Spatial Analysis of Soil Lead Exposures from Lead Poisoning Tragedy in Artisanal and Small-Scale Gold Mining Villages of Zamfara, Nigeria

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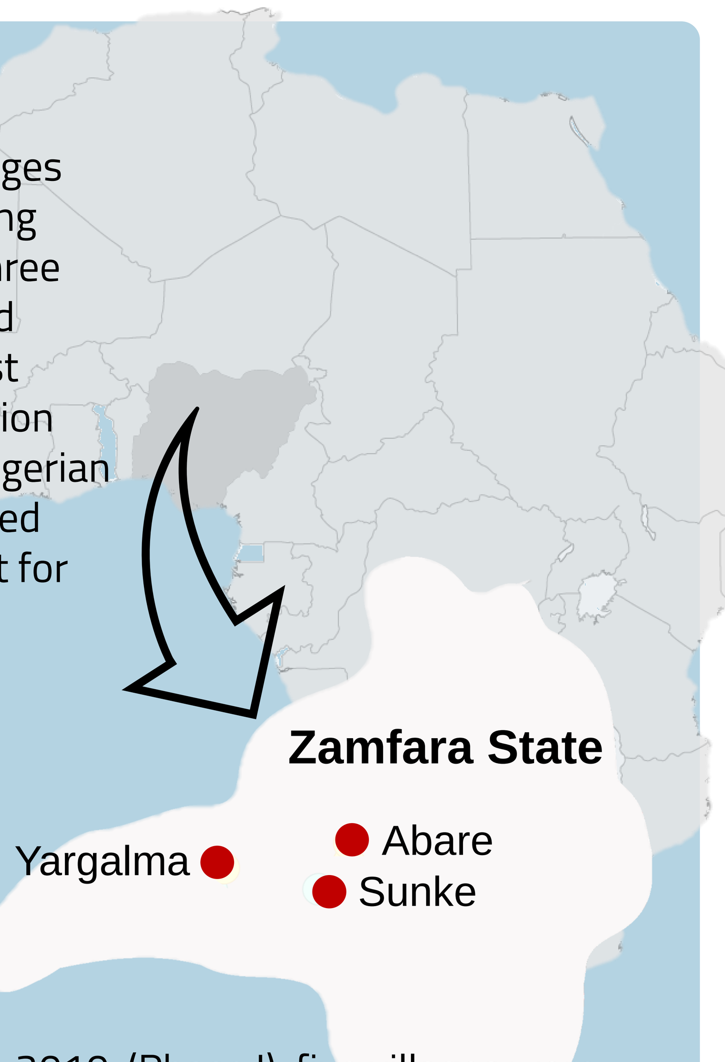
Background



In 2010, several remote northern Nigerian villages experienced unprecedented mass lead poisoning resulting in the death of over 400 children in three months.[1] Artisanal gold ore processing resulted in severe lead exposures via incidental soil/dust ingestion. TerraGraphics International Foundation (TIFO), Médecins Sans Frontières (MSF), and Nigerian health and environmental agencies implemented emergency remediation and medical treatment for exposed children. Handheld X-ray Fluorescent Spectrometer (XRF) was used to assess contamination before and after remediation, resulting in a database of >10,000 soil lead concentrations. The interdisciplinary project team remediated eight villages in Zamfara State, including 820 homes, reducing exposures for nearly 3000 children and 16,000 community members.[2] Two villages were assessed and remediated from May-June 2010 (Phase I), five villages were addressed from Sept 2010-March 2011 (Phase II), and one village was remediated in 2013 (Phase III). Pre-remediation residential *in-situ* XRF soil lead levels averaged 1,113 mg/kg (range 19 - 35,380 mg/kg), and decreased to average 94 mg/kg post-remediation.[3] Geometric mean blood lead levels decreased from 149 μg/dL pre-remediation to <30 μg/dL post-remediation.[2,3]

Figure 1. (Left to right) Incidental ingestion of soil and dust is a significant source of children's exposure to environmental contaminants; remediation crew removing contaminated soil in a compound; Zamfara Environmental Sanitation Agency using XRF to measure lead in compound soil.

