yielded a relationship between BLL and lead concentration value at nearest confirmed site ($p = 1.06 * 10^{-3}$; 95% CI: 1.0010686, 1.004260) where the median BLL increased by 0.27% as lead concentration value doubled. Finally, the model showed no dependencies between BLLs and distance from nearest confirmed site ($p = 9.04 * 10^{-2}$; 95% CI= 0.9955904, 1.000322), well site (p= 0.99127; 95% CI: 0.9967975, 1.003249), or confirmed*release (p= 0.29872; 95% CI: 0.9975793, 1.000744) (Table 1).

Honolulu County

The MLR for Honolulu County showed a dependency between BLLs and distance from nearest confirmed site ($p = 9.42 * 10^{-14}$; 95% CI: 0.9833242, 0.9902344) where median BLL decreased by 1.32% as distance from nearest confirmed site doubled. The model also yielded a relationship between BLL and nearest potential site ($p = 2.65 * 10^{-5}$; 95% CI: 1.0046724, 1.012892) where BLL increased by 0.88% as distance from potential site doubled. Finally, the model gave a significant relationship between BLL and lead concentration value at nearest confirmed site ($p = 2.99 * 10^{-6}$; 95% CI: 1.0022260, 1.0054513) where the median BLL increased by 0.38% as lead concentration value doubled. The model showed no dependencies between BLLs and distance from nearest well site (p= 0.669; 95% CI: 0.9954870, 1.0029081) or confirmed site*release (p= 0.447; 95% CI: 0.9988486, 1.0026169) (Table 2).

Hawaiʻi County

The MLR for Hawaiʻi County showed a dependency between BLLs and lead concentration value at nearest confirmed site ($p = 0.3 * 10^{-3}$; 95% CI: 1.0098876, 1.033862) where the median BLL increased by 2.2% as lead concentration at the nearest confirmed site value doubled. The model yielded no significant relationships between BLLs and distance from nearest confirmed site (p= 0.445225; 95% CI: 0.992705, 1.003223), nearest potential site (p= 0.317577; 95% CI: 0.9936728, 1.019741), nearest well site (p= 0.955791; 95% CI: 0.9902388, 1.00931), or confirmed*release (p= 0.897303; 95% CI: 0.9907515, 1.008177) (Table 3).

Maui County

The MLR that was ran for Maui County showed no dependencies between BLLs and distance from nearest confirmed site (p= 0.3540; 95% CI: 0.9875291, 1.004502), potential site (p= 0.9711; 95% CI: 0.9889312, 1.010784), well site (p= 0.3181; 95% CI: 0.9983700, 1.005031), lead concentration value at nearest confirmed site (p= 0.0596; 95% CI: 0.9991570, 1.043550), or confirmed*release (p= 0.3037; 95% CI: 0.9558820, 1.014166) (Table 4).

Kaua‘i County

The MLR that was ran for Kaua‘i County showed no dependencies between BLLs and distance from nearest confirmed site (p= 0.2098; 95% CI: 0.9944416, 1.001226), potential site (p= 0.2755; 95% CI: 0.9723001, 1.008046), well site (p= 0.5969; 95% CI: 0.9960345, 1.00693), lead concentration value at nearest confirmed site (p= 0.9902; 95% CI: 0.9867566, 1.013592), or confirmed*release (p= 0.0777; 95% CI: 0.9558820, 1.014166).

Table 2. Summary of results for BLLs and their relationship to nearest site distance and lead concentration at nearest confirmed site. Percentages correspond to percent change in BLLs as factors such as distance and lead concentration increase. NR: No statistically significant relationship

Region	Distance from Confirmed site	Distance from Potential Site	Lead Conc. At nearest Confirmed Site	Distance from Nearest Well Site	Lead Con. At Nearest Confirmed*Release
Statewide	NR	0.81%	0.27%	NR	NR
Honolulu Co.	-1.32%	0.88%	0.38%	NR	NR
Hawai‘i Co.	NR	NR	2.2%	NR	NR
Maui Co.	NR	NR	NR	NR	NR
Kaua‘i Co.	NR	NR	NR	NR	NR

EBLL rates and Number of Sites within Census Tracts

EBLL rates per census tract were calculated using ArcGIS Online’s aggregation tool. A multiple linear regression model was then run in R Studio to determine if EBLL rates per census tract were dependent upon the number of confirmed sites, potential sites, or well sites within a census tract.

Statewide

The results of the model showed that EBLL rates within a census tract were dependent upon the number well sites within the tract (p= 0.00314, 95% CI: 1.0861476, 1.4987829), where the median EBLL rate increased by 27.59% as the number of well sites doubled. The model did not show dependencies between EBLL rates and the number of confirmed sites (p= 0.38116; 95% CI: 0.8441122, 1.5558406) or potential sites (p= 0.84168; 95% CI: 0.7630927, 1.3930962) within a census tract (Table 6).

Honolulu County

The MLR that was ran for Honolulu County showed no dependencies between EBLL rates and the number of confirmed sites (p= 0.931; 95% CI: 0.6933336, 1.398458), potential sites (p= 0.330; 95% CI: 0.7993962, 1.943579), and well sites (p= 0.141; 95% CI: 0.9132699, 1.88531) within a census tract (Table 7).

Hawai'i County

The MLR that was ran for Hawai'i County showed no dependencies between EBLL rates and the number of confirmed sites (p= 0.141; 95% CI: 0.7939544, 4.687093), potential sites (p= 0.690; 95% CI: 0.4511887, 1.706171), and well sites (p= 0.065; 95% CI: 0.9813838, 1.818504) within a census tract (Table 8).

Maui County

The MLR that was ran for Maui County showed no dependencies between EBLL rates and the number of confirmed sites (p= 0.240; 95% CI: 0.4057147, 12.620443), potential sites (p= 0.255; 95% CI: 0.2061453, 1.543982), and well sites (p= 0.435; 95% CI: 0.7760401, 1.77534) within a census tract (Table 9).

Kaua'i County

The MLR that was ran for Kaua'i County showed no dependencies between EBLL rates and the number of confirmed sites (p= 0.828; 95% CI: 0.02041455, 24.592000), potential sites (p= 0.884; 95% CI: 0.20262960, 6.174374), and well sites (p= 0.043; 95% CI: 0.33281289, 1.675130) within a census tract (Table 10).

Table 3. Summary of results for EBLL rates and number of sites within census tracts. Percentages correspond to percent change in EBLL rates as the number of confirmed, potential, and well sites increase. NR: No statistically significant relationship

Region	Number of Confirmed Sites	Number of Potential Sites	Number of Well Sites
Statewide	NR	NR	27.59%
Honolulu Co.	NR	NR	NR
Hawai‘i Co.	NR	NR	NR
Maui Co.	NR	NR	NR
Kaua‘i Co.	NR	NR	NR

Conclusion

Our analysis yielded positive relationships at the state level between BLLs and distance from potential sites and lead concentration values at nearest confirmed site, where median BLLs increased by 0.81% and 0.27%, respectively, as distance and lead concentration value doubled (Table 1). An increase in median BLL as distance from a contaminated site increases implies that the contaminated site is unlikely to be a significant source of lead for children in the area. Since initial predictions were that BLLs would decrease as distance from lead contamination sites increased, these results were unexpected. Possible reasons to explain these occurrences are the majority of exposure occurring at a child’s residence and the possibility of lead being absent altogether when it comes to some potential sites due to a lack of analytical data on those sites. When analyzing the relationship between the BLLs and the explanatory variables at a county level we saw that Honolulu County showed an inverse relationship between BLLs and distance from nearest confirmed site where median BLL decreased by 1.32% as distance doubled (Table 2). Honolulu County also showed positive relationships between BLLs and distance from nearest potential site and lead concentration values at nearest confirmed site where median BLLs increased by 0.88% and 0.38%, respectively, as distance and value doubled (Table 2). Hawaiʻi County showed a positive relationship between BLLs and lead concentration value where median BLL increased by 2.2% as concentrations doubled (Table 3). Both Maui and Kauaʻi counties did not show any dependencies between BLLs and the explanatory variables (Tables 4 and 5). Overall, our results did not demonstrate a correlation of EBLL with residing closer to a confirmed or potential lead contaminated site. This supports the idea that most childhood exposures to lead in Hawaiʻi are occurring from lead contamination in and around the home.

When comparing EBLLs rates and the explanatory variables for the second MLR model we found that at the state level there was a positive relationship between EBLL rates and number of well sites within a census tract where median EBLL rates increased by 27.59% as number of well sites doubled (Table 6). This finding is of interest as drinking water is rarely considered a likely source of lead exposure in Hawaiʻi due to a lack of lead contamination in regulated utility water sources and requires further investigation due to possible confounding variables. No relationship between EBLL rates and the other explanatory variables were found at the county level (Tables 7-10).

