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Soil publics: regenerating relations with urban soils through citizen science*

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ABSTRACT

In contexts of regulatory neglect, it often falls to concerned individuals and community groups to identify and reduce people's exposure to health-threatening pollutants in urban soils. The Our Soil project, based in Troy, New York (U.S.A.) proposed that engaging people in a "do-it-together" process of scientific inquiry could cultivate both appreciation of soil's value and urgency to protect people from toxic soil pollution. In this paper, we develop the concept of "soil publics" and use it to critically reflect on how Our Soil used participatory research methods to measure urban soil pollution, exchange and value local knowledge, and cultivate a sense of concern for soil as a public issue. Soil publics come together through collective participatory practices, such as community gardening or, in this case, citizen science. This paper argues that when citizen science is pursued with a focus on producing soil publics, it is not just a means of collecting data about soil; it is part of the process of recognising past harms and transforming human-soil relations.

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Key Policy Highlights

- Efforts to increase public awareness and appreciation of the vitality of soil to ecosystem health should also address soil pollution as a matter of environmental justice.
- "Do-it-together" soil testing can be an effective means of both raising the issue of soil pollution and forming a public that wants to address it.
- Citizen science can be more than a means of collecting data about soil; it can be part of the process of recognising past harms and transforming human-soil relations.

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*The first draft of this paper was written by Hannah Price, based on ethnographic field observations that she and Chie Xu made during the Our Soil workshops in Troy in August 2021. Abby Kinchy was the PI and project coordinator. Other authors are listed alphabetically.

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Introduction

Under a rainbow of shade tents in the city of Troy, New York (U.S.A.), six Soil Justice Fellows huddled around a table, their plastic yard chairs clattering against the gravel of an urban backyard. The group was convened as part of Our Soil, a project that taught people to use simple, low-cost field tests to measure lead and arsenic in soil samples. Using the test kits, the participants had recently discovered a high level of lead in the soil of a nearby vacant lot where neighbourhood children often play. Sarah,[1] a young gardener and grassroots activist, suggested that if the owner continued to neglect the lot, they could do a small "guerrilla gardening effort" by mowing overgrown weeds and then using mulch to cover any areas of bare soil. Susan, also a gardener and activist, wondered aloud about the legality of attempting to garden on private – albeit neglected – property. In response, Sarah offered the idea of throwing "seed bombs", to cover the contaminated soil with plants. Lidia, a youthful and active grandmother, joked that they were forming a "soil gang", expressing hopes that others in the community would join in this rebellious effort to make their neighbourhood safer.

These practical and playful responses to pollution and neglect of soil in an urban neighbourhood are part of a broader guerrilla gardening movement (Hardman and Larkham 2014). For the purposes of this study, they are important examples hinting at the complexity of human-soil relations in today's cities, where soil pollution commonly evades regulatory oversight. Legacies of anthropogenic impacts are impressed in and on city soils as a geochemical record, both seen and unseen. Excavation, demolition, burial, pavement, industrial waste, and settled airborne pollutants change soil ecosystems and pose human health risks (regarding soil's health consequences, see Brevik and Burgess 2013). Urban soils are often hidden under pavement, but even when exposed, city dwellers may seek to avoid interacting with soil. Scott Kellogg, an environmental educator in Albany, New York explains: "because of soil contamination many city dwellers rightfully have a fear of touching or growing food in the soils in their communities, contributing to ecological alienation overall" (Kellogg 2022, 63).

Current regulatory mechanisms have not addressed the full extent of contamination in urban soils within the U.S., a problem that transgresses fence-lines of industrial sites (Walls et al. 2022). Soil qualities in cities vary across even short distances, which makes it difficult to make general recommendations about where it is safe to grow food or play in the dirt. The challenge is compounded if neither officials nor the general public recognise healthy soils in cities as a vital environmental amenity on par with clean air and water.

Thus, it often falls to concerned individuals and community groups to identify contaminated areas of soil and to reduce people's exposure to it. Urban gardeners play a key role in this process. In the U.S., home and community gardening has been on the rise. In 2021, partly due to the COVID-19 pandemic, there were 18.3 million new self-identified gardeners (National Gardening Association 2021). In many instances, urban gardeners are raising awareness, as Sara Shostak (2022, 402) puts it, "of the multiple burdens of soil contamination, as well as of practices of socioecological care and repair". In urban gardening, "healing the soil" (Shostak 2022, 409) means not only confronting a legacy of environmental injustice but also engaging in practices that build soils that nourish healthy plants and people.

In the Our Soil project, we aimed to support community efforts to "heal the soil" by developing accessible tools for soil testing. We proposed that engaging people in a "do-it-together" process of scientific inquiry could cultivate both appreciation of soil's value and urgency to protect people from toxic soil pollution. The idea of the project is reflected in Krzywoszynska and Marchesi's (2020) argument for empowering "soil publics" with tools for scientific inquiry about their relations with soils:

> We see a role for scientific inquiry in developing knowledge tools and practices which would empower and enable various soil workers, soil users, soil citizens – what we could call soil publics – to explore their soil relationalities. Such sense-abilities should make the best of scientific forms of soil investigation while opening up

> techno-scientific tools and practices to such publics. There is a huge role here for reflexive forms of scientific soil inquiry, and for a close collaboration between soil sciences and soil publics in order to enhance the sense-ability of soil-relating humans to soils (their perceptive apparatuses); to open up and multiply conversations about what desirable soil relational materialities may look like; and to prevent the inadvertent obfuscation of ultimately socio-ecologically destructive ontologies.

In line with Krzywoszynska and Marchesi and other recent scholarship on the social study of soils (Engel-Di Mauro 2020; Meulemans 2020; Puig de la Bellacasa 2019; Salazar et al. 2020), we see an untapped potential in retooling the knowledge practices of soil science with the aim of not solely producing data, but also – and even more centrally – producing novel forms of engagement between people and soils. Urban gardeners, of course, are included among those people, given their close connections with soils. But we also aimed to encourage non-gardeners to discover and explore their relationships with soil; for instance, through outdoor play, food consumption, or exposure to dust.

