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The Current State of Community Engagement in Urban Soil Pollution Science

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Environmental burdens disproportionately impact the health of communities of color and low-income communities. Contemporary and legacy industry and land development may pollute soils with pesticides, petroleum products, and trace metals that can directly and indirectly impact the health of frontline communities. Past efforts to study environmental injustice have often excluded those most impacted, created distrust of researchers and other experts among frontline communities, and resulted in little to no structural change. Prevailing research methods value formal knowledge systems, while often dismissing the knowledge of those most harmed by environmental hazards. Community science has emerged as a process of doing science that centers the participation of community members, who may co-develop research questions, inform study methods, collect data, interpret findings, or implement projects. While community science is one of several research methods that can advance community goals, it can also be implemented in ways that are extractive or harm communities. Research on best practices for community science is robust; however, how community science has been used in urban soil research is not well understood. We identified sixteen relevant urban soil studies published between 2008 and 2021 that used community science methods or engaged with community members around soil pollution. We then assessed the selected studies using two community engagement models to better understand community engagement practices in urban soil pollution science. The Spectrum of Community Engagement to Ownership (SCEO) model, which organizes engagement from level 0 (ignore) to 5 (defer to) was used to assess all studies. Studies that explicitly aimed to co-develop research with the community were additionally assessed using the Urban Sustainability Directors Network High Impact Practices (USDN HIPs). The majority of the studies assessed were aligned with levels 1–3 of the SCEO. Studies assessed as levels 4–5 of the SCEO were associated with delegating power to communities, community engages decision-making, creating space for community voices, and remediation efforts. We propose that future urban remediation soil pollution work that engages at higher levels of the SCEO and employs USDN HIPs, will be more effective at addressing crucial environmental health challenges by supporting, equitable, inclusive, and sustainable solutions.

Keywords: citizen science, environmental justice, urban ecology, equity, community science, participatory research, community-academic partnership

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INTRODUCTION

Soils in urban landscapes vary widely due to factors introduced by human settlement, which result in a "mosaic" of soil conditions (Pouyat et al., 2010). Urbanization can degrade soil systems through the formation and management of urban infrastructure; erosion from construction and its associated materials; industrial manufacturing, such as spills and waste; transportation; waste dump sites; management supplements like irrigation and fertilization; and land cover alteration (Law et al., 2004; Tenenbaum et al., 2006; Zhu et al., 2006; Byrne, 2021). Urbanization-caused soil degradation can generate repercussions for biodiversity, ecosystem services, and human health (Byrne, 2021). Indirect effects of urbanization can also impact soil conditions through mechanisms such as the urban heat island effect, atmospheric deposition, and shifts in animal and plant species (Brazel et al., 2000; Lovett et al., 2000; Savva et al., 2010; Rao et al., 2013; Huang et al., 2015; Hall et al., 2016).

The impacts of soil pollution continue to pose risks to the health of frontline communities. Frontline communities are groups of people who are directly affected by injustice in society (on the "frontlines") and experience disproportionate rates of environmental health risk because of these existing inequities (The National Association for the Advancement of Colored People [NAACP], 2010). Frontline communities often include people of color, people who are low-income, who have disabilities, who are LGBTQ, who identify as women, etc., (The National Association for the Advancement of Colored People [NAACP], 2010). Traditional "top down," or extractive, research models value the knowledge of the formally trained expert over that of frontline communities and prioritize evidence in the form of empirical and testable results (Tucker and Taylor, 2004). Community perspectives are often discounted or viewed as biased (Tucker and Taylor, 2004). In addition, observational and epidemiological evidence of harm is sometimes rejected by the researchers based on statistical insignificance, denying the damage from toxic waste facilities and derailing regulation efforts (Shrader-Frechette, 2017). The use of such research methods have generated distrust of scientists, researchers, and other experts in the communities in which they work (Davis and Ramirez-Andreotta, 2021).

Lack of structural change or benefit to communities from research, in addition to the distrust of researchers generated within frontline communities, has resulted in a shift in research methods toward more inclusive methods. In these models, community members often work in tandem with academia, non-profit organizations (NGOs), and government agencies to research, monitor, and respond to community member concerns (Conrad and Hilchey, 2010). This type of research may manifest itself in various formats, ranging from community-based participatory research (CBPR), participatory action research (PAR), community-engaged research (CEnR), and more (Davis and Ramirez-Andreotta, 2021). All of these approaches are rooted in the active participation of impacted community members who may co-develop research questions, inform study methods, collect data, or interpret findings.

Both citizen and community science center the participation of community members and use various community engagement research methods and formats previously mentioned. Community science aspires to protect human rights, create measurable advancements for communities who face environmental injustices, and is motivated by social action (Cooper et al., 2021). Community science often emerges from a need for scientific evidence that is outside of institution-based science agendas (Cooper et al., 2021). Citizen science, on the other hand, exists within the realm of institution-based science and often centers the work of volunteers within research (Cooper et al., 2021). While the term citizen science originally referred to institutionally-led projects in which data was collected by volunteers, the term has since expanded to describe research with public-inclusive approaches that aims to achieve goals around science, engagement, education, policy, and empowerment (Cooper et al., 2021). This manuscript is inclusive of both community and citizen science approaches and collectively refers to them as participatory approaches.

Participatory approaches offer a model for the co-production of environmental research; however, they can also be implemented in ways that are extractive. Community partnerships with scientists, university researchers, and/or local government have the potential to harm frontline communities by manipulating analytical techniques, such as using small or non-representative samples, distorting uncertainty, and misusing statistical significance (Shrader-Frechette, 2017). Partnerships can also manifest in ways in which community members collect data as free labor without mechanisms or support for community members to participate in creating research questions or analyzing results. For example, "helicopter research" is a term used to describe when researchers from outside of a community conduct a study with the help of local infrastructure and local knowledge, but then publish the results of the study without the involvement of community members and without structural improvement for local communities (Minasny et al., 2020).

Despite these potential pitfalls, participatory approaches, when implemented ethically, could be an important model for urban soil pollution science. A recent online survey found that the majority of LA County residents are concerned about soil contamination (Schwarz et al., 2022). The same study shared that stakeholders across LA County see a need for accessible soil testing and data, communication and engagement that centers underserved communities, and building alliances across organizations, individuals, and agencies focused on urban soils (Schwarz et al., 2022). Additionally, urban soils offer an opportunity for communities to connect with ecosystems and learn about ecological systems through citizen science (Pouyat et al., 2017).