Limitations

A limitation that was experienced during this study was the limited quantity of test results due to Hawaiʻi not currently performing universal testing when it comes to blood lead tests. Since children are tested for lead only if they screen in for being at risk, the children getting blood tests for lead have a higher pre-test probability of having an EBLL. Therefore, the dataset does not represent all children in Hawaiʻi. Additional limitations of the available data include test results with incomplete address information, results only having PO boxes or healthcare provider addresses, and the fact that not all eligible test results were able to be geocoded. These limitations resulted in there being only 28,372 test results that were available for mapping and analysis Another possible limitation has to do with our choice of using the largest test result available for cases that had multiple tests regardless if the result was from a venous or capillary blood lead test. The potential issue with this decision is that there is a significant rate of false positive results from capillary lead tests, creating a possibility that we included false positives in our analysis. One final limitation was the search limitations for both the iHEER and Access databases. It's possible that some sites may have been excluded from the analysis due to neither system possessing the functionality to search by contaminant or substance.

Recommendations

A recommendation for a continuation of this study would be to obtain the lead concentration values for the water in the domestic wells included in this study. The inclusion of these data in a future analysis will help further investigate the relationship between well sites and lead exposure. Adding this information would also give deeper insight into the relationships that were observed during this study. One final recommendation would be to obtain housing information, such as age of housing, since older housing is more likely to have lead based paint which is the primary exposure source when it comes to childhood lead poisoning.

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Appendix

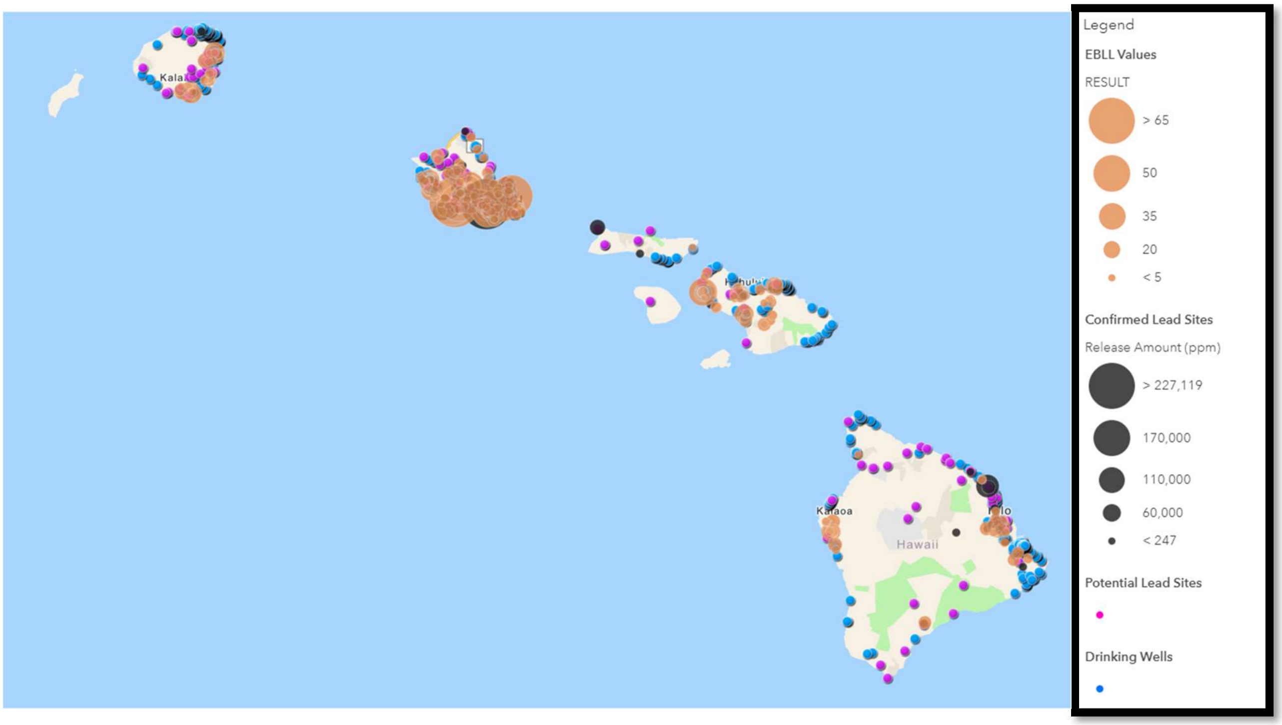


Figure 1. Map of EBLL values at their corresponding residential addresses and the locations of environmental exposure sites with their corresponding lead release values for the entire state of Hawai'i.

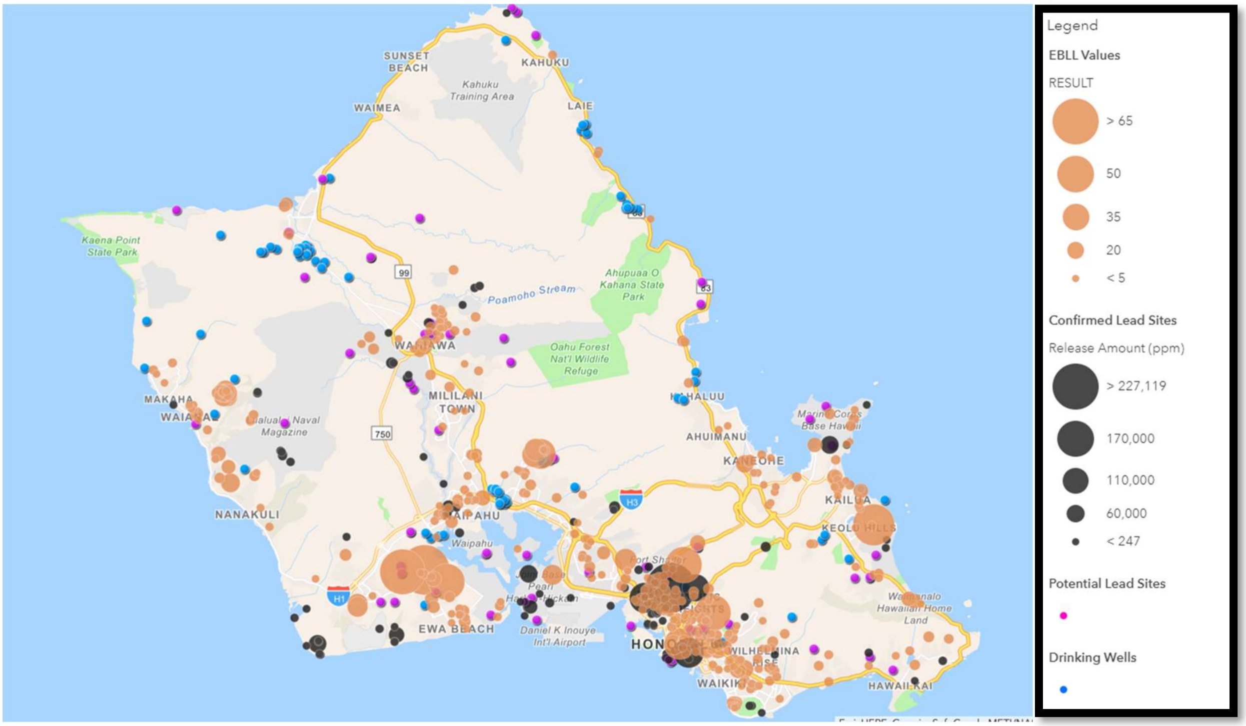


Figure 2. Map of EBLL values at their corresponding residential addresses and the locations of environmental exposure sites with their corresponding lead release values for Honolulu County.