In this paper, we further develop the concept of "soil publics" and use it to critically reflect on our use of participatory research methods to measure urban soil pollution. In terms of methods, this paper is an ethnographic account focused on our participatory soil study in Troy. The co-authors of this paper – all academic researchers and students at the time of the study – collaborated to design a soil sampling and testing toolkit, organise community soil study workshops, collect ethnographic observations, and extensively debrief and reflect on our work together and with the community-based participants in the project. We report what we have learned collectively through structured self-reflection and analysis of field notes.[2]

Soil publics

Using the concept of "soil publics" to refer to the people taking part in a participatory soil study requires some explanation. In recent decades, the concept of publics has become a carrier of "multiple meanings and empirical referents, according to the context of its use" (Welsh and Wynne 2013, 542). In our usage, we follow Dewey's (1927) classic notion of a public, as interpreted by Marres (2005, 213):

> a grouping of actors who are affected by human actions, but who do not have direct influence on those actions. Lacking such influence, these indirectly affected actors must get organised into a public if they are to address the problems ensuing from these actions.

Importantly, as Marres (2005, 214) expands, a public is a "community of strangers … jointly implicated in an issue". The issue – such as family planning or climate change, or in this case polluted soil – affects each member of the public in different ways but crucially, they cannot engage with it effectively as individuals (for example, in terms of reducing their negative effects). So, a public must organise itself to acquire the resources necessary to resolve the issue.

The relationship between issues and publics poses a first challenge to the development of soil publics. As noted in almost any publication on soil-related topics, soil is rarely treated as an issue that affects people. There are, of course, notable exceptions, but generally speaking, in the United States and elsewhere, urban soil contamination is *not* an issue of widespread social concern. Even when extensive scientific research identifies soil as a source of toxic exposures such as lead poisoning (e.g. Laidlaw and Filippelli 2008; Mielke and Reagan 1998), the people affected by these exposures may not be aware of the problem (Kim et al. 2014; Witzling, Wander, and Phillips 2011), particularly if soil is not mentioned in public health messaging. Likewise, while farmers and gardeners may develop heightened awareness of soil problems, extensive social distancing between food producers and consumers impedes the spread of knowledge. The formation of soil publics, therefore, must start by articulating what the "issue" is – challenging the everyday invisibility of soil pollution to the very people affected by it.

Research in the interdisciplinary field of science and technology studies (STS) demonstrates the idea that issues and publics are mutually constituted. For example, Felt and Wynne (2007, 53),

writing about participatory governance of science and technology, argue that "publics are never simply there, and just in need of being invited to participate, but are constructed and performed through the very process of involving them in one way or the other". It is also recognised that intentional participatory practices are vital to producing publics and issues. For instance, Chilvers and Kearnes (2016, 18) write that commonly "the public and public knowledge-commitments do not pre-exist, but are instead the outcome of, collective participatory practices". Rather than spontaneously erupting, there are often lead organisers who aim "to move participants, to affect them and their views, to generate movement, to break deadlocks" (Lezaun and Soneryd 2007, 293). Furthermore, the formation of a public also depends on interactions with nonhuman beings, such as material artifacts and natural phenomena (Marres 2012). In the case of soils, the material qualities of ecosystems and the built environment – for instance, the availability of open spaces for planting gardens, or the intensity of dust storms – can importantly affect whether a public and an issue emerge or not.

One increasingly common participatory activity is "citizen science". Citizen science refers to the collective involvement of ordinary people in collecting and/or analysing scientific observations. Citizen science (also known as street science, community science, or participatory science) is often deployed to engage people in environmental issues (e.g. Corburn 2007; Rey-Mazón et al. 2018). For instance, it has been argued that community-led pollution monitoring can generate "just good enough data" to support political action by creating "a shared space for discussion that can communicate community awareness of pollution events to regulators" (Gabrys and Pritchard 2018, 12). With this idea in mind, STS scholars have contributed to the creation of air and water testing devices and information-sharing platforms, while simultaneously analysing the cultural contexts and power relations in which these scientific tools and technologies are deployed (Wylie 2018; Zhang et al. 2019). From this research, we are beginning to understand how devices like sensors and sampling kits, as well as practices like participatory interpretation of data can help to produce – or obstruct – a sense of common interest and public engagement.

Building on the ideas summarised above, we initiated the Our Soil project as an attempt to produce soil-issues and soil-publics through participatory environmental research. Over the course of the project, we extensively considered our roles as organisers of participatory science and our relationships with the people who participated. Two concepts – *scripts* and *incorporations* – have proven useful for thinking through the relationship between organisers of and participants in a citizen science project, and we elaborate them in the analysis of one of our participatory soil study workshops below.

The Our Soil project

Our Soil has origins in two projects: Gardenroots/Project Harvest led by Mónica Ramírez-Andreotta and Nuestros Suelos, a project based in Chile and developed by a highly interdisciplinary team (Ureta et al. 2022). The work of Gardenroots and Project Harvest, which engage community members through citizen science about the health of their soil, water, and plants, has been presented in an array of publications (Ramirez-Andreotta et al. 2013; 2015; Sandhaus, Kaufmann, and Ramírez-Andreotta 2019; Trahan 2022). Nuestros Suelos (NS), a newer and less formalised project, requires some more detailed introduction.

Motivated by the lack of affordable tools for soil pollution assessment in Chile, NS began in 2016 to design and test an easy-to-use set of tools for the participatory evaluation of heavy metal-related soil pollution (especially arsenic, lead and copper), derived from the country's pervasive mining industry. Instead of costly and scarce lab-based methods for environmental assessment, NS took a citizen science approach. NS took inspiration from Gardenroots and other projects that had already used citizen science to build community capacity to address environmental health challenges. NS looked to develop a toolkit – including components such as a colour-based soil testing

kit and a thought-provoking board game – that people could autonomously use to assess the degradation of local soils.