Objectives

1. Use XRF database to quantify spatial variability in *in situ* soil lead concentrations for each home, neighborhood, and village
2. Determine spatial factors with potential impact on children's exposure

Methods

1. Organize and geolocate data
   Compare XRF data to compound (home) and exterior (common) area maps to confirm correct soil lead concentration for each location. Import soil lead data into ArcGIS™
2. Compute summary geo-statistics for compounds, exteriors, and neighborhoods
   Use three-step spatial model to determine neighborhood means for each compound, inclusive of exteriors, at radius lengths of 100-500' at 100' increments

3a. Find exterior effects
   Repeat step 2 by examining neighborhood means of exteriors and neighborhood means of interiors, excluding surrounding exteriors

3b. Neighborhood analysis
   Use the Cluster and Outlier Analysis ArcGIS® tool and Anselin Local Moran's I statistic to identify compound outliers and clusters

Results

- Compared to the Phase I village (Yargalma), Phase II villages (Sunke and Abare) have lower community means and greater variability in lead concentrations, resulting in clusters of high or low areas (Fig 4a-c)
- Depending on a child's independent mobility, children from the same home may have different exposure severity (Fig 5a-c)
- Children in Phase II compounds with low soil lead concentrations can experience high exposure if living in a high neighborhood (and vice versa) (Fig 6a-c)
- Exterior areas with wells and where grinding occurred have higher concentrations of lead than other types of exteriors (data not shown)

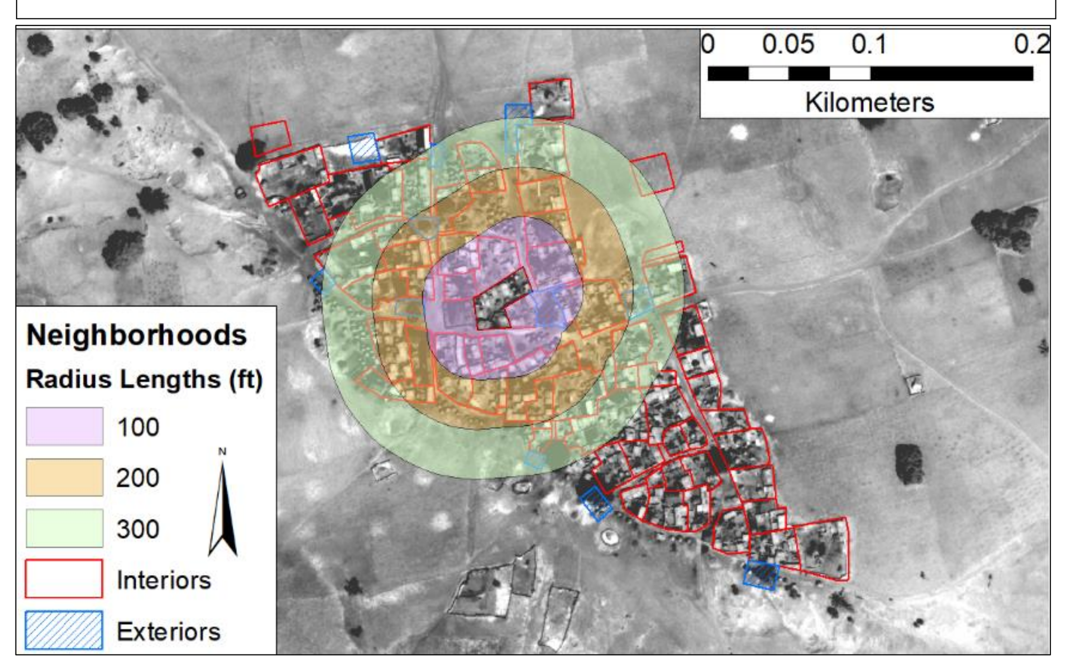


Figure 2. Yargalma village map showing the radius areas of 100', 200', and 300' used to calculate the neighborhood means (400' and 500' not shown)