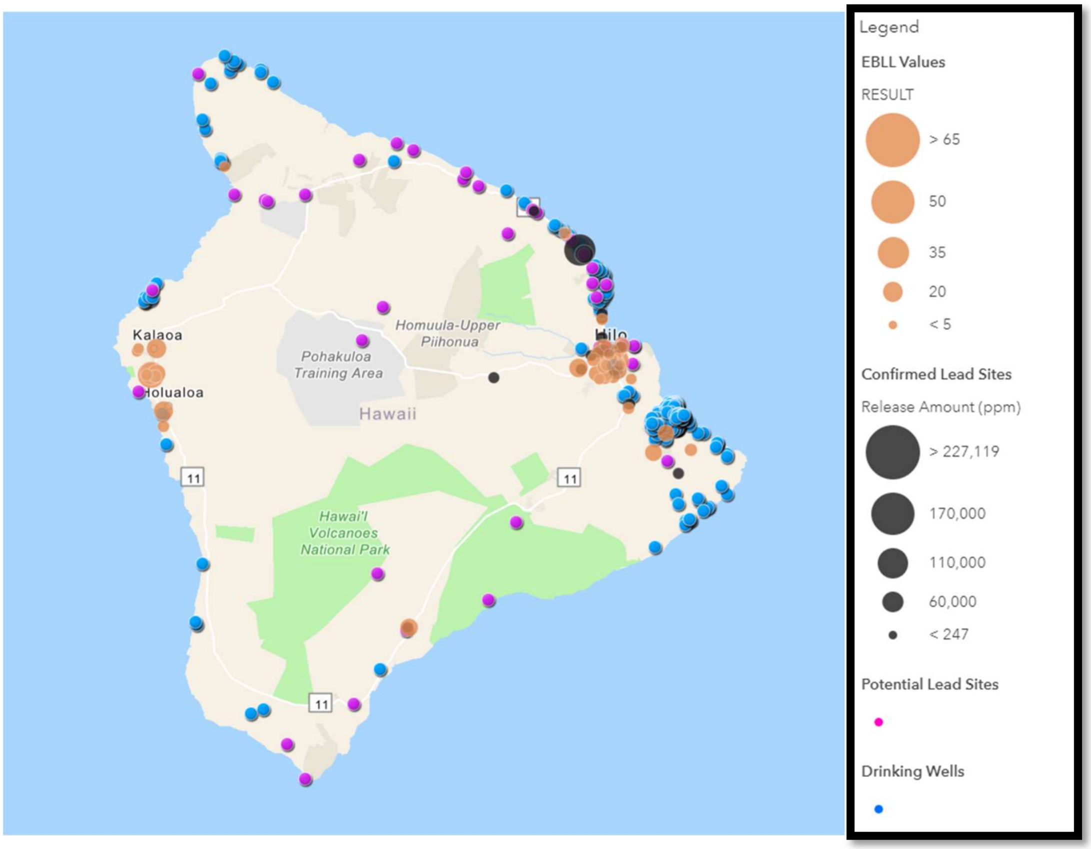


Figure 3. Map of EBLL values at their corresponding residential addresses and the locations of environmental exposure sites with their corresponding lead release values for Hawaiʻi County.

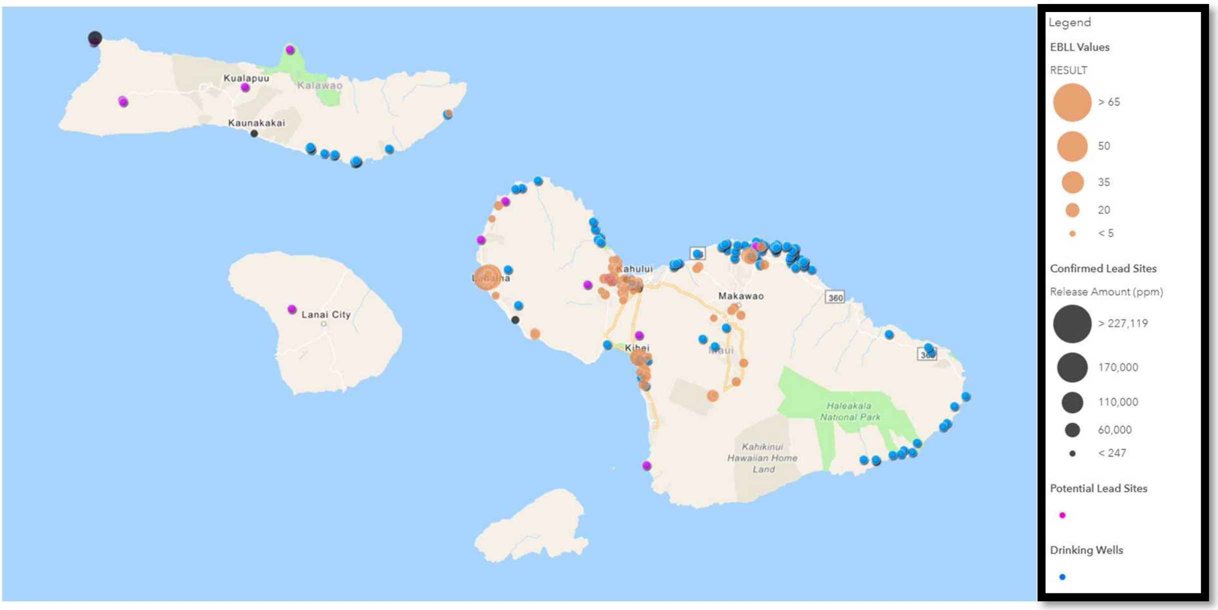


Figure 4. Map of EBLL values at their corresponding residential addresses and the locations of environmental exposure sites with their corresponding lead release values for Maui County.

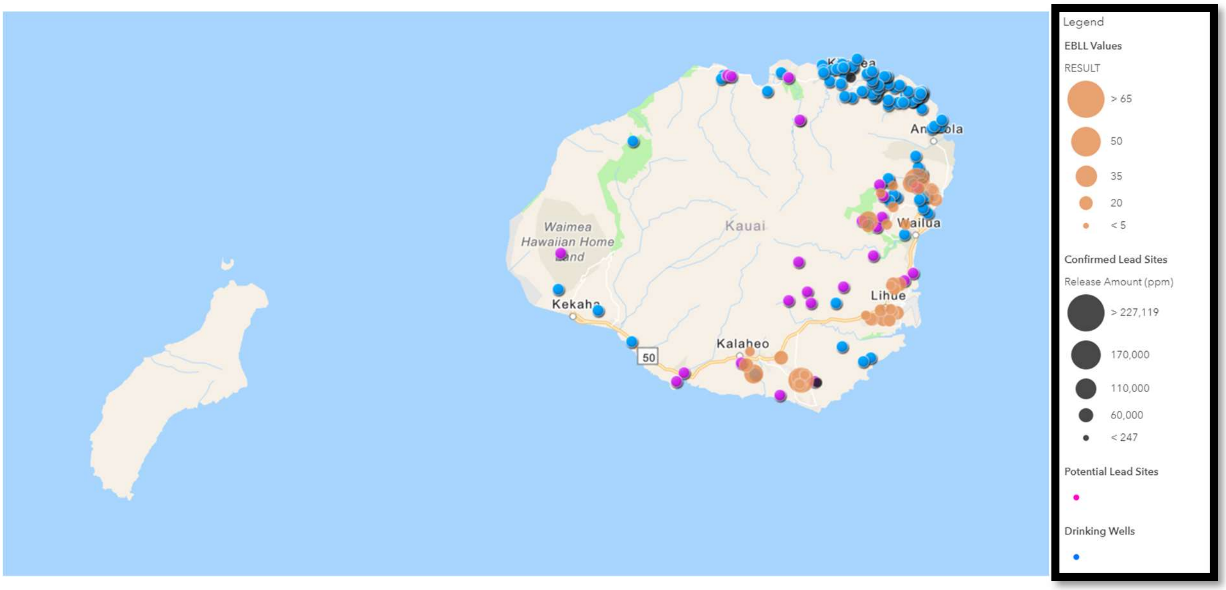


Figure 5. Map of EBLL values at their corresponding residential addresses and the locations of environmental exposure sites with their corresponding lead release values for Kaua‘i County.

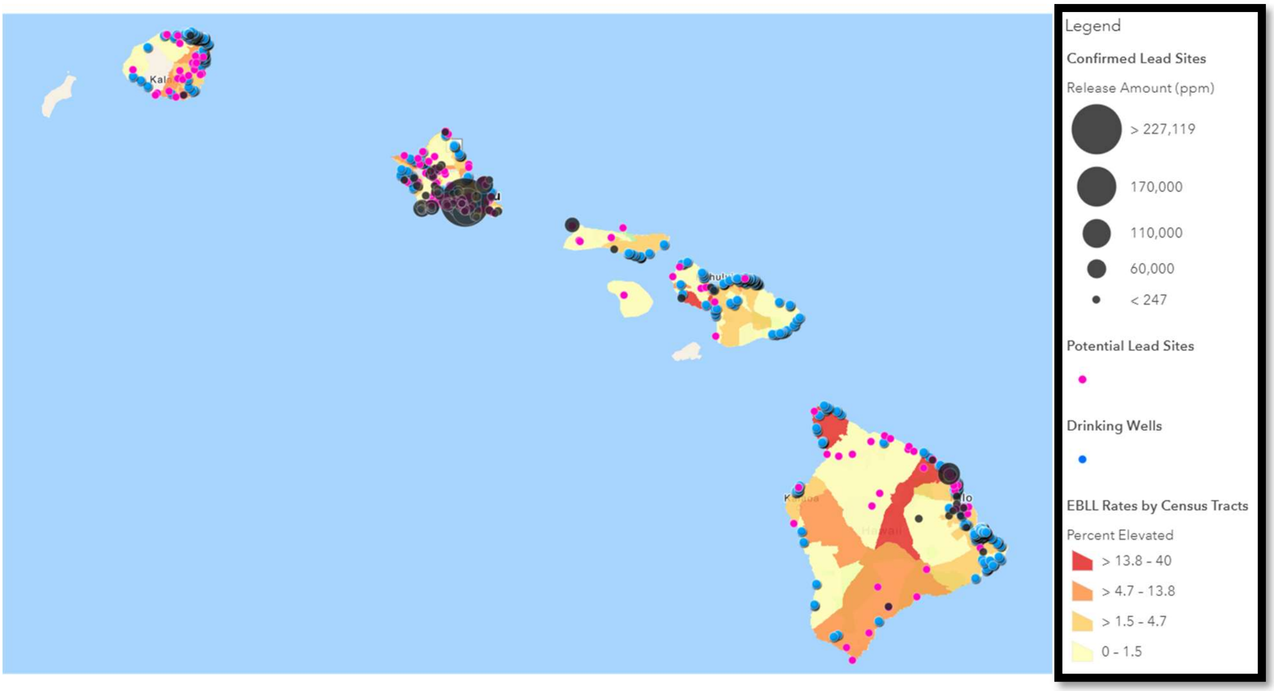


Figure 6. Map of EBLL rates and the locations of environmental exposure sites with their corresponding lead release values within their corresponding census tract for the entire state of Hawai‘i.