Previous STS research on users of technoscience (Oudshoorn and Pinch 2003) has examined the ideas that designers have about imagined users, and how the technologies they design imply "scripts" for the users. In a classic paper, Akrich (1992, 208) argues that designers

> define actors with specific tastes, competences, motives, aspirations, political prejudices, and the rest, and they assume that morality, technology, science, and economy will evolve in particular ways. A large part of the work of innovators is that of 'inscribing' this vision of (or prediction about) the world in the technical content of the new object.

Here, the organisers of NS, in designing tools and activities that encourage people to test and learn about soil, were imagining actors and the futures that they would inhabit. These ideas were rooted in experience, including prior field work in Chilean communities affected by polluted soils. Yet they still made some assumptions about people's interests and motivations, creating tools that scripted a particular "framework of action" (Akrich 1992, 208).

In developing the components of the NS toolkit, the research team worked with the assumption that most mining-related pollution in Chile concentrates in rural areas, affecting small-scale agricultural activity. The potential soil publics they scripted were low-income rural producers whose main engagement with soil was through agriculture. Thus, most of the components of the first version of the toolkit focused on producing qualitative data and in-depth discussions about soil agricultural fertility and the way in which heavy metals affect it. The original design of the toolkit intended for people to use these tools independently, without need for guidance or interpretation by experts.

Tests carried out with rural farmers in northern Chile (Ureta et al. 2022, 8–10) revealed that the NS organisers had vastly underestimated the practical complexities of engaging people in the scientific production process when they had no previous experience with science whatsoever. Looking again to Akrich's (1992, 208) discussion of how designers produce scripts, we note that it has long been known that "it may be that no actors will come forward to play the roles envisaged by the designer. Or users may define quite different roles of their own". While rural farmers enthusiastically participated in guided soil testing with the kits, they did not follow the script of "do-it-yourself" research and environmental advocacy. On the contrary, they needed constant support from the organising team to advance through most procedures. Even tasks that were thought by the organisers to be extremely simple (such as manipulating vials containing soil samples) appeared to be quite challenging for many of them.

So, a final recommendation from this stage of the project was that future iterations should leave aside the script of soil publics as formed by laypersons who autonomously use a toolkit. In its place began to emerge a script of soil publics as complex collectives in which the organisers of the project – some being scientists who developed the soil testing tools and activities – work in collaboration with communities, in a "do-it-together" manner.

With support from the National Science Foundation, in 2018 members of Gardenroots and Nuestros Suelos joined with researchers at Rensselaer Polytechnic Institute and SUNY New Paltz to start a new phase of the project, dubbed Our Soil. A key change of its new incarnation was a specific focus on urban areas, taking on new questions about pervasive contaminants, particularly lead, in urban and residential soils. Working in parallel with the NS team in Chile, Our Soil focused on Troy, New York, a small city located upstate in the capital region. Troy is an old, formerly industrial city with many lead-exposure pathways, including polluted soil, old lead-based paint in homes, and lead water pipes. A disproportionate number of children in Troy have blood lead levels that exceed official reference values (Pell and Schneyer 2016). As in other places throughout the US, racial discrimination and economic and political marginalisation have contributed to disparities in lead exposure within Troy, particularly regarding access to lead-safe homes and yards. We focused on the neighbourhood of North Central Troy, a community that has been chronically under-serviced. Many homes are owned by absentee landlords who care little about the welfare

of their tenants and may not even understand the climate needs of the Northeast. Renters also have few rights when making the upkeep demands as much of building maintenance is unregulated. It also costs the city of Troy tens of thousands of dollars to demolish vacant and abandoned buildings, a waste of potential resources and adding to landfills. This is all on top of the historic displacement of the Indigenous peoples who originally inhabited this river front region, the Stockbridge-Munsee Mohican Tribal Community. They were removed by the Dutch starting in the eighteenth century and relocated multiple times (Miles n.d.).

Reflecting on lessons from the extensive literature on environmental citizen science (for an overview see Kimura and Kinchy 2019) and existing models of community-engaged soil testing (Ebitu et al. 2021; Pino et al. 2022; Walls et al. 2022), we sought to develop accessible and reliable methods and tools for "do-it-together" – rather than fully autonomous and individualised – soil testing. We tentatively imagined a soil public that would emerge – along with recognition of lead contamination as an issue to be confronted – through hands-on engagement with soil testing in a communal space.

Members of our team refined and calibrated two chemistry-based soil testing kits, one for lead, the other for arsenic. The field method to screen soil for lead was first reported by a research team at Columbia University (Landes et al. 2019). The method we used to analyse arsenic in soil was developed in the laboratory of Ramírez-Andreotta, by adapting a commercial water kit. Our team included these testing tools and procedures in simple, low-cost Community Soil Study Toolkits, which included step-by-step processes with visual aids and checklists for people to easily follow. They were designed to be used by high school students and adults, involving basic activities like measuring, stirring, mixing, using test strips, and analysing colour-based visual results. In each test, the visual results were easy to read with a colour scale.

Our ideas about the soil public that we were scripting were shaped, in large part, by our partnership with The Sanctuary for Independent Media (colloquially known as "The Sanctuary"), a Troy-based community arts and activist organisation. Founded in 2005 by a group of progressive media producers called Hudson Mohawk Indy Media, the Sanctuary is located in a former church that now houses several media initiatives, such as a community radio station, and offers space for community gatherings. Within a few years, The Sanctuary purchased its first empty lot on the block and turned it into the thriving "Collard City Growers Garden" with the help of volunteers. The name is a pun on Troy's nickname as the "Collar City" due to its nineteenth-century textile industry that produced the men's shirt collars, and left a legacy of industrial waste throughout the North Troy area. Farmland soils were brought into the garden to build raised beds on top of what was suspected to be "non-productive" soil. Since that time, a collective of gardeners has further developed and expanded the space into another lot, adding other facilities. So, the issue of local soil pollution was a long-lasting concern to The Sanctuary, and there was already a small group of volunteers who were invested in tending the garden and engaging in environmental projects. In 2017 the Sanctuary purchased another building to open a community science laboratory. Known as NATURE Lab, it followed in the lineage of community bio labs, offering a space to conduct science outside of a university setting, promoting accessibility and research driven by communities.