Participatory approaches may help address knowledge gaps and concerns of community members by shifting decision-making power toward community members. Additionally, participatory approaches have been found to improve both research quality and community understanding of health hazards (Davis and Ramirez-Andreotta, 2021). A smaller pool of evidence also supports the view that participatory approaches may support and create structural change to address environmental health hazards (Davis and Ramirez-Andreotta, 2021). Participatory approaches are also beneficial to scientists through the potential to engage large numbers of people, and thus offer a mechanism for more frequent monitoring compared to traditional scientific research (Roger and Motion, 2021). This expansive potential may support both researchers and policymakers in understanding global problems and supporting local solutions (Roger and Motion, 2021). Partnering with community members may also make private lands accessible to research that otherwise wouldn't be (Kobori et al., 2016).

The literature review presented here aims to assess current community engagement practices in urban soil pollution science. We believe this work may serve as a guide for future urban soil pollution research and policy that aims to effectively engage communities and address community goals. In this study, we ask the following research questions:

1) Through what processes have communities been engaged in existing urban soil pollution research, and how have these processes met stated research/project goals?
2) What engagement strategies have resulted in higher levels of community involvement? and
3) What community engagement practices have resulted in direct action or change (e.g., soil remediation) for communities?

MATERIALS AND METHODS

A search of the literature was conducted on urban soil pollution research and community science. The following terms were used to search the PubMed database: *community drive**, *community partnership, community based, citizen science, and community science*. These search terms were combined with *urban, superfund, legacy pollution, lead, soil collect**, *soil analy**, *and soil sampl** to identify soil related studies that used participatory approaches. While citizen science and community science are different methodologies they both hold potential to engage communities (Cooper et al., 2021) and were therefore both included in the search terms. Fifty-five studies met the initial search criteria. Many of the studies identified in our initial search criteria only mentioned soil science briefly, with a primary focus on other environmental issues such as water or air quality, and thus were removed from our final selection. Only studies that focused a large part of the discussion on community-based participatory research, citizen science, or community science were included in the final set. To avoid redundancy in our data set, we eliminated studies that were based on the same project. Additionally, literature reviews or studies that did not present original data were also eliminated from our selection. Study selection was further refined by identifying studies that used the terms *community research, citizen science, community-based participatory research, community partnerships,* and mention of *soil science*. In particular, we selected studies that involved direct participation from the community as described by the Spectrum of Community Engagement to Ownership (SCEO) (González, 2020). One study by Moawad et al. (2016) that was identified as a "community-based cross-sectional study" was eliminated because the definition of the term *community-based* in this study did not overlap with the SCEO's definition of community participation. Of the fifty-five initial studies identified, sixteen met the final selection criteria.

All selected studies were assessed using the *Spectrum of Community Engagement to Ownership* (SCEO). This tool was created by Rosa González from Facilitating Power and combines several public participation tools including Arnstein's Ladder of Citizen Participation and the Public Participation Spectrum developed by the International Association for Public Participation (**Figure 1**; González, 2020). The SCEO outlines a path to strengthen and transform community engagement by defining six levels of engagement, starting with no or limited community engagement and progressing toward increased engagement (González, 2020). The six levels, zero to five, are: ignore, inform, consult, involve, collaborate, and defer to González (2020). In level 1 the stance toward the community is *inform* and the impact on the community is *preparation or placation* (González, 2020). At this level of community engagement, researchers inform the community, providing what they perceive to be relevant information (González, 2020). Activities associated with level 1 might include distributing fact sheets, hosting open houses, giving presentations, or producing videos. There is limited community participation at this level of the spectrum. In level 2 the stance toward the community is *consult* and the impact on the community is *limited voice or tokenization* (González, 2020). Projects aligned with level 2 aim to collect input from the community and activities may include public comment, focus groups, community forums, and surveys (González, 2020). The stance toward the community in level 3 is *involve*, and the suggested impact is space for the community's *voice* to be heard (González, 2020). Projects aligned with level 3 work to "ensure community needs and assets are integrated into process and inform planning" (González, 2020). Activities related to level 3 are community organizing and advocacy, interactive workshops, polling, community forums, and open planning forums. Projects aligned with level 4 aim to *delegate power* to the community and ensure that the community plays a leadership role in decision-making (González, 2020). Activities associated with level 4 include memorandum of understanding documents (MOU) with community-based organizations, citizen advisory committees, collaborative data analysis, co-designed solutions, and collaborative decision making. In level 5 the stance toward community is *community ownership*, and projects aligned with this level aim to promote democratic participation and equity through community-driven decision making (González, 2020). Activities in level 5 include community-driven planning and governance, consensus building, participatory action research, and cooperative models (González, 2020). All studies were assessed using the SCEO scale based on information contained in the paper, including stated goals/objectives, structural changes attributed to the research, commitments to equity or racial justice, and more. Some studies aligned with multiple levels, in which case, they were assigned the highest level to which they aligned.

Studies that aligned with levels 3 through 5 were also assessed using the *Urban Sustainability Directors Network High Impact*