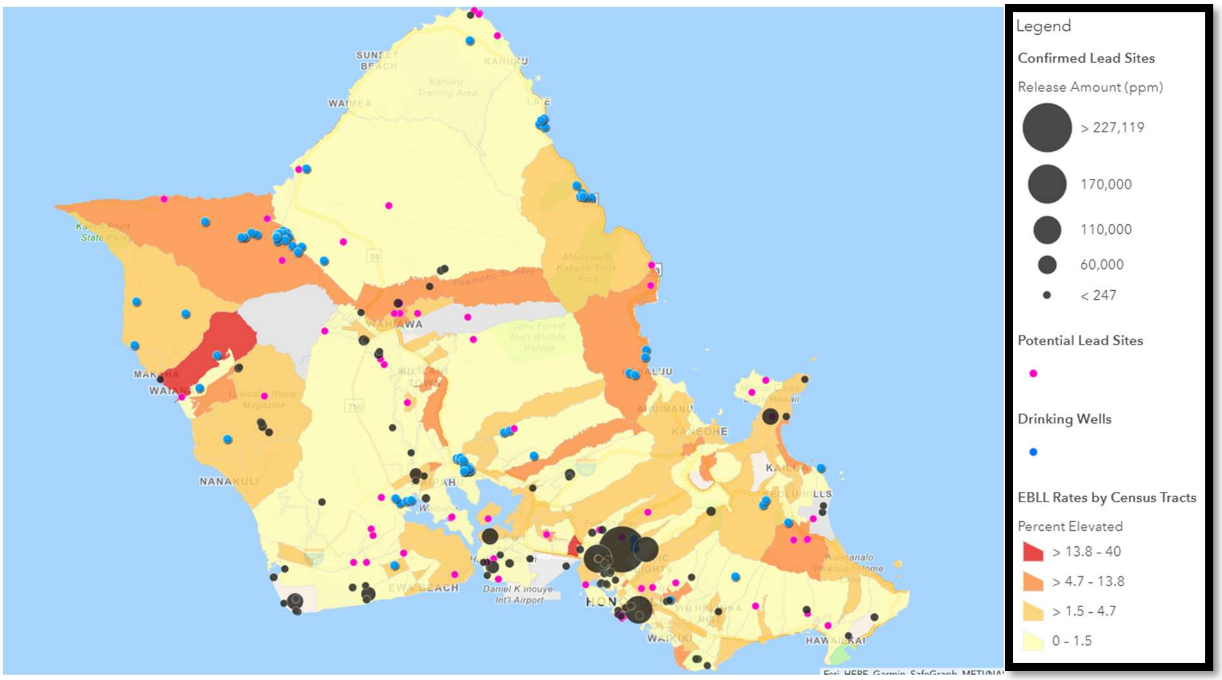


Figure 7. Map of EBLL rates and the locations of environmental exposure sites with their corresponding lead release values within their corresponding census tract for Honolulu County.

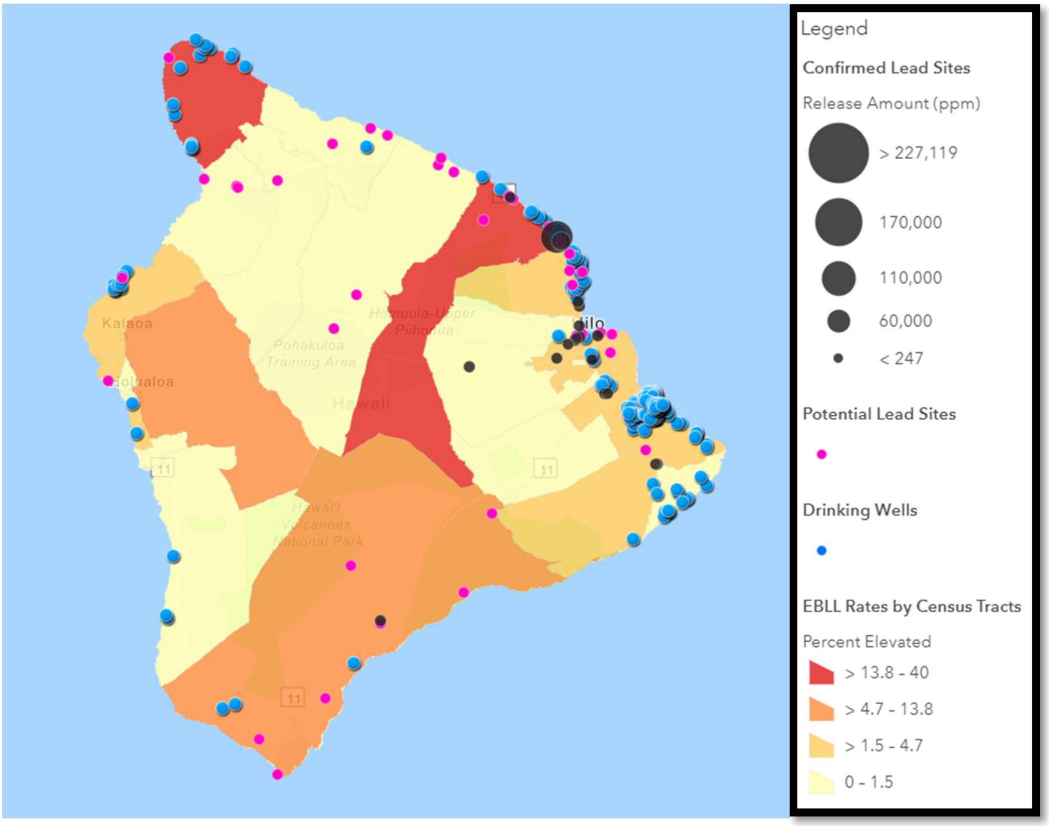


Figure 8. Map of EBLL rates and the locations of environmental exposure sites with their corresponding lead release values within their corresponding census tract for Hawai‘i County.

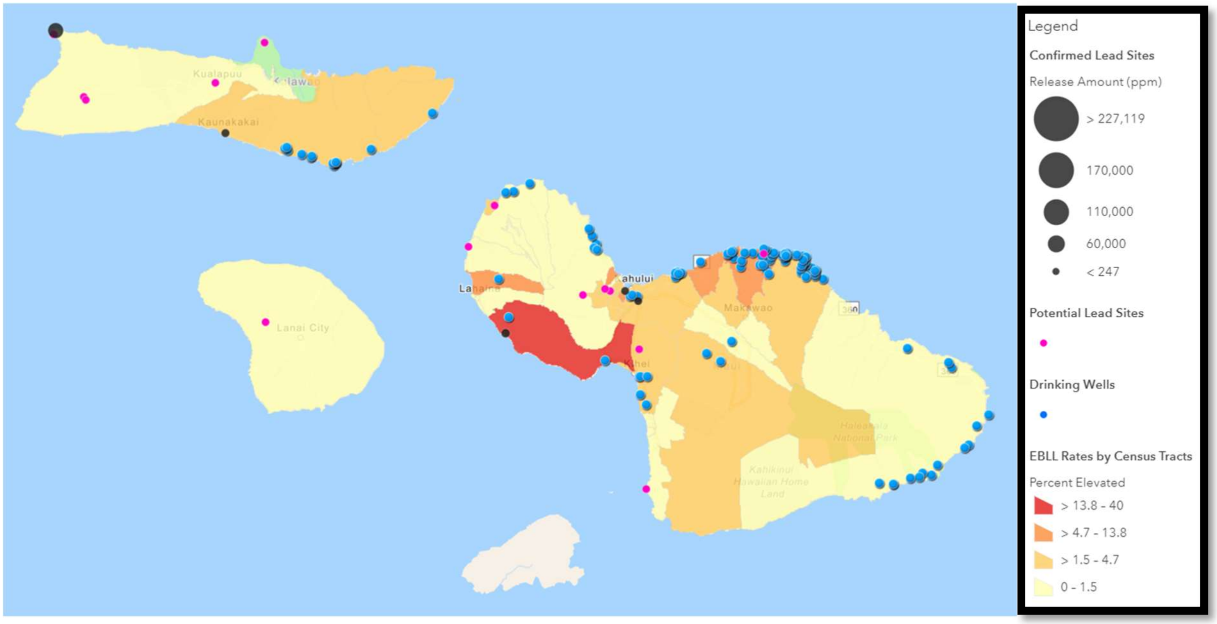


Figure 9. Map of EBLL rates and the locations of environmental exposure sites with their corresponding lead release values within their corresponding census tract for Maui County.