In all, Our Soil imagined – based on existing relationships in the community – a soil public that was motivated by a sense of environmental justice, was excited for the opportunity to do science themselves, and primarily had exposure to soils from urban gardening and public spaces, like playgrounds. Much like the urban gardeners described by Shostak (2022, 400), we felt motivated by a belief that "racialized social processes – including deindustrialization, redlining, disinvestment, and neglect – have harmed the health both of urban soils and urban residents". In our own articulation of "soil justice", everyone should experience the same degree of protection from soil-based health hazards where they live, learn, work, and play, and have equal access to the resources and decision-making processes that result in healthy soils. Following from this, the soil study toolkit was explicitly designed to make soils visible in a context where participants could engage in sustained discussion about the meaning of their observations; in other words, we (the authors of this

paper) scripted a soil public that would – with scientific tools and opportunities to talk – recognise soil contamination as a shared issue. We had the expectation that this soil public would use measurements of lead and arsenic pollution to start discussions and take actions to deal with this injustice. Grant funding allowed us to offer stipends to participants, who we called Soil Justice Fellows.

The Troy workshops

After over a year of design and planning, the Our Soil team finally convened in Troy in the summer of 2021 to do the first series of workshops using the lead and arsenic screening kits. To find suitable participants, we used various means to invite Troy residents to become Soil Justice Fellows, such as going door-to-door with brochures and comic books that we created to share information about lead and soil, posting flyers in corner stores, and giving interviews on a community radio station. While we hoped to have enough applications to merit a competitive selection process, in the end just eleven people registered. The low interest is not surprising, given the relative invisibility of soil compared to more pressing concerns that have become public issues in Troy, such as police violence and evictions. All Soil Justice Fellows were women, with the majority being women of colour. They included mothers and caregivers, a doctor, a wellness practitioner, and gardeners, who wanted to know about lead and arsenic in their backyards, gardens, and public playgrounds. Their main motivations for signing up were concerns about the wellbeing not just of their soil, but also of their families and neighbours. While most of the participants were new acquaintances for us, we observed that the people who chose to participate fit very well our expectations about what the participants would be like. Their dedication to their communities, families, and environments, however, reminded us of the double-edged sword of their position as "traditional carers". As Puig de la Bellacasa (2017, 9) writes, "Those considered as traditional carers – women generally – or as typical professional carers – nurses and other marginalised unpaid or low paid workers – are constantly moralised for not caring enough, or not caring 'anymore', or for having 'lost' some 'natural' capacity to care". Our Soil risked moralising these women for not yet caring enough about/for soil.

Because of COVID-19 safety precautions, the workshops took place outdoors, in a yard behind NATURE Lab, halfway down the block from the community garden. When the Our Soil team arrived at the site, our first task was to set up pop-up tents, each weighted with four heavy sandbags, so that participants would be shaded from the summer sun. After lugging these items outside, we encountered a test of our ability to work together; four people had to orchestrate their movements to open each large, unwieldy tent. As we moved through the subsequent workshops, follow-up meetings, and discussions, the tents came to represent not just a test of collaboration, but also the necessity of neighbourhood infrastructure for enacting soil publics and engaging in soil inquiry. In this particular case, such infrastructure included the NATURE Lab, where the team could create the kits for the workshops and store soil samples, a large garden, outdoor space for COVID-safe workshops, a small kitchen to store and prepare snacks and drinks, public bathroom, and an array of equipment such as folding tables and chairs, among other amenities.

Up to this point, we had anticipated who would participate and we scripted the nature of their participation. We now need another concept to address how the scripts were actually "read", resisted, or revised by the participants themselves. Quite commonly, the assumptions embedded into scripts – such as in relation to the deliberative capacities of future publics (Kelty 2019) or their appreciation of urban soils (Engel-Di Mauro 2014) – cause problems when actual citizens try to embody them. We suggest using the concept of *incorporation* (Hayles 1999, 200) to refer to this process. Ureta (2015) writes about incorporation as a process through which tools, infrastructures, and plans are taken up by people and made part of their embodied practices. The idea of incorporation emphasises that while designers and organisers of citizen science projects may produce a script, participants may incorporate it in diverse ways – or outright refuse it. After all, in contrast with formal plans, "the experience of participation is immediate, affective, emotional and more than (or other than) individual. … it cannot be satisfied by simply following rules or

playing a role" (Kelty 2019, 18). In a way, scripts are there to be challenged, as in any incorporation "there is always something potentially subversive, and unpredictable" (Baiocchi and Ganuza 2016, 23). Incorporation always produces surprises, as the participant takes tools provided by the organisers and transforms them to suit their own aims and values.

In our case, the general procedure for sampling and testing the soil went according to plan, apart from some small mishaps such as spilling some fluid or breaking a plastic syringe. The participants were divided into two groups, with each group participating in two four-hour workshops. Sampling kits were delivered to Fellows in advance of the first workshop so that they could collect soil from places of interest to them. The first workshop was organised around sharing the importance of the places where each participant took samples, coming to a group understanding of what soil is and its significance, using the colour-based screening tools to measure lead and arsenic in participants' samples, and interpreting the results of the screening tools. A total of 25 soil samples were analysed. Lead and arsenic were detected in five and one sample(s) respectively. Three samples had lead measurements greater than 500 mg kg^{-1} and one sample had a "medium" arsenic measurement. We observed that the intensity of colour change – such as dark purple for a high amount of lead in soil – often produced strong emotional responses Figure 1.