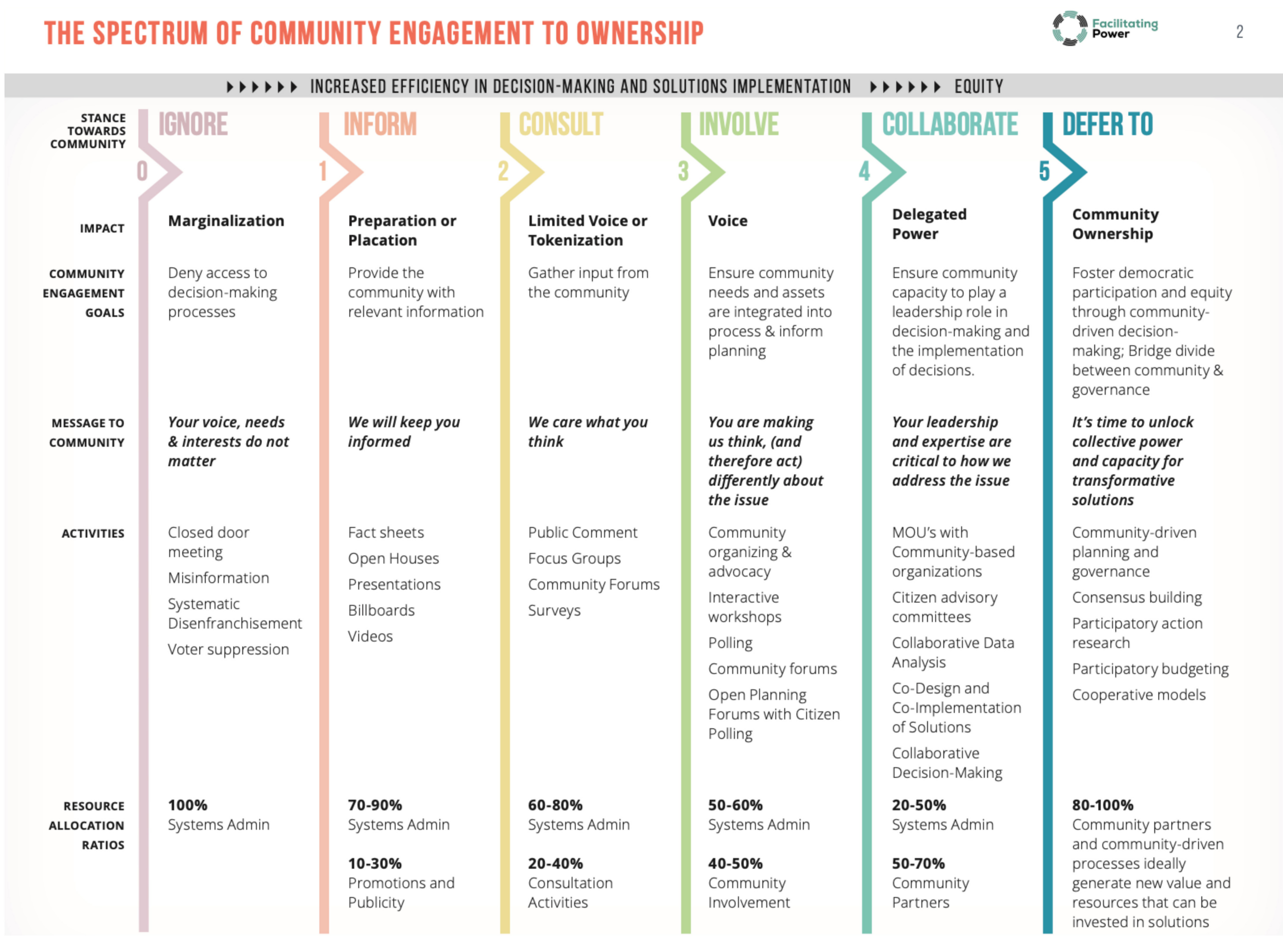

FIGURE 1 | Spectrum of Community Engagement to Ownership (González, 2020). Outlines a path to strengthen and transform communities by charting six levels of engagement with a community.

Practices (v 2.0) (USDN HIPs, **Figure 2**) to obtain a more complete understanding of how communities were engaged and the potential impacts of the research. The USDN HIPs are priorities USDN has set to promote impactful actions that advance equity, reduce greenhouse gas emissions, and support community resilience (Urban Sustainability Directors Network, 2020). These priorities include taking a people-centered, equity focused approach; building relationships and collaborating with community partners, institutionalizing sustainability goals and resources, influencing key leverage points beyond local authority; taking an interdisciplinary approach and working across borders of geographies, institutions, levels of government, and fields; and building personal and professional competencies and capacity (Urban Sustainability Directors Network, 2020). Again, each study was evaluated based on information contained in the paper, specifically references to the above-mentioned high impact practices. Evaluating the selected studies using two community engagement models allows us to better understand current practices in urban soil pollution community science.

RESULTS

All sixteen studies, their respective SCEO level alignments, and USDN HIPs are listed in **Table 1**. Seven of the studies aligned with level 2, *consult*, of the SCEO, three aligned with level 3, *involve*, two aligned with level 4, *collaborate*, and four aligned with level 5, *defer to*. Studies that aligned with levels 1 or 2 did not use practices included in the USDN HIPs, whereas eight of the nine studies that aligned with level 3 through 5 used at least one of the practices mentioned in the tool, indicating that higher levels of community engagement are often aligned with research practices that advanced equity and community resilience.

Consult: Limited Voice or Tokenization

Of the seven studies that aligned with level 2, *limited voice*, three used community scientists to collect soil samples (Mandigo et al., 2016; Filippelli et al., 2018; Tighe et al., 2019). While the SCEO model does not explicitly mention the use of community scientists to collect data, all three of these studies

Foundational Practices

- **Take a People-Centered, Equity-Focused Approach**
  - Lead with race. Prioritize racial equity analysis, recognizing how the intersectionality of identities and groups also impacts outcomes.
  - Center people in the process, goals, design, decision-making, and institutionalization.
  - Approach climate and sustainability goals in the context of community priorities, using targeted universalism in policy and program design.
- **Build Relationships and Collaborate with Community Partners**
  - Acknowledge and shift power to the community, and particularly to low-wealth and BIPOC communities, in setting priorities, designing solutions, and leading engagement.
  - Value and invest in accountable relationships between community partners and local government.
  - Create transparency in communicating with and listening to communities openly, accessibly, clearly, and often.
- **Institutionalize Sustainability Goals and Resources**
  - Foster alignment, commitment, collaboration, and accountability across local government departments, other public agencies, community partners, and outside organizations.
  - Build political capital to advance change in locally relevant ways (e.g., through community-inspired initiatives, government operations and high-visibility projects).
  - Work toward large, durable funding mechanisms and policy tools to sustain investment necessary to achieve community priorities.
  - Prioritize diversity and inclusion within member offices and in partner agencies.
- **Influence Key Leverage Points Beyond Local Authority**
  - Engage in collective influence efforts to shift state or federal policy or programs, regional markets, or utility and industry priorities.
  - Recognize underlying goals and local government leverage points in planning and strategy development.
- **Take an Interdisciplinary Approach and Work Across Borders of Geographies, Institutions, Levels of Government, and Fields**
  - Look for and work across the intersections of issues, programs, and goals, including adjacent disciplines such as public health and economic development. Seek to break down silos, recognize connections between human systems and ecosystems, and draw on universal fields, like arts, culture, and communication.
  - Explore opportunities to work within others' framing of issues--such as housing, mobility, or workforce development--and participate in others' programs, plans, and processes.
  - Recognize systems and in particular the long-lasting harm of historically oppressive governance and systems. Work to undo and avoid perpetuating harm and trauma in future government decisions.
- **Build Personal and Professional Competencies and Capacity**
  - Spend time and resources gaining skills (e.g., technical, leadership, change management), deepening personal practices (e.g., equity analysis, power analysis, and emotional intelligence), and exploring problem diagnosis and interdisciplinary connections.
  - Invest in the leadership and professional growth of staff who are Black, indigenous, and people of color to build their individual leadership and skills in a culturally relevant manner so that they have resources and tools needed to engage confidently with their peers, within their organization, and USDN.