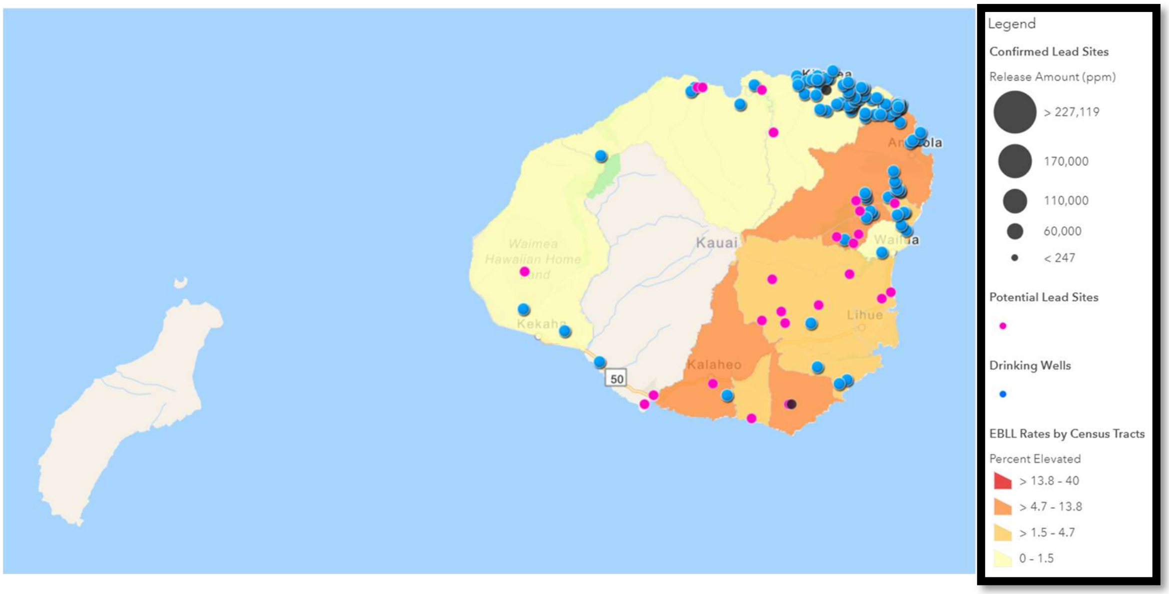


Figure 10. Map of EBLL rates and the locations of environmental exposure sites with their corresponding lead release values within their corresponding census tract for Kaua‘i County.

Table 4. Corresponding p-values and 95% confidence intervals for the associations between BLLs and distance from nearest confirmed site, potential site, well site, lead concentration value at nearest confirmed site, confirmed*release for the Entire State of Hawai‘i.

Environmental Exposure Site/Release	p-value	95% CI
Confirmed Site	$9.04 * 10^{-2}$	0.9955904, 1.000322
Potential Site	$1.73 * 10^{-6}$	1.0047672, 1.011423
Well Site	0.99127	0.9967975, 1.003249
Lead Concentration Value at Nearest Confirmed Site	$1.06 * 10^{-3}$	1.0010686, 1.004260
Confirmed*Release	0.29872	0.9975793, 1.00169

Table 5. Corresponding p-values and 95% confidence intervals for the associations between BLLS and distance from nearest confirmed site, potential site, well site, lead concentration value at nearest confirmed site, and confirmed*release for Honolulu County.

Environmental Exposure Site/Release	p-value	95% CI
Confirmed Site	$9.42 * 10^{-14}$	0.9833242, 0.9902344
Potential Site	$2.65 * 10^{-5}$	1.0046724, 1.012892
Well Site	0.669	0.9954870, 1.0029081
Lead Concentration Value at Nearest Confirmed Site	$2.99 * 10^{-6}$	1.0022260, 1.0054513
Confirmed*Release	0.447	0.9988486, 1.0026169

Table 6. Corresponding p-values and 95% confidence intervals for the associations between BLLS and distance from nearest confirmed site, potential site, well site, lead concentration value at nearest confirmed site, and confirmed*release for Hawaiʻi County.

Environmental Exposure Site/Release	p-value	95% CI
Confirmed Site	0.4452	0.992705, 1.003223
Potential Site	0.317577	0.9936728, 1.01974192
Well Site	0.955791	0.9902388, 1.00931
Lead Concentration Value at Nearest Confirmed Site	$0.3 * 10^{-36}$	1.0098876, 1.033862513
Confirmed*Release	0.897303	0.9907515, 1.008177

Table 7. Corresponding p-values and 95% confidence intervals for the associations between BLLS and distance from nearest confirmed site, potential site, well site, lead concentration value at nearest confirmed site, and confirmed*release for Maui County.

Environmental Exposure Site/Release	p-value	95% CI
Confirmed Site	0.3540	0.9875291, 1.004502
Potential Site	0.9711	0.9889312, 1.010784
Well Site	0.3181	0.9983700, 1.005031
Lead Concentration Value at Nearest Confirmed Site	0.0596	0.9991570, 1.043550
Confirmed*Release	0.3037	0.9558820, 1.014166

Table 8. Corresponding p-values and 95% confidence intervals for the associations between BLLS and distance from nearest confirmed site, potential site, well site, lead concentration value at nearest confirmed site, and confirmed*release for Kaua‘i County.

Environmental Exposure Site/Release	p-value	95% CI
Confirmed Site	0.2098	0.9944416, 1.001226
Potential Site	0.275577	0.9723001, 1.008046
Well Site	0.5969	0.9960345, 1.00693
Lead Concentration Value at Nearest Confirmed Site	0.9902	0.9867566, 1.013592
Confirmed*Release	0.0777	0.9558820, 1.014166

Table 9. Corresponding p-values and 95% confidence intervals for the associations between EBLL rates and number of confirmed sites, potential sites, and well sites within census tracts for the entire state of Hawai‘i.

Environmental Exposure Site	p-value	95% CI
Confirmed Sites	0.38116	0.8441122, 1.5558406
Potential Sites	0.84168	0.7630927, 1.3930962
Well Sites	0.00314	1.0861476, 1.4987829

Table 10. Corresponding p-values and 95% confidence intervals for the associations between EBLL rates and number of confirmed sites, potential sites, and well sites within census tracts for Honolulu County.

Environmental Exposure Site	p-value	95% CI
Confirmed Sites	0.931	0.6933336, 1.398458
Potential Sites	0.330	0.7993962, 1.943579
Well Sites	0.141	0.9132699, 1.88531

Table 11. Corresponding p-values and 95% confidence intervals for the associations between EBLL rates and number of confirmed sites, potential sites, and well sites within census tracts for Hawai‘i County.

Environmental Exposure Site	p-value	95% CI
Confirmed Sites	0.141	0.7939544, 4.687093
Potential Sites	0.690	0.4511887, 1.706171
Well Sites	0.065	0.9813838, 1.818504

Table 12. Corresponding p-values and 95% confidence intervals for the associations between EBLL rates and number of confirmed sites, potential sites, and well sites within census tracts for Maui County.