Beyond the measurement of pollution, the design of the workshops was intended to create space for learning and reflection about soils, health, and society. Since the arsenic and lead soil tests had different procedural timelines, there were open spans of time for discussion and exchange of knowledge. We had planned to use some of this open time to invite participants to examine soil from an ecological perspective. Salvatore Engel-Di Mauro – one of the project organisers with a background in environmental geography and soil science – invited everyone to gather around a mound of dirt containing bits of old brick, rock, grass, and soil of various colours and textures, which was left from an unfinished landscaping project (see Figure 2). Crouching, Salvatore passed each Fellow a handful of soil from the heaping mound. Reassuringly, he encouraged participants to use their bare hands so that they could feel the texture of the soil through their fingers. Some of the participants appeared sceptical or confused at first. One participant later told us that she had a fear of soil (generally, not just soil pollution) and that she had joined the workshop in an effort to overcome it; in this activity she declined to handle the soil. Yet most participants did pick up small handfuls of soil. Moving the soil with his fingers and holding it up for closer examination, Salvatore asked the group, "What do you see in it? What is the soil like?" Holding the soil closer to their faces, a few Fellows saw insects or bits of twigs in the samples. Seeming to relax and become increasingly interested in the activity, one of the participants pointed out that the soil "is soft and smells fresh".

Through these sensory experiences, participants were incorporating a scripted soil public that saw and appreciated the ecological complexity of soil. Yet, beyond naïve calls to "kiss the ground" (as expressed in the recent Netflix documentary of that title), the workshop invited participants to simultaneously consider the value of soils *and* the legacy of industrial contamination. Indeed, moments after the lesson on soil formation, the participants returned to testing for toxic metals. Later, we wondered whether we had adequately resolved the tension between these two activities. Touching and smelling soil enables us to sense its liveliness and diversity, but in the context of a study of toxic metal contamination, such intimate engagement with soils could lead to exposure Figure 2.

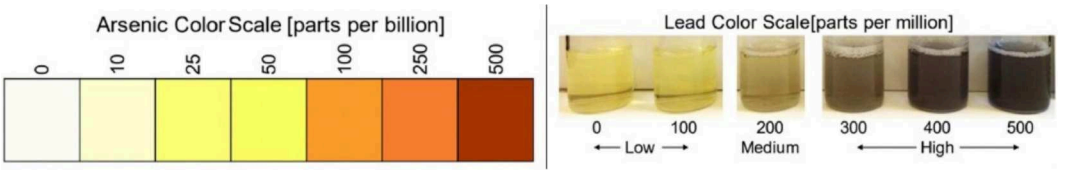

Figure 1. Colour scales for results of arsenic and lead tests. Source: the authors.

Figure 2. Members of the Our Soil team handling local soils. Source: the authors.

In other periods of waiting between steps of soil testing, Fellows were able to speak candidly and sympathise with one another. Some Fellows already knew each other, which eased some conversations, but many were strangers. One of our key assumptions was that through citizen science, the politics of soil pollution would become more explicit, allowing people to connect emotionally and

interpersonally with the complex challenge of neglected and disturbed soils. Therefore, from the very beginning, we encouraged Fellows to share personal narratives as well as their knowledge about soil in their surroundings. For example, our introductory activity asked Fellows to collaboratively draw a map of the places where they interact with soil and would like to collect samples. That activity seemed to establish a literal common ground between many of the participants, with some saying things like, "oh yes, my children play there too".

In contrast with the traditional citizen science approach of seeing participants as mere producers of data (Tubridy et al. 2022), the Our Soil workshops were designed for participants who were assumed to be carriers of knowledge and emotions, people seeking novel means to continue long-lasting struggles for environmental justice. However, whether the participants would trust each other with such conversations was not guaranteed, especially because participants had varying degrees of privilege across race and class dimensions. The Fellows' openness was facilitated by carefully explaining how we would protect their privacy. We took time with informed consent procedures, discussed how we would refrain from photographing the Fellows or revealing their identities in other ways, and asked for decisions about a detailed data sharing agreement. Once the workshop space was established as somewhere safe to disclose personal experiences, most Fellows appeared comfortable sharing stories and emotions, connecting them with the scientific inquiry in which they were engaged. For example, during various moments of the workshop, Fellows told stories about their families or loved ones who had been affected by lead poisoning Figure 3.

During one break in the first workshop, Fellows stood up from their tables to meander around the outdoor classroom to inspect one another's samples with curiosity. Since Fellows had collected their samples from a variety of locations, the soil of each fellow was unique in colour and texture. Later, after Fellows had finished analysing their soil samples and comparing the hue of their vial or test strip to the colour scales of the Toolkit, many Fellows walked around to see other participants' results. They supported each other through the "readings" of their soil results. While evaluating the colour indicators (see Figure 3), participants revisited where everyone had collected their samples. Since they all knew who had sampled their local playgrounds, or areas near their backyard gardens, as results came up there was anticipation and varied emotions depending upon the results. For samples that revealed traces of lead or arsenic, many participants hypothesised about the possible exposure, drawing from the collective knowledge gained from their participation in the workshop process. Some also aided others in interpretation of their results, and collectively

Figure 3. Vials with liquid solutions obtained from soil samples in process of lead screening. Source: the authors.

contemplated what could be done to contain the contamination of the sampling locations of other Fellows. Hence, reading data was not an end in itself, but a step in larger discussions and reflections.

Many Fellows expressed sentiments of anxiety and concern about responsibility for contamination and community health. After sharing a personal story, one Fellow expressed how lead poisoning brings "a great deal of trauma" to a family. Others articulated that they did not have a sense of control over their exposure and that regulatory bodies were failing them, pointing to a long history of regulatory neglect, complicity, and inadequacy in the face of industrial pollution and manufacture of toxic materials as well as the absence of lead-safe housing. While none of the Fellows were traditional stewards of the land they inhabited, at least one Fellow pointed to the settler colonial roots of the United States, questioning whether the government could function as a steward of the land and redress the harm of contamination. Furthermore, because of past experiences of regulatory neglect and corporate harm, some Fellows distrusted authorities to fairly or adequately address environmental concerns on both public and private lands. Some Fellows' wariness stemmed from feeling blamed or held responsible by state institutions for the impact of legacy industrial toxins on their families' health. For example, one Fellow even shared a distressing story about how she was penalised for not allowing the health department to inspect her home during the height of the pandemic. She described this experience as part of a larger issue where regulatory bodies demonise caretakers for issues caused by contaminants like lead in their living spaces, even though these problems stem from the misuse of lands that long predate their relationships with it.