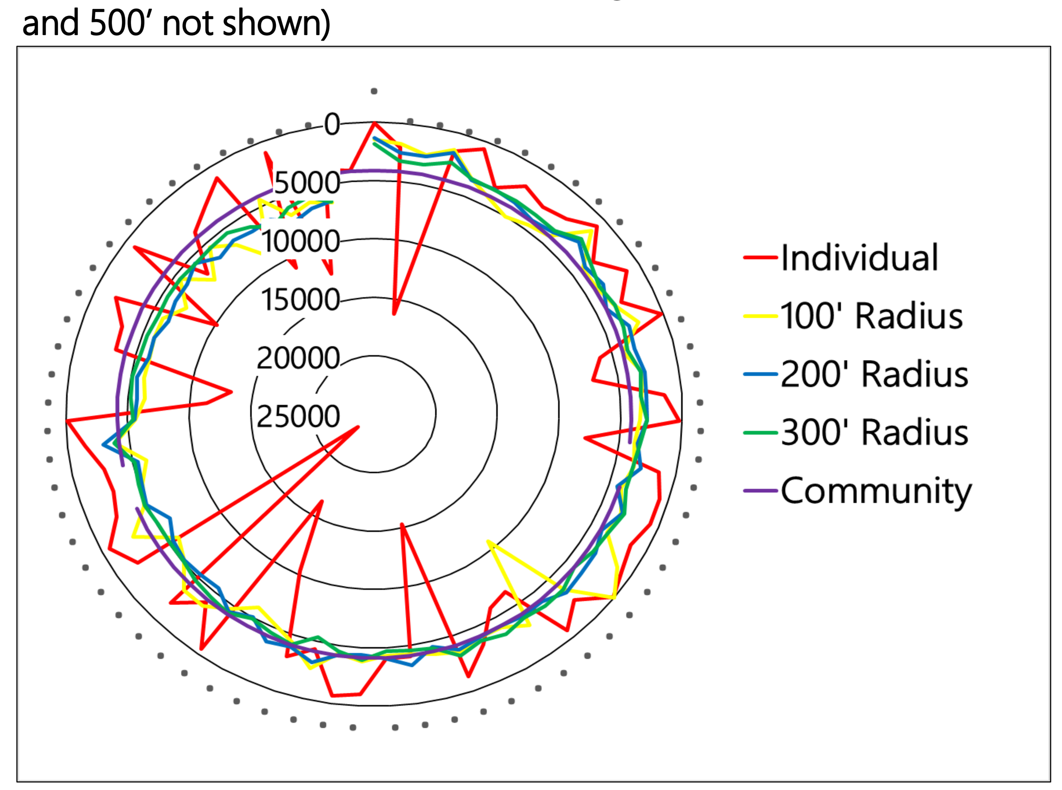
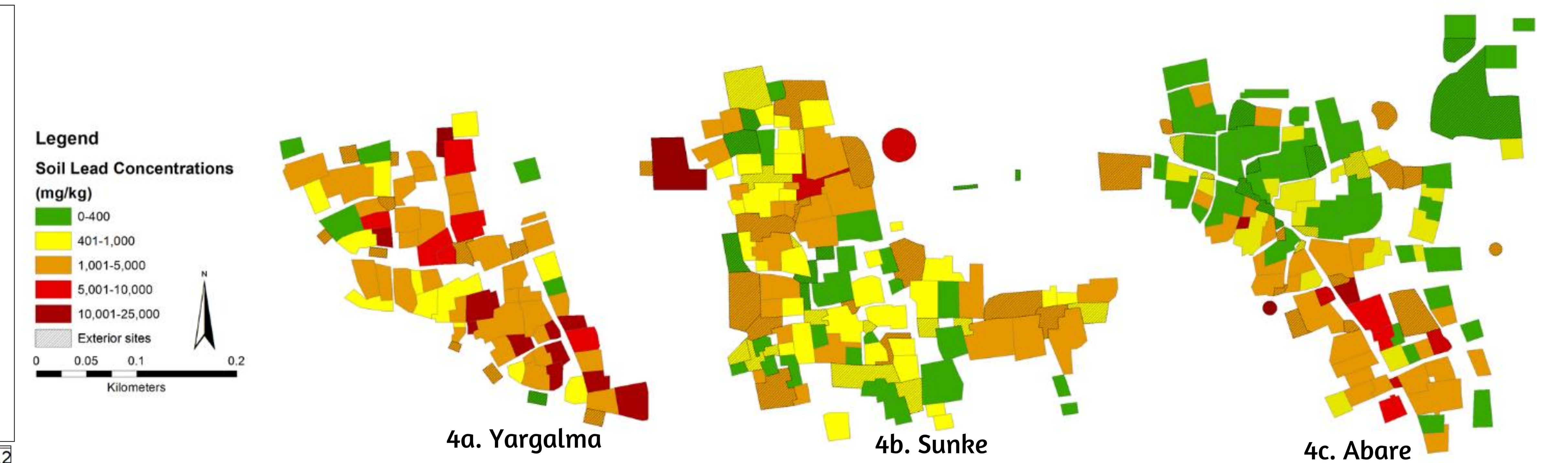
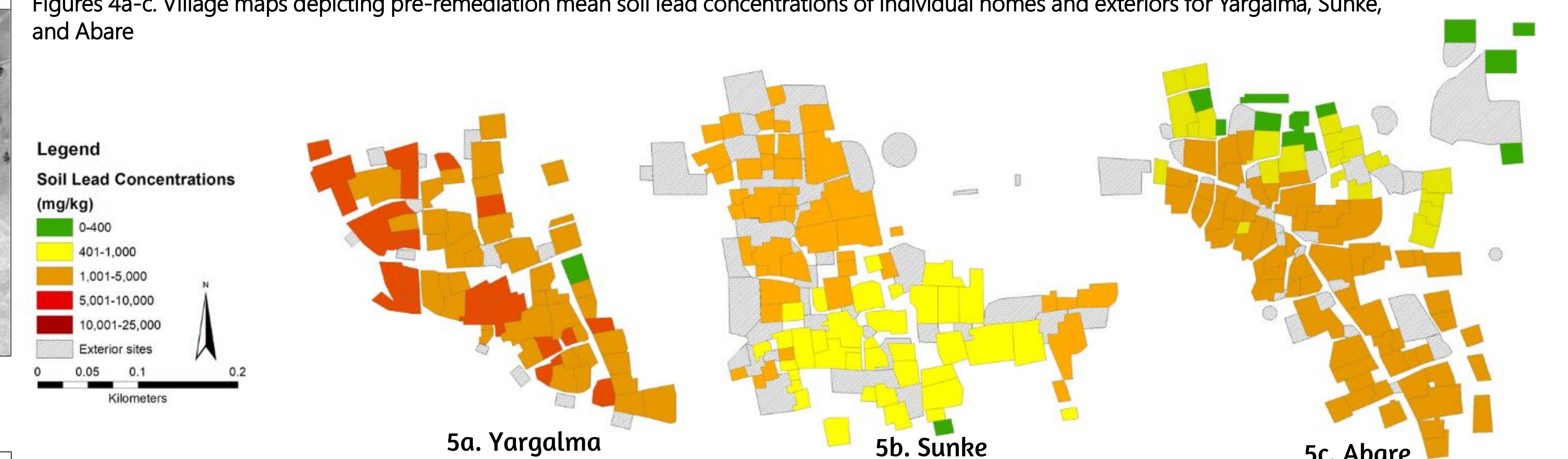