FIGURE 2 | USDN High Impact Practices (v. 2.0) (Urban Sustainability Directors Network, 2020). Priorities USDN has set for itself to help community members take impactful actions to advance equity, reduce greenhouse gas emissions, and support community resilience.

were assessed at level 2 because engagement did not extend beyond data collection. These three studies provided community scientists with instructions on how to collect soil samples; community scientists were asked to fill a clean plastic bag with soil. Additionally, study participants in Indianapolis were provided a soil Pb awareness and safety handbook to guide sampling locations (Filippelli et al., 2018). The Indianapolis study used two types of sampling schemes to collect samples from community scientists: open-call and campaign-style (Filippelli et al., 2018). Open-call sampling schemes were requested through community events, flyers, and through promotional efforts of the Marion County Public Health Department and Purdue Universities Agricultural Extension Office (Filippelli et al., 2018). The campaign-style sampling schemes were completed by "individual communities or community groups who would canvas neighborhoods and take samples at high sampling densities—sometimes as frequently as every other property on a given block" (Filippelli et al., 2018, p. 4). The paper also mentioned working with community partners including local organizations such as Keep Indianapolis Beautiful, Groundwork Indy, and the KHEPRW Institute (Filippelli et al., 2018). Notably, this study aims to "show how citizen science can be utilized to better constrain the geochemical fabric of human impacts on a typical city, to catalyze action in those areas where environmental quality is poor" (Filippelli et al., 2018, p.4). A study conducted in New York recruited community scientists through a social networking website that promoted the study's campaign *Send Us Your Dirt From Sandy* (SUDS) (Mandigo et al., 2016). The volunteers were living, working, or volunteering in areas affected by the aftermath of Hurricane Sandy (Mandigo et al., 2016).

TABLE 1 | List of urban soil pollution studies organized by Spectrum of Community Engagement to Ownership (SCEO) levels 1–5 and Urban Sustainability Directors Network High Impact Practices (USDN HIPs).

	Author and Year Published	Study Location	Community Engagement Strategies Used	Outcomes	SCEO Level Assigned (1–5)	USDN HIPs Satisfied
Urban gardens: lead exposure, recontamination mechanisms, and implications for remediation design	Clark et al., 2008	Roxbury and Dorchester, MA, United States	Partnered with community organizations, gathered input from community. Level of input from community and partnerships was unclear.	Demonstrated the limitations of raised gardening beds in reducing exposure to lead. Identified the source and amount of daily exposure to lead in children.	2	
Mapping the Urban Lead Exposome: A Detailed Analysis of Soil Metal Concentrations at the Household Scale Using Citizen Science	Filippelli et al., 2018	Indianapolis, IN, United States	Aligned with community concerns, but limited community decision making. Community scientists collected soil samples.	Identified locations that were of high metal exposure risk to children.	2	
Safe Community Gardening Practices: Focus Groups with Garden Leaders in Atlanta, Georgia	Hunter et al., 2020	Atlanta, GA, United States	Used interviews/surveys to understand community beliefs and perceptions. Partnered with local organizations to locate participants.	Identified composting, hygiene, and mulching behaviors/beliefs in gardeners, and knowledge gaps.	2	
Urban community gardeners' knowledge and perceptions of soil contaminant risks	Kim et al., 2014	Baltimore, MD, United States	Used interviews/surveys to understand community beliefs and perceptions. Partnered with local organizations to locate participants.	Identified community gardeners' perceptions of soil contamination, barriers to investigating a garden site's history, and lack of knowledge on how to reduce exposure.	2	
Chemical contamination of soils in the New York City area following Hurricane Sandy	Mandigo et al., 2016	New York City, NY, United States	Aligned with community concerns, but limited community decision making. Community scientists collected soil samples.	Identified areas of arsenic, lead, PCBs, and PAHs contamination.	2	
Validation of a screen kit to identify environmental lead hazards	Tighe et al., 2019	Saint Joseph County, IN, United States	Aligned with community concerns, but limited community decision making. Community scientists collected soil samples.	Demonstrated the efficacy of a take-home lead screening kit that can be used by untrained citizens. Offers a potential option to help reduce lead poisoning in children, and allow families to engage in the primary prevents of lead exposure.	2	
Perceived Benefits of Participation and Risks of Soil Contamination in St. Louis Urban Community Gardens	Wong et al., 2018	St. Louis, MO, United States	Used interviews/surveys to understand community beliefs and perceptions. Partnered with local organizations to locate participants.	Identified community perceptions of soil contamination and risk.	2	
Atlanta Residents' Knowledge Regarding Heavy Metal Exposures and Remediation in Urban Agriculture	Balotin et al., 2020	Atlanta, GA, United States	Surveys/Interviews. Partnered with community organizations/community researchers. Community members helped design research questions. Interactive workshops.	Identified communities and demographics in need of additional resources for soil remediation. Outreach event allowed for over 50 Atlanta residents to have their soil tested, which led to an EPA investigation and excavation of heavy metal and metalloid contaminated soil.	3	People-Centered, Equity-Focused Approach
Lead Health Fairs: A Community-Based Approach to Addressing Lead Exposure in Chicago	Lippert et al., 2020	Chicago, IL, United States	Community-based health fairs, community partnerships. Community scientists collected soil samples.	Identified elevated concentrations of lead across the city. Provided educational outreach and health promotion, which helped community members take steps to reduce exposure. Increased self-efficacy of community members by having them observe on-site testing and public health leaders in action.	3	Build Relationships and Collaborate with Community Partners
A citizen science approach to identifying trace metal contamination risks in urban gardens	Taylor et al., 2021	Australia.	Surveys to understand efficacy of program. Community scientists responsible for collecting data, Community members proposed research questions.	Identified the legacy risks in Australian garden soils associated with petrol emissions and lead paint. Study participants reported an improved understanding of contaminants, felt safer in their home environments, and undertook remedial action based on the results they received.	3	

(Continued)

TABLE 1 | (Continued)