The second workshop was devoted to demonstrating straightforward ways to act on the knowledge produced through the screening tools. We explained and demonstrated inexpensive ways to minimise exposure where lead or arsenic were identified at "medium" or "high" levels in yards, gardens, and play areas. For example, bare soil can be covered with a thick layer of wood chips, provided by the city's sanitation department. Fellows gained knowledge, experience, and confidence in ways to safely interact with soil, encouraging perceptions of soil as a foundation of life requiring care and cultivation rather than a threat to be avoided or neglected and ignored. However, even access to free resources like wood chips requires vehicles, shovels, buckets, physical strength, and free time. Such obstacles make it difficult to incorporate into a script of a soil public that actively tends to patches of contaminated soil.

In this workshop, the previous knowledge of the fellows themselves proved highly valuable. For example, when discussing possible methods to cultivate food crops on polluted soils, Lily – one of the Fellows – gave an impromptu tour of the Sanctuary's Collard City garden, where she had been growing perennial fruits and vegetables for several years. She told us that there had been some initial testing to check the safety of the garden's soil, and some measures were taken, such as building raised beds and incorporating a great deal of compost. Over time, she and other gardeners took incremental steps to reduce some of the ongoing risks they perceived. For example, as the tour approached the front of the garden, one of us pointed out large rocks that surrounded one of the beds near the compost piles. Lily explained that those rocks replaced what used to be old pieces of rubble that used to line various garden beds throughout the garden. A few feet away, tires were laid out next to the walkway, protecting strawberry plants. Lily explained that they have purposely planted fruits (strawberries) and not leafy vegetables (such as lettuce) in that area because fruits are less likely to take up heavy metal contamination from the soil.

Lily went on to express her view that accessibility to "pure" materials and "perfect" conditions shouldn't get in the way of engaging with soil to grow food and create biodiverse environments. Her testimony conveyed the idea that protecting people from soil contamination does not have to mean rupturing relations with soil; in fact, exposure prevention might be most effective when people develop appreciation for soil and adopt caring practices toward it.

From these discussions and activities, a picture began to emerge of the multiple-scaled web of socio-material relations that must be cultivated and maintained in order to produce healthier relations with soils. Establishing gardens and the gardening process provides the conditions for the making of soil issues and soil publics that work to resolve such issues. But we observed that

participating in a collaborative soil study, too, can produce a soil public – albeit in a time-limited way – through all the processes we described above. The Our Soil project, combined with the knowledge of workshop participants, provided the tools and evidence needed to further champion local soil quality as a matter of concern for the Troy community. Not only did participants answer their specific questions about possible lead and arsenic contamination, they also considered the necessity of socioecological care relations with the soils, even in urban areas. For example, one means of reducing exposure to toxic soil contamination is to maintain dense perennial plant growth, which requires attention to water, soil nutrients, pH, and so forth. Workshop discussions and hands-on activities showed the possibility of strengthening the socio-ecological relations that can, at a local level, begin to address the systemic and structural causes of environmental injustice.

Conclusions

As Krzywoszynska and Marchesi (2020, 199) have argued, novel technoscientific tools can be created or repurposed "to open up and multiply conversations about what desirable soil relational materialities may look like". In our case, novel tools – employed in a "do-it-together" setting – enabled soil appreciation, recognition of soil contamination as a public issue, and deeply complex conversations about the past and future of human-soil relations. In the analysis above, we examined how this happened, using the concepts of scripts and incorporation to examine what emerges in the enactment of plans for a citizen science project dealing with contaminated soils. Through this close examination of a two-day workshop, we showed how soil-issues and soil-publics are simultaneously produced, not just though talking about soil or looking at data, but through collaborative, hands-on engagement with materials such as soils, chemistry kits, and garden plots.

Through various activities in the Our Soil workshops, it was clear that Fellows brought their existing "funds of knowledge" (Gonzalez, Moll, and Amanti 2006) and understanding of soil pollution, lead exposure, or other relevant topics. Fellows were provided with tools to engage with soil and strengthen their relationship with the surrounding environment. Beyond the mere collection of data, the workshops became a means to produce more complex kinds of engagement with city soils and connect these new understandings with their previous understandings. Participants showed an understanding of soil that went beyond simple appreciation to simultaneously acknowledge both its value and its problems. By conducting soil research collaboratively, the participants were able to not only gain insight into each participant's soil samples, but additionally to learn about each other's life stories, to aid one another in the interpretation of results, and to form a community of collaboration. This group format created an opportunity for Fellows *and* organisers (the authors of this article) to form ourselves into an emerging soil public, by not only sharing our increased understanding of our surrounding ecosystem, but by also combining local knowledge with the new soil monitoring skills and capacities, which are now informing the development and implementation of new and emerging ideas around urban soil health. These results were the outcome of the workshops' collaborative environment, whereby scientists and non-scientists gathered on common ground and placed high value on communication and discovery of shared concerns.

There are obstacles, however, to sustaining a soil public over time. While we continue to use the Community Soil Study Toolkit with other groups of participants,[3] we remain uncertain about the enduring effects of each encounter – a question for further study. Furthermore, as the funding for the project runs out, we wonder how we, as academic workers, might be able to sustain our own collaborative engagement with each other and with the soil public we have sought to develop. We have learned from other community-engaged researchers that funding bodies supporting citizen science tend to encourage projects that are "innovative" – like piloting a new sensor or test kit – while initiatives that "merely" want to continue engaging with a community do not find all the support they need (Walls et al. 2022). This is a challenge, because as we have observed, soil publics are not self-perpetuating. The challenge may be even greater in other cities and

countries. Infrastructure that aided Our Soil, such as a community lab, shared garden, and accessible space for meetings (even during a pandemic), are not typical features of urban neighbourhoods, so we expect the challenge of ongoing support may be even more difficult in other places.