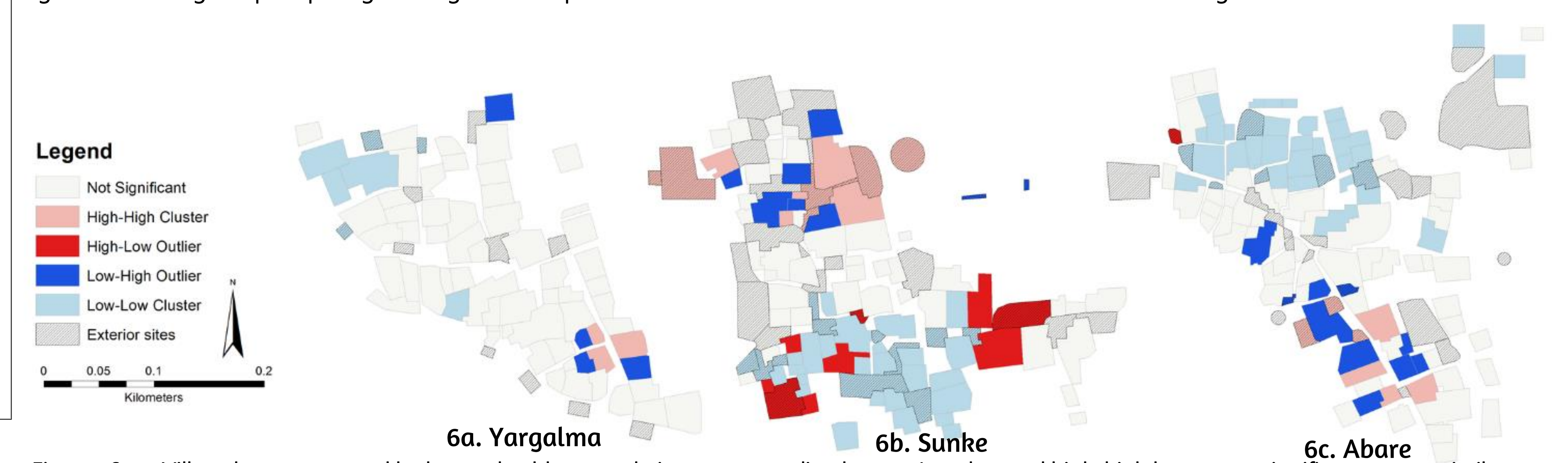
Figure 3. Radar graph of Yargalma showing pre-remediation soil lead concentrations for individual homes, neighborhood areas at radius lengths of 100', 200', and 300', and the overall community mean. Each dot around the outer circle represents one compound.