	Author and Year Published	Study Location	Community Engagement Strategies Used	Outcomes	SCEO Level Assigned (1–5)	USDN HIPs Satisfied
Risk assessment of soil heavy metal contamination at the census level in the city of Santa Ana, CA: implications for health and environmental justice	Masri et al., 2021	Santa Ana, CA, United States	Collaborative decision making, co-design of solutions, interactive workshops, and community meetings to discuss ideas.	Identified areas of heavy metal contamination across the study region, and at risk and affected populations. Developing a public health equity action plan that demands soil remediation, education tools to increase community awareness of contaminant exposure, investment in community institutions, and access to healthy food and healthcare for residents.	4	Take a People-Centered, Equity-Focused Approach; Build Relationships and Collaborate with Community Partners; Institutionalize Sustainability Goals and Resources
Citizen Science-Informed Community Master Planning: Land Use and Built Environment Changes to Increase Flood Resilience and Decrease Contaminant Exposure	Newman et al., 2020	Manchester, TX, United States	Collaborative decision making, co-design of solutions, community partnerships, regular meetings with community members to discuss ideas/concerns.	Assessed air, water, indoor dust, and outdoor soil in a marginalized community near industrial facilities and Houston ship channel. Designed a community-scaled master plan to increase flood resiliency, and decrease exposure to contaminants by decreasing runoff, air and water pollution, increasing carbon sequestration, and improving groundwater replenishment.	4	Take a People-Centered, Equity-Focused Approach; Take an Interdisciplinary Approach
Participatory testing and reporting in an environmental-justice community of Worcester, Massachusetts: a pilot project	Downs et al., 2010	Worcester, MA, United States	Community partnerships, community driven planning, community ownership. Community defined research questions, designed study, collected, and interpreted data.	Created a community accessible website that publicizes results to residents and public agencies. Identified community exposure levels to lead, radon, and PM2.5 and used results to advocate for changes to existing state lead testing procedures. Partnership helped form the Worcester Lead Action Collaborative, which received $9 M in grants for lead remediation.	5	People-Centered, Equity-Focused Approach; Build Relationships and Collaborate with Community Partners; Take an Interdisciplinary Approach; Build Personal and Professional Competencies and Capacity
A Collaborative Approach to Assess Legacy Pollution in Communities Near a Lead-Acid Battery Smelter: The "Truth Fairy" Project	Johnston et al., 2019	Los Angeles County, CA, United States	Community partnerships, citizen advisory committee, community driven planning, community ownership.	Increased community awareness of lead contamination. Collaboration between community organizations, academics, and public health agencies formalized into an official State advisory board on the closure and cleanup of the smelter. This board extended the investigation zone to over 10,000 properties, secured $176.6 M to support remediation in the community, made data easy to interpret and publicly available, and established new regulations to reduce emissions from lead processing facilities.	5	Take a People-Centered, Equity-Focused Approach; Institutionalize Sustainability Goals and Resources; Take an Interdisciplinary Approach
Building a co-created citizen science program with gardeners neighboring a superfund site: The Gardenroots case study	Ramirez-Andreotta et al., 2015	Dewey-Humboldt, AZ, United States	Community driven planning, community ownership. Community defined research questions, designed study, collected, and interpreted data.	Informed community of arsenic contamination in soil and steps to reduce their exposure. Increased community understanding of soil contamination and food quality. Increased social capital and community capacity and generated environmental communication efforts within community. Community reported results to USEPA and ADEQ. As a result, the municipal water supplier was issued seven citations.	5	Institutionalize Sustainability Goals and Resources; Take an Interdisciplinary Approach
The Community-Driven Approach to Environmental Exposures: How a Community-Based Participatory Research Program Analyzing Impacts of Environmental Exposure on Lupus Led to a Toxic Site Cleanup	Terrell et al., 2008	East Buffalo, NY, United States	Community driven planning, citizen advisory committees, community partnerships.	Linked high prevalence of lupus in study region to a toxic waste site. Conducted empowerment outreach events to help community compile information and prepare a remediation plan. The suggestions were accepted by DEC, and remediation of site was completed in 2007, with significant cleanup to residential standards.	5	Take a People-Centered, Equity-Focused Approach; Build Relationships and Collaborate with Community Partners; Institutionalize Sustainability Goals and Resources; Build Personal and Professional Competencies and Capacity

Studies were analyzed based on their alignment with different levels of the SCEO. Studies aligned with or above Level 3 were further assessed with USDN HIPs (González, 2020; Urban Sustainability Directors Network, 2020).

Similarly, a study conducted in Saint Joseph County recruited study participants through local organizations, as well as medical practices. The goal of the Saint Joseph County study was to test the validity of a home lead screening kit; thus, participants were asked to collect three dust, two soil, and two paint samples in their home (Tighe et al., 2019).

Three other level-2 studies used interviews and/or surveys to understand community beliefs and perceptions around urban soil pollution and gardening and their associated health risks and benefits (Kim et al., 2014; Wong et al., 2018; Hunter et al., 2020). These studies partnered with local community organizations to recruit participants for interviews. The methods for all three indicated that survey and interview questions were designed by the research team. Survey and interview questions covered topics such as, garden sites, demographics, gardening practices, and general knowledge and concerns around soil quality and health. Notably, the study conducted in Baltimore also collected and analyzed soil samples from representative community gardens and shared the results with garden leaders and interviewees (Kim et al., 2014). This research study reported sample results and helped identify both community needs and gaps in knowledge (Kim et al., 2014).

The final study worked to support the goals of a local organization in Roxbury, Massachusetts that built and promoted raised gardening beds as a mechanism to limit human exposure to contaminated soil (Clark et al., 2008). The research team investigated the effectiveness of raised gardening beds in reducing soil lead concentrations (Clark et al., 2008). It was unclear from the paper the level of input from the community or the local organization, and thus it could not be determined how involved community voices were in developing research questions and guiding the project. However, the study's partnership with a community organization and its alignment with the organization's goals suggests that community input was considered when designing the study.

Involve: Voice

Three of the sixteen studies were aligned with level 3, *involve*, of the SCEO (Balotin et al., 2020; Lippert et al., 2020; Taylor et al., 2021). Additionally, two of the studies used practices outlined in the USDN's HIPs (Balotin et al., 2020; Lippert et al., 2020).