A soil public easily flourished in the protected space provided by the workshop – including the presence of several experts, the support of The Sanctuary, funding for stipends – but those structural supports are not consistently available. Did the Troy soil public simply vanish, soon after the workshops concluded? A limitation of this study is that we have not collected data about the ways that Fellows have continued to think about and act on their concerns about soil pollution in the two years since the workshops took place. It is unlikely that soil has become a non-issue for them; however, ongoing public engagement with soil issues requires more organisational support than we were able to continuously provide. This observation calls for further reflection on the broader social arrangements that might allow citizen science to be an enduring support to soil publics.

Notes

1. Names of Soil Justice Fellows in this paper are all pseudonyms. Real names are used for all professional researchers.
2. Data include extensive field notes and videos from the collaborative soil workshops, in-depth interviews with five Soil Justice Fellows conducted in the months after the workshops, and our own reflections on what we have learned in the process of carrying out this work. This study was approved by the Institutional Review Board of Rensselaer Polytechnic Institute, protocol ID 1820. All participants provided written informed consent, as further detailed in the case study presented in this paper.
3. We held further workshops in Troy in 2023, as well as in Arica, Chile, in 2021 and 2022, each with groups of around 10–13 participants. Outcomes of these collaborations will be reported in future publications.

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References

Akrich, M. 1992. "The De-Scription of Technical Objects." In *Shaping Technology/Building Society - Studies in Sociotechnical Change*, edited by W. E. Bijker and J. Law, 205–224. Cambridge, MA: MIT Press.
Baiocchi, G., and E. Ganuza. 2016. *Popular Democracy: The Paradox of Participation*. Stanford: Stanford University Press.

Brevik, E., and L. Burgess, eds. 2013. *Soils and Human Health*. London/New York: CRC Press.
Chilvers, J., and M. Kearnes. 2016. "Science, Democracy and Emergent Publics." In *Remaking Participation: Science, Environment and Emergent Publics*, edited by J. Chilvers and M. Kearnes, 1–28. London: Routledge.
Corburn, J. 2007. "Community Knowledge in Environmental Health Science: Co-Producing Policy Expertise." *Environmental Science & Policy* 10 (2): 150–161. https://doi.org/10.1016/j.envsci.2006.09.004.
Dewey, J. 1927. *The Public and Its Problems*. Oxford: Holt.
Ebitu, L., H. Avery, K.A. Mourad, and J. Enyetu. 2021. "Citizen Science for Sustainable Agriculture – A Systematic Literature Review." *Land Use Policy* 103 (April): 1–13. https://doi.org/10.1016/j.landusepol.2021.105326.
Engel-Di Mauro, S. 2014. *Ecology, Soils, and the Left: An Eco-Social Approach*. New York: Pallgrave.
Engel-Di Mauro, S. 2020. "The Troubling and Troublesome Worlds of Urban Soil Trace Element Contamination Baselines." *Environment and Planning E: Nature and Space* 3 (1): 95–113. https://doi.org/10.1177/2514848619896234.
Felt, U., and B. Wynne. 2007. *Taking European Knowledge Society Seriously*. Geneva: European Commission.
Gabrys, J., and H. Pritchard. 2018. "Just Good Enough Data and Environmental Sensing: Moving beyond Regulatory Benchmarks toward Citizen Action." *International Journal of Spatial Data Infrastructures Research* 13 (0): 4–14. https://doi.org/10.2902/ijsdir.v13i0.473.
Gonzalez, N., L. C. Moll, and C. Amanti, eds. 2006. *Funds of Knowledge: Theorizing Practices in Households, Communities, and Classrooms*. New York: Routledge.
Hardman, M., and P. J. Larkham. 2014. *Informal Urban Agriculture: The Secret Lives of Guerrilla Gardeners*. New York/London: Springer.
Hayles, N. K. 1999. *How We Became Posthuman*. Chicago, IL: University of Chicago Press.
Kellogg, S. 2022. *Urban Ecosystem Justice: Strategies for Equitable Sustainability and Ecological Literacy in the City*. London: Routledge Equity, Justice and the Sustainable City.
Kelty, C. 2019. *The Participant : A Century of Participation in Four Stories*. Chicago: The University of Chicago Press.
Kim, B. F., M. N. Poulsen, J. D. Margulies, K. L. Dix, A. M. Palmer, and K. E. Nachmann. 2014. "Urban Community Gardeners' Knowledge and Perceptions of Soil Contaminant Risks." *PLoS One* 9 (2): e87913. https://doi.org/10.1371/journal.pone.0087913.
Kimura, A. H., and A. J. Kinchy. 2019. *Science by the People: Participation, Power, and the Politics of Environmental Knowledge*. New Brunswick: Rutgers University Press.
Krzywoszynska, A., and G. Marchesi. 2020. "Towards a Relational Materiality of Soils. Introduction to the Special Issue 'Conceiving Soils and Humans in the Anthropocene,'" 19.
Laidlaw, M.A.S., and G.M. Filippelli. 2008. "Resuspension of Urban Soils as a Persistent Source of Lead Poisoning in Children: A Review and New Directions." *Applied geochemistry* 23 (8): 2021–2039. https://doi.org/10.1016/j.apgeochem.2008.05.009.
Landes, F.C., A. Paltseva, J.M. Sobolewski, Z. Cheng, T.K. Ellis, B.J. Mailloux, and A. van Geen. 2019. "A Field Procedure to Screen Soil for Hazardous Lead." *Analytical Chemistry* 91 (13): 8192–8198. https://doi.org/10.1021/acs.analchem.9b00681.
Lezaun, J., and L. Soneryd. 2007. "Consulting Citizens: Technologies of Elicitation and the Mobility of Publics." *Public Understanding of Science* 16 (3): 279–297. https://doi.org/10.1177/0963662507079371.
Marres, N. 2005. "Issues Spark a Public into Being: A Key but Often Forgotten Point in the Lippmann-Dewey Debate." In *Making Things Public: Atmospheres of Democracy*, edited by B. Latour, and P. Weibel, 208–218. Cambridge, MA: The MIT Press.
Marres, N. 2012. *Material Participation: Technology, the Environment and Everyday Publics*. London: Pallgrave Macmillan.
Meulemans, G. 2020. "Urban Pedogeneses: The Making of City Soils from Hard Surfacing to the Urban Soil Sciences." *Environmental Humanities* 12 (1): 250–266. https://doi.org/10.1215/22011919-8142330.
Mielke, H.W., and P.L. Reagan. 1998. "Soil is an Important Pathway of Human Lead Exposure." *Environmental Health Perspectives* 106 (suppl 1): 217–229. https://doi.org/10.1289/ehp.98106s1217.
Miles, L.J. n.d. "1784-1829: Pressures on the Tribe 2." Stockbridge-Munsee Band of Mohican Indians. Stockbridge-Munsee Community. Accessed January 12, 2023. https://www.mohican.com/services/cultural-services/our-history/1784-1829-pressures-on-the-tribe-2/.
National Gardening Association. 2021. "2021 National Gardening Survey Released," Accessed November 20, 2023. https://garden.org/newswire/view/dave/114/2021-National-Gardening-Survey-released/.
Oudshoorn, N., and T. Pinch. 2003. *How Users Matter: The Co-Construction of Users and Technologies*. Cambridge, MA: MIT Press.
Pell, M. B., and J. Schneyer. 2016. "Reuters Finds Lead Levels Higher than Flint's in Thousands of Locales." *Reuters*, 2016. http://www.reuters.com/investigates/special-report/usa-lead-testing/.
Pino, V., A. McBratney, E. O'Brien, K. Singh, and L. Pozza. 2022. "Citizen Science & Soil Connectivity: Where Are We?" *Soil Security* 9 (December): 100073. https://doi.org/10.1016/j.soisec.2022.100073.
Puig de La Bellacasa, M. 2017. *Matters of Care: Speculative Ethics in More Than Human Worlds*. Vol. 41. Minneapolis: U of Minnesota Press.
Puig de la Bellacasa, M. 2019. "Re-Animating Soils: Transforming Human–Soil Affections through Science, Culture and Community." *The Sociological Review* 67 (2): 391–407. https://doi.org/10.1177/0038026119830601.