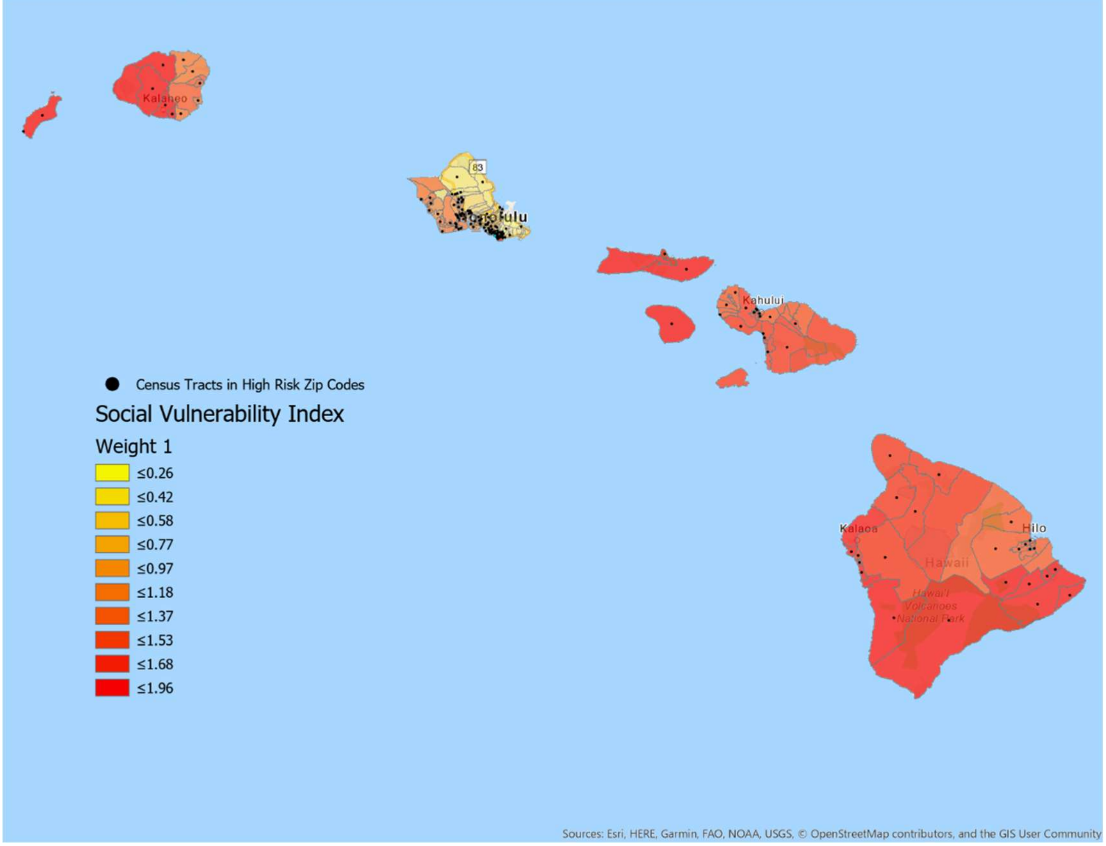
Environmental Exposure Site	p-value	95% CI
Confirmed Sites	0.240	0.4057147, 12.620443
Potential Sites	0.255	0.2061453, 1.543982
Well Sites	0.435	0.7760401, 1.77534

Table 13. Corresponding p-values and 95% confidence intervals for the associations between EBLL rates and number of confirmed sites, potential sites, and well sites within census tracts for Kaua‘i County.

Environmental Exposure Site	p-value	95% CI
Confirmed Sites	0.828	0.02041455, 24.592000
Potential Sites	0.884	0.20262960, 6.174374
Well Sites	0.043	0.33281289, 1.675130

Other Relevant Information

High Risk Maps



Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 1. High risk map for the entire state of Hawai‘i based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.

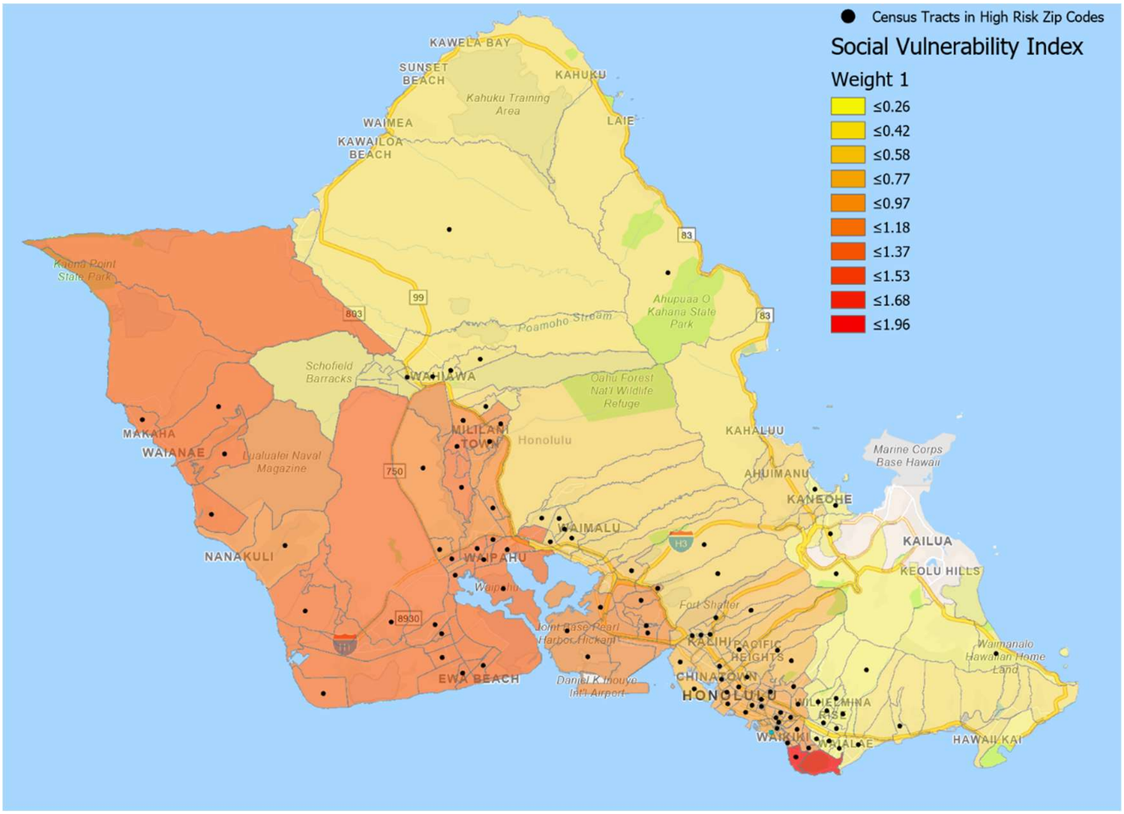


Figure 2. High risk map for O‘ahu based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.

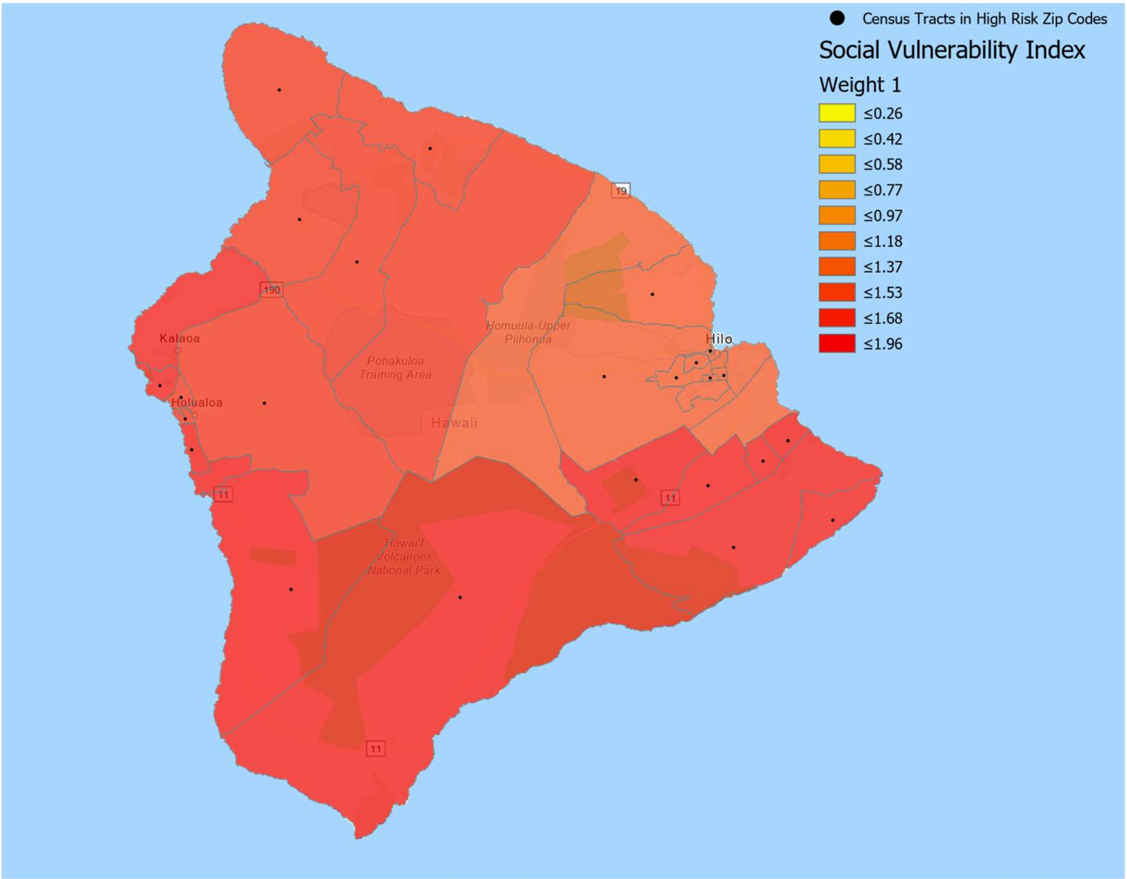


Figure 3. High risk map for Hawai‘i Island based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.