Balotin et al. (2020) used surveys and follow-up interviews to understand community awareness of health risks associated with soil. While this study relied on interviews and surveys, similar to work aligned with level 2, this study also included partnership with community organizations and community researchers, more closely aligning it with level 3 of the SCEO model. The research team worked closely with a local organization dedicated to providing West Atlanta communities with resources and education to develop and maintain their gardens (Balotin et al., 2020). Notably, both community researchers and representatives from the partner organization helped design research questions, providing a mechanism for the community to shape the research. This study also included an interactive workshop; "the study concluded with an outreach event at a final ASF event, entitled "Getting Dirty: Exploring Soil on Atlanta farms… [which] included an urban farm tour focused on soil contamination and remediation education, as well as a booth where community soil samples were analyzed with x-ray fluorescence. All participants received seeds and a garden startup kit for attending the event" (Balotin et al., 2020, p. 4). In addition, this study used one of the foundational practices of the USDN HIPs: "taking a people-centered, equity-focused approach" that prioritizes racial equity analysis and the intersectionality of different identities. It does so by noting that differences in exposure to environmental contaminants and unequal distribution of resources due to racism may impact a person's capacity to address an environmental hazard, or may put them at a higher risk of being exposed to a contaminant (Balotin et al., 2020). In particular, this study found a disparity in the knowledge among study participants that identified as white compared to study participants that identified as Black; white-identifying participants were much more likely to be aware of the health effects of heavy metal and metalloid contamination in soils. Based on this knowledge, the authors of the study concluded that public health interventions and remediation efforts should be directed towards Black communities (Balotin et al., 2020).

Lippert et al. (2020) aligned with level 3 because it held several community-based health fairs and established community partnerships. The goal of this project was to mitigate the effects of lead exposure through community-based outreach efforts, such as water and soil testing for lead contamination, educational materials, and through surveying the community (Lippert et al., 2020). Seven health fairs were organized in partnership with local organizations, and they were structured to encourage health promotion and community participation (Lippert et al., 2020). Each health fair had student volunteers, including a bilingual volunteer, who were educated about lead through a train-the-trainer model, an effective method to help health educators deliver information to the community (Lippert et al., 2020). The study participants were recruited through email listservs and social media (Lippert et al., 2020). Partner organizations were tasked with distributing sampling kits with instructions for sample collection in both English and Spanish to participants. Student volunteers shared the results from the soil analyses with participants at the health fairs (Lippert et al., 2020). Due to the study's deep engagement with community organizations and community members, this study was found to align with the second USDN HIP of building relationships and collaborating with community partners.

Taylor et al. (2021) did not use any of the USDN HIPs, but they did use participatory approaches to collect data and engage with the community. This study implemented a nationwide program called *VegeSafe* in Australia to assist individuals who were concerned about soil contaminants in their home gardens. Community members participated in this study in several ways. Community scientists were responsible for collecting data. Notably, and what set this study apart from others that used community scientists to collect data, it included a mechanism for community members to propose their concerns as research questions. In this study, community members asked the following: "is our soil trace metal contaminated? Are our vegetables and fruit produce safe to eat?" (Taylor et al., 2021, p. 155). Additionally, this study used surveys to understand the efficacy and value that the program offered the community (Taylor et al., 2021).

Collaborate: Delegate Power

Two of the studies were aligned with level 4, *collaborate*, of the SCEO (Newman et al., 2020; Masri et al., 2021). Both studies aligned with several of the USDN HIPs. Additionally, both studies worked closely with community partners and ensured communities were empowered to make decisions and that community needs were addressed.

Masri et al. (2021) implemented a CBPR study to assess the distribution of soil contaminants and social vulnerabilities to soil contaminant exposure across census tracts in the community. The research team held regular in-person workshops where local residents met with academic partners to discuss community concerns, develop data collection skills, and share ideas and questions that would help guide the research for this project (Masri et al., 2021). In partnership with the community, the research team created a list of recommendations and policies to remediate soil heavy metals and support exposure prevention in alignment with community priorities (Masri et al., 2021). Additionally, this study used several practices outlined in the USDN HIPs. It focused its work around low-income Latino communities that were found to have two times higher soil lead levels than other communities and centered its research questions around the needs of these communities, using a people-centered, equity-focused approach (Masri et al., 2021). This study also collaborated with community partners; "this analysis was carried out as part of the ¡Plo-NO Santa Ana! Lead-free Santa Ana! Community-academic partnership…our partnership has been working to understand and intervene upon environmental injustices to promote health equity, and economic, political, and social well-being in Santa Ana, CA, United States" (Masri et al., 2021, p. 23). Finally, it institutionalized sustainability goals and resources by creating a public health equity plan that demanded governmental agencies remediate soil, use educational tools to increase community knowledge of soil contamination, and ensure that residents have access to quality healthcare (Masri et al., 2021).

Newman et al. (2020) was aligned with this level because of its close work with community members, local organizations, and dedication to promoting community decision making power. This study focuses on the Manchester community in Houston, TX, United States which is 98% people of color, 65% low-income, and 37% living at or below the poverty line, which aligns with the first USDN HIPs (Newman et al., 2020). In line with the USDN HIPs to take an interdisciplinary approach and work across fields, the research team worked with Manchester residents, local environmental justice organizations, faculty, engagement staff, and public health, landscape architecture, and urban planning students to conduct environmental sampling and design a remediation plan (Newman et al., 2020). This study valued local knowledge and used community based evidence and understanding of issues to help inform decisions and extend scientific knowledge throughout the research study (Newman et al., 2020). It held several meetings with the research team and the community to discuss potential problems and share local knowledge as well as meetings with the local government to discuss community concerns (Newman et al., 2020).

Defer to: Community Ownership

Four of the sixteen studies were aligned with level 5, *defer to*, of the SCEO (Terrell et al., 2008; Downs et al., 2010; Ramirez-Andreotta et al., 2015; Johnston et al., 2019). All of the studies used several of the USDN's HIPs.