Figures 4a-c. Village maps depicting pre-remediation mean soil lead concentrations of individual homes and exteriors for Yargalma, Sunke, and Abare



Figures 5a-c. Village maps depicting the neighborhood pre-remediation mean soil lead concentrations for each home using a radius of 200 feet



Figures 6a-c. Village homes grouped by hot and cold spots relative to surrounding homes. Low-low and high-high homes are significant among similar nearby concentrations (low home in a low surrounding area or high home in a high surrounding area, respectively). Low-high and high-low homes are significantly different from nearby areas (low home in a high area and high home in a low area, respectively)

Discussion and Conclusions

This study demonstrates the influence of neighborhood size and compound location on child lead exposure. To account for the wide variation of contamination between homes, neighborhoods, and communities, a combination of soil lead concentrations from each is important in predicting exposure. The Nigeria lead poisoning tragedy provides a unique opportunity to better understand heavy metal exposures in low-income, subsistence communities, where environmental health crises are seen with increasing frequency.[4] Eighty-two percent (82%) of lead poisoning deaths occur in low and middle-income countries and children under the age of five are at the highest risk.[5] Analysis of XRF data from the Zamfara crisis can be applied to other artisanal mining communities.

Future Analyses

- Complete pre-remediation radius analyses for remaining Zamfara villages and look for patterns among phases, neighborhoods, etc.
- Examine proximity to high-concentration exterior areas as a potentially significant exposure variable
- Complete similar analyses using post-remediation and Remedial Effectiveness Evaluation (REE) soil lead data; assess differences between pre, post-rem, and REE spatial results
- Use existing geo-located blood lead level dataset and the Integrated Exposure Uptake Biokinetic (IEUBK) model to determine the best fitting radius value for a typical child's neighborhood

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Literature Cited

1. Thurtle, Natalie, Jane Greig, Lauren Cooney, Yona Amitai, et al. 2014. "Description of 3,180 Courses of Chelation with Dimercaptosuccinic Acid in Children ≤5 y with Severe Lead Poisoning in Zamfara, Northern Nigeria: A Retrospective Analysis of Programme Data." PLOS Medicine 11 (10): 1-18. pmed.1001739. doi:10.1371/journal.pmed.1001739. **2.** Bartrem, Casey, Simba Tirima, Ian von Lindern, Margrit von Braun, et al. 2013. "Unknown risk: co-exposure to lead and other heavy metals among children living in small-scale mining communities in Zamfara State, Nigeria." International Journal of Environmental Health Research (2013): 1-16. http://dx.doi.org/10.1080/09603123.2013.835028 **3.** Tirima, Simba, Casey Bartrem, Ian von Lindern, Margrit von Braun, et al. 2016. "Environmental remediation to address childhood lead poisoning epidemic due to artisanal gold mining in Zamfara, Nigeria." Environmental Health Perspectives 124 (9): 1471–1478. http://dx.doi. org/10.1289/ehp.1510145. **4.** Pruss-Ustun Annette, J Wolf, Carlos Corvalon, R Bos, and Maria Neira. 2016. "Preventing disease through healthy environments: A global assessment of the burden of disease from environmental risks estimate of the environmental burden of disease." World Health Organization (2016): 1-176. ISBN 978 92 4 156519 6 **5.** Landrigan J, Philip, Richard Fuller, Nereus J R Acosta, Olusoji Adeyi, et al. 2017. "The Lancet Commission on pollution and health." Lancet 391: 462–512. http://dx.doi.org/10.1016/S0140-736(17)32345-0