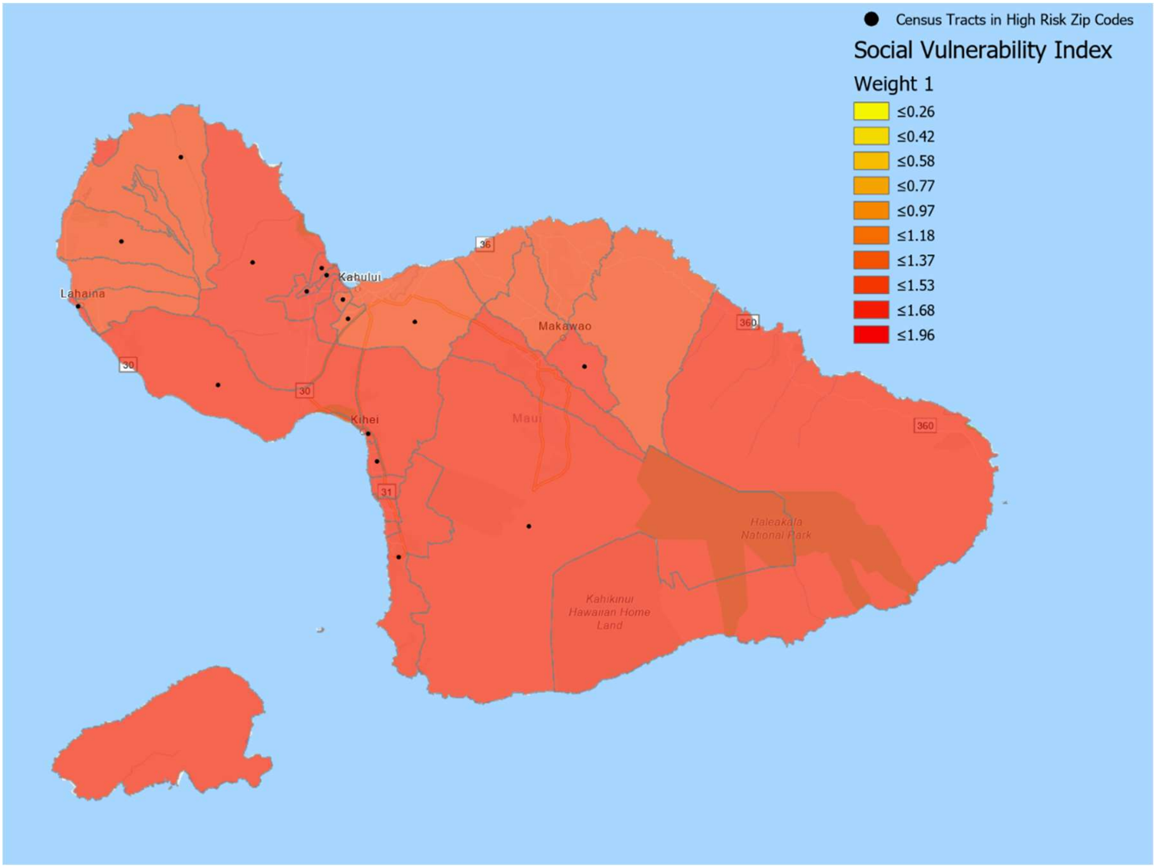


Figure 4. High risk map for Maui based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.

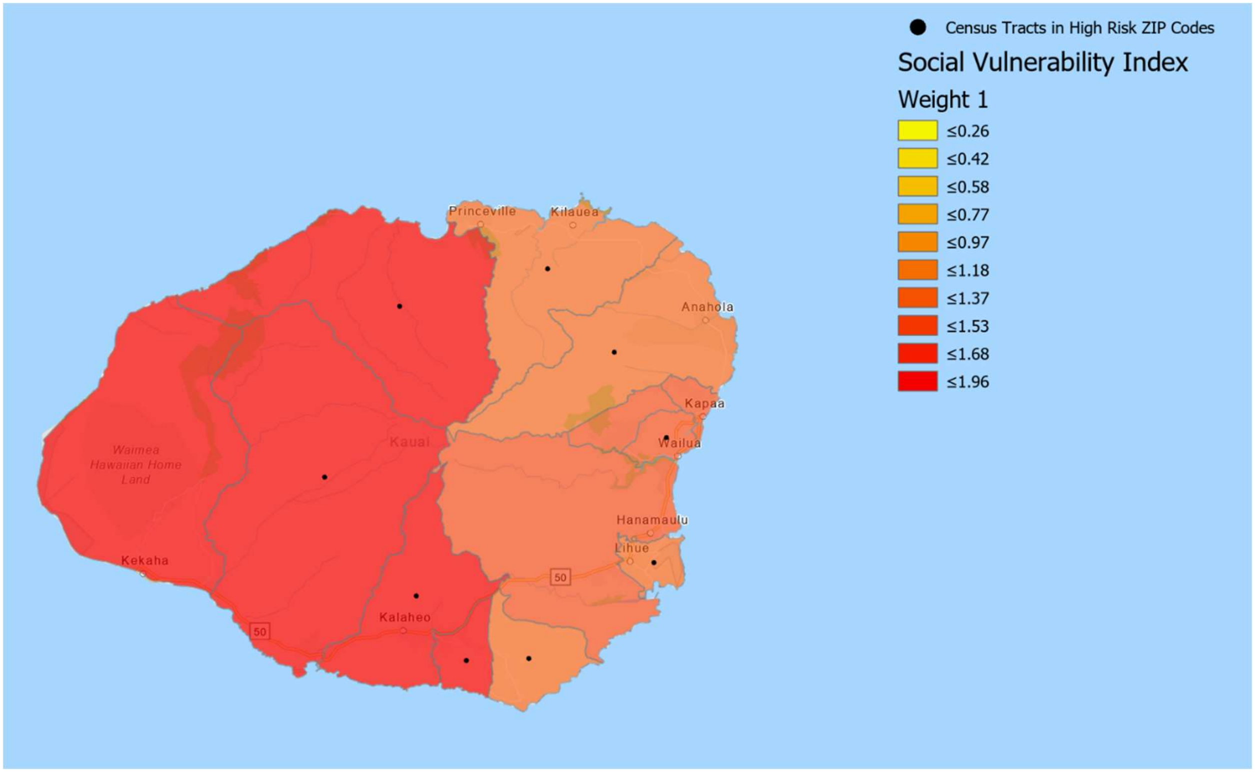


Figure 5. High risk map for Kaua'i based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.

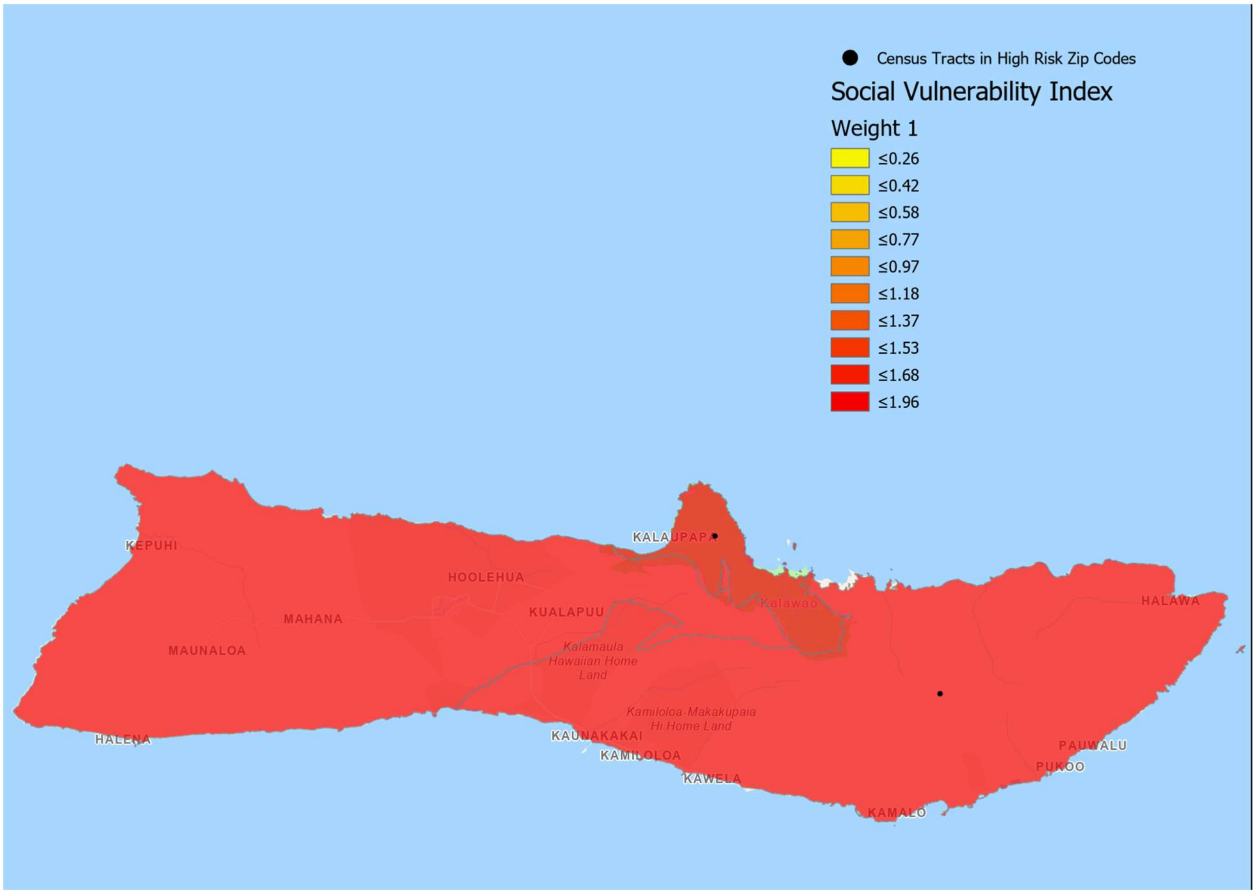


Figure 6. High risk map for Moloka‘i based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.