Ramirez-Andreotta et al. (2015) aligned with level 5 because community members worked with the research team during every step of the study. Together with the research team, the community helped define the research questions for the study, gather information, develop hypotheses, design data collection methodologies, collect environmental samples, interpret data, and translate results into action (Ramirez-Andreotta et al., 2015). The aim of this study was to "determine the uptake of arsenic in garden vegetables grown by the Dewey-Humboldt, AZ community, and conduct an exposure assessment and characterize the potential risk posed by gardening and consuming vegetables from residential home gardens" (Ramirez-Andreotta et al., 2015, p. 4). The authors mention that oftentimes in environmental justice communities, concerns and research about environmental hazards have been long in the works even before research teams become involved (Ramirez-Andreotta et al., 2015). This rings true for this study as well, in which community members attending a seminar raised concerns about soil quality, and one of the researchers then suggested they work together to address the proposed concerns (Ramirez-Andreotta et al., 2015). The community members who proposed the original research questions promoted the project and used their networks to recruit study participants (Ramirez-Andreotta et al., 2015). At the same time, the main academic investigator maintained a consistent presence in the community and attended town council meetings, community events, and was regularly involved in the community. Study participants attended a 1.5 hour training session where they were taught how to collect soil, water, and vegetable samples from their home garden, and were offered an instruction manual and tool kit with all the supplies needed to take samples (Ramirez-Andreotta et al., 2015). This project discovered that the local public water system, as well as nearby private wells, were supplying water that had arsenic levels that exceeded the drinking water standard of 0.010 mg/L (Ramirez-Andreotta et al., 2015). Additionally, this study aligned with several USDN HIPs including an interdisciplinary approach by building a transdisciplinary team, including disciplines like environmental chemistry, microbiology, soil ecology, hydrology, public health, and visual communications, as well as institutionalizing sustainability goals through bidirectional communication with government agencies (Ramirez-Andreotta et al., 2015).

The study by Downs et al. (2010) was aligned with level 4 due to its close work with community partners and its stated goal to empower marginalized residents. This study worked with four partners: a youth development community center, an environmental justice non-profit, a community based health center, and a local university (Downs et al., 2010). This environmental justice CBPR study was designed and executed by both community partners and the research team, and both residents and researchers were responsible for taking and testing soil samples (Downs et al., 2010). Samples were collected through a method called participatory testing and reporting: "an approach to environmental testing that enables inhabitants of those environments to participate in meaningful and empowering ways in the testing activity, and reports-back actionable results in a timely fashion" (Downs et al., 2010, p. 2). Additionally, community-based listening sessions were held to better understand residents' health needs and concerns, and a collaborative survey was implemented to understand household vulnerabilities and asthma prevalence (Downs et al., 2010). The approach also worked to strategically halt street trash and illegal dumping and educated and empowered youth to promote environmental justice (Downs et al., 2010). This study aligned with several of the USDN HIPs: it took a people centered approach by focusing its work around vulnerable populations and working to empower them, built relationships and collaborated with community partners, took an interdisciplinary approach, and built personal and professional capacities through educating youth.

Johnston et al. (2019) aligned with level 4 because of its community driven approach to combine environmental hazard exposure assessment with community organizing. This study centered on a primarily working-class, Latino community near a toxic waste facility, and formed a partnership with a local environmental justice organization led by community members (Johnston et al., 2019). Notably, one of the authors was both a community member and a leader of the partner organization, which satisfies the USDN HIPs to build personal and professional competencies and capacities. This research aimed to understand prenatal and early-life exposures to toxic metals through two routes: soil testing and baby teeth as biomarkers (Johnston et al., 2019). An interactive bilingual workshop was designed to educate residents on lead exposure and to recruit study participants (Johnston et al., 2019). The soil testing results found that 97.7% of the residential homes tested did not meet "safe" threshold levels of lead established by the state of California, <80 ppm, and that almost 40% of all the homes exceeded the soil lead health screening limits for industrial property, >320 ppm (Johnston et al., 2019). In addition, pre- and postnatal tooth lead levels were significantly and positively associated with soil lead levels, and continued to be that way after adjusting for maternal education (Johnston et al., 2019). An appointed advisory committee, comprised of community leaders, public officials, and academics, succeeded in extending the investigation zone to over 10,000 properties up to 1.7 miles from the facility and securing $176.6 million dollars to support remediation in the community (Johnston et al., 2019). The homes that had lead levels above 400 ppm were prioritized to receive remediation (Johnston et al., 2019). This study aligned with several USDN HIPs, including an equity-focused approach, institutionalized sustainability goals, and an interdisciplinary approach.

The final study by Terrell et al. (2008) was aligned with level 5 due to its close work with community partners and residents. This study used CBPR methods to improve environmental quality in a low income minority community in East Buffalo (Terrell et al., 2008). The academic research team worked closely with a local coalition to examine the high prevalence of lupus in the area, and what relationship there might be to the chemicals released by a New York State Superfund site (Terrell et al., 2008). Several community events were organized to educate residents and to garner support to fence off the contaminated site to protect community members (Terrell et al., 2008). Additionally, "the partnership's CBPR outreach strategy was based on the division of efforts among four committees, which each had the responsibility of developing tools to empower the community" (Terrell et al., 2008, p. 90). This coalition investigated three toxic waste sites, and both residents and academic representatives approached governing agencies to mobilize them to take action (Terrell et al., 2008). This study found that lead levels in surface soil samples were elevated, ranging from 500 to 1,000 ppm, in the investigation sites. Both arsenic and mercury levels were not high enough for remediation concern at all of the sites. This study aligned with several of the USDN HIPs, including utilizing an equity-focused approach, collaborating with community partners, institutionalizing sustainability goals, and building professional competencies and capacity.

DISCUSSION

Through our research we found that seventeen communities have been engaged in urban soil pollution research at levels 2–5 of the SCEO. Both the SCEO and USDN HIPs offer a model for best practices when conducting community science. These models can ensure that researchers have clearly outlined goals and appropriately aligned methods when engaging with communities. For example, researchers that aim to better understand a community's concerns or goals may use approaches outlined in level 2 and 3 of the SCEO to connect with a community. Our research identified several studies that successfully used activities both in level 2 and 3 of the SCEO to better understand community needs and knowledge around soil quality (Kim et al., 2014; Wong et al., 2018; Balotin et al., 2020; Hunter et al., 2020). These studies worked with community organizations to recruit study participants and effectively conduct surveys, focus groups, and community forums to understand community need. Additionally, one of these studies used surveys to understand the efficacy and value that research programs offered communities (Taylor et al., 2021).

Similarly, we found that studies that engaged communities in soil research through involvement, delegating power, or deferring to communities, i.e., levels 3 through 5 of the SCEO, more often mentioned structural change as a result of their work, including securing funds for remediation, creating plans to improve environmental conditions, and greater community agency. Thus, ensuring communities play a leadership role in, or drive decision-making processes may be an effective way to advance soil research goals and effect change. Balotin et al. (2020), which aligned with level 3 of the SCEO, offered a particularly effective approach to community engagement in which community members co-designed and produced questionnaires and surveys. This study resulted in an EPA investigation and excavation of contaminated soil within the community. This suggests that deeper levels of community engagement, that foster more community decision making, may lead to more effective solutions including remediation efforts. The study by Johnston et al. (2019), which aligned with level 5 of the SCEO, used community-driven planning, participatory action research, and citizen advisory committees to create structural change in the community. Johnston et al. (2019) deferred to the community by ensuring that community members were engaged throughout the duration of the research project. Community members participated in the research team, were leaders of an advisory committee, and were engaged through interactive workshops (Johnston et al., 2019). This study was among the few that we found that mentioned clear structural change; through the team's work they were able to extend the investigation zone surrounding the lead-acid battery smelter to over 10,000 properties and secure $176.6 million dollars to support remediation (Johnston et al., 2019). While some studies mentioned limited community participation as a barrier to their research, in particular reaching those most harmed by structural racism and environmental hazards, greater community involvement in the Johnston et al. (2019) study resulted in greater inclusion. This highlights how research questions evolving from the community may lead to greater community involvement and interest, and thus structural change that is led by and benefits the community. One study that exemplifies this is Ramirez-Andreotta et al. (2015), in which community members went to a local seminar to express concerns about the quality of their soil. From that interaction a research project began in which community members were involved in every phase of the study, from developing research questions to collecting and analyzing data. This study was associated with several positive outcomes for the community, including several citations for local municipalities, the result of study participants sharing their soil testing results with regulatory agencies. These findings suggest that engaging communities at levels 3–5 of the SCEO may offer benefits to both scientists and communities. By involving and co-powering community members, scientists may be able to connect with communities that have been historically excluded. This broader reach within communities can lead to collaborations on research, data sharing, and discussions around methods (Balazs and Morello-Frosch, 2013). These new lines of research may advance interventions to improve environmental conditions, and can deepen scientific investigation by linking research with policy interventions (Balazs and Morello-Frosch, 2013). In turn, community involvement at levels 3–5 of the SCEO may result in community goals, including remediation efforts, being realized.

Our analyses also revealed several challenges to participatory approaches in urban soil pollution science. Participatory approaches require regular strategy analysis and close communication with community members, and both can prove to be challenging to implement. Several studies mentioned various steps they could have taken to improve the outcomes of their study. "Regular group reflection and structured dialogue mitigate, but may not prevent conflict burden. One of the major challenges of CBPR partnerships is to continuously and dynamically renegotiate the relationships among partners, working in creative ways so that trust, co-ownership and an energizing sense of pride can be built" (Downs et al., 2010, p. 9). This realization prompted the research team to commit to future research that funds the active participation of residents of color, and to no longer rely on community-based groups for partnership (Downs et al., 2010). Additionally, several studies mentioned struggling to find a large and diverse enough group of participants through the recruiting methods they used; this raised concerns among researchers regarding how well the data they used actually represented their target populations (Balotin et al., 2020). This again highlights the need to center participatory approaches on the communities most impacted to ensure that the needs of those most harmed by environmental impacts are being addressed.

Our study has several limitations. A relatively small sample of studies met our final selection criteria, which may have impacted our findings. While we strived to capture all relevant studies with our search terms, we may have excluded relevant studies. For example, studies that did not self-identify as citizen science, community science, or community-based research may have been missed, despite using community engagement methods. Additionally, our understanding of community partnerships and community engagement was limited to the information described within each paper. Conclusions were drawn based solely on the information provided in each study, some studies may have offered more information around community engagement practices than others. Finally, fifteen out of the sixteen studies we found were conducted in the United States. While this was not an explicit search criteria in our study, it could be a limitation of the research. Our search may have missed community projects that have not been published in peer-reviewed journals, such as the "Soilsafe Aotearoa" project conducted in New Zealand (Soilsafe Aotearoa, 2021).

We conclude that participatory approaches that support space for community members to propose research questions, design and structure survey and interview questions, participate in and lead interactive workshops, and lead advisory committees may result in greater community interest, community involvement, community led changes, and structural change in alignment with community need as shown in these studies: Terrell et al., 2008; Downs et al., 2010; Ramirez-Andreotta et al., 2015; Johnston et al., 2019; Balotin et al., 2020; Newman et al., 2020; Masri et al., 2021. Our analysis demonstrated that studies that employ such practices resulted in projects meeting their stated goals, including support for soil remediation. At the same time, our research found that studies that engaged communities at lower levels of the SCEO did not discuss structural change for communities within their studies, as seen in these studies: Clark et al., 2008; Kim et al., 2014; Mandigo et al., 2016; Filippelli et al., 2018; Wong et al., 2018; Tighe et al., 2019; Hunter et al., 2020; Lippert et al., 2020; Taylor et al., 2021. The Union of Concerned Scientists states that "*scientist-community partnerships, when approached thoughtfully, can bring about* *meaningful change and help level the playing field for communities that are being shut out of important policy decisions...*" (Center for Science and Democracy at the Union of Concerned Scientists, 2016). Our research suggests that urban soil pollution participatory approaches that align with levels 4 and 5 of the SCEO and use USDN HIPs may be more effective in bringing about structural change. In addition, our review suggests that best practices in urban soil pollution participatory approaches include regular and direct communication between community members and researchers, equitable funding mechanisms, and centering impacted communities.

Participatory approaches in urban soil pollution research are growing in use as a tool to determine community needs and address environmental justice concerns especially in regards to soil pollution. While our work has focused explicitly on pollution in urban soil systems, our approach is likely relevant to other aspects of environmental fields, including ecology, air and water quality research. Future research might include a broader review of participatory approaches in soil systems, encompassing biological and ecological studies that use participatory approaches to meet research objectives (Keuskamp et al., 2013; Crous et al., 2021; Ziter et al., 2021). Additionally, it may be of interest to researchers who use participatory approaches to understand how the communities they work with mobilize outside of research, and if there is any overlap between community members who participate in research and those who are active in their community in other ways.

The SCEO and USDN HIPs are models of best practices that researchers can use to ensure that the process of doing their science will result in the intended outcome. If the intended outcome is structural change, our review of the current literature suggests that researchers should employ community-driven decision-making processes that center equity and inclusion.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

NF-V, YC, and KS designed the study. NF-V conducted analyses and interpretation with guidance from KS and YC. NF-V wrote the manuscript with substantial contributions from KS and YC. All authors contributed to the article and approved the submitted version.

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