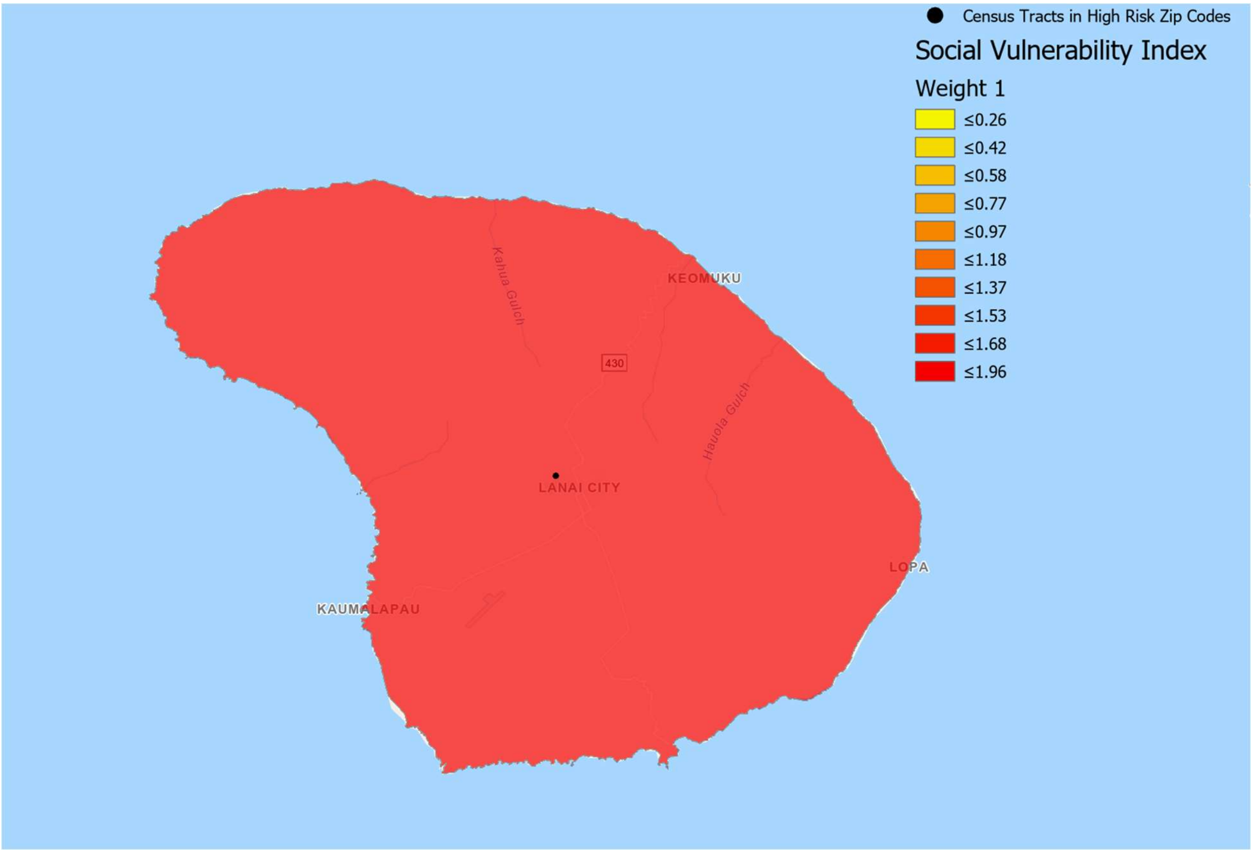


Figure 7. High risk map for Lānaʻi based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.

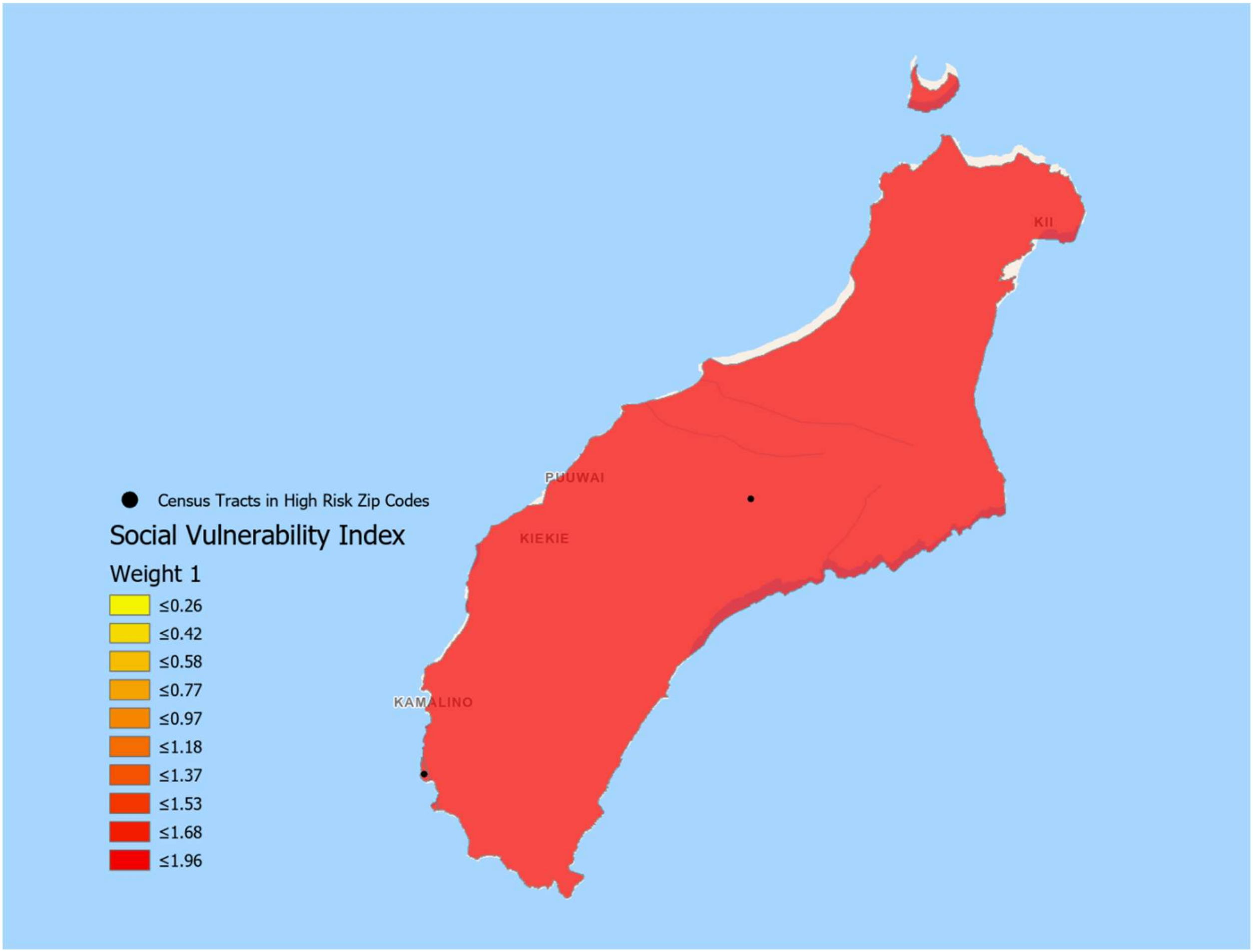


Figure 8. High risk map for Niʻihau based on the Social Vulnerability Index (SVI) which takes into account factors such as socioeconomic status, household composition and disability, minority status and language, and age of housing in its analysis. Increases in weight 1 values and increasingly darker colors represent increasing in risk. The black dots denote census tracts that have already been designated as high risk by the current zip code based system.