Ramirez-Andreotta, M.D., M.L. Brusseau, J. Artiola, R.M. Maier, and A.J. Gandolfi. 2015. "Building a Co-Created Citizen Science Program with Gardeners Neighboring a Superfund Site: The Gardenroots Case Study." *International Public Health Journal* 7 (1): 139–153.

Ramirez-Andreotta, M.D., M.L. Brusseau, P. Beamer, and R.M. Maier. 2013. "Home Gardening near a Mining Site in an Arsenic-Endemic Region of Arizona: Assessing Arsenic Exposure Dose and Risk via Ingestion of Home Garden Vegetables, Soils, and Water." *Science of The Total Environment* 454-455 (June): 373–382. https://doi.org/10.1016/j.scitotenv.2013.02.063.

Rey-Mazón, P., H. Keysar, S. Dosemagen, C. D'Ignazio, and D. Blair. 2018. "Public Lab: Community-Based Approaches to Urban and Environmental Health and Justice." *Science and Engineering Ethics* 24 (3): 971–997. https://doi.org/10.1007/s11948-018-0059-8.

Salazar, J.F., C. Granjou, M. Kearnes, A. Krzywoszynska, and M. Tironi. 2020. *Thinking with Soils: Material Politics and Social Theory*. London: Bloomsbury Academic.

Sandhaus, S., D. Kaufmann, and M. D. Ramírez-Andreotta. 2019. "Public Participation, Trust And Data Sharing: Gardens as Hubs for Citizen Science and Environmental Health Literacy Efforts." *International Journal of Science Education, Part B* 9 (1): 54–71. https://doi.org/10.1080/21548455.2018.1542752.

Shostak, S. 2022. "'When You Heal the Soil … ': Environmental Racism and Socioecological Repair in Contemporary Urban Agriculture." *Environmental Sociology* 8 (4): 400–412. https://doi.org/10.1080/23251042.2022.2073626.

Trahan, A.S. 2022. "Environmental Health Catalyst: Visualizing Soil Contamination and Bioavailability of Metal(Loid)S for Action with Communities." Master's thesis, University of Arizona, Tucson, USA.

Tubridy, F., A. Mölter, M. Lennon, and F. Pilla. 2022. "Citizen Science and Environmental Justice: Exploring Contradictory Outcomes through a Case Study of Air Quality Monitoring in Dublin." *Local Environment* 27 (5): 622–638. https://doi.org/10.1080/13549839.2022.2068143.

Ureta, S. 2015. *Assembling Policy: Transantiago, Human Devices, and the Dream of a World-Class Society*. Cambridge: MIT Press.

Ureta, S., M. Llona, D. Rodríguez-Oroz, D. Valenzuela, C. Trujillo-Espinoza, C. Guiñez, A. Rebolledo, M. J. Maiza, and C. Rodríguez Beltrán. 2022. "Nuestros Suelos: exploring new forms of public engagement with polluted soils." *Journal of Science Communication* 21 (01): N01. http://dx.doi.org/10.22323/2.21010801.

Walls, D., A. Kinchy, T. Margalit, M.D. Ramírez-Andreotta, and S. Engel-Di Mauro. 2022. "Confronting Legacy Lead in Soils in the United States: Community-Engaged Researchers Doing Undone Science." *Environmental Science & Policy* 128 (February): 165–174. https://doi.org/10.1016/j.envsci.2021.10.035.

Welsh, I., and B. Wynne. 2013. "Science, Scientism and Imaginaries of Publics in the UK: Passive Objects, Incipient Threats." *Science as Culture* 22 (4): 540–566. https://doi.org/10.1080/14636778.2013.764072.

Witzling, L., M. Wander, and E. Phillips. 2011. "Testing and Educating on Urban Soil Lead: A Case of Chicago Community Gardens." *Journal of Agriculture, Food Systems, and Community Development* 1 (2): 167–185.

Wylie, S. A. 2018. *Fractivism: Corporate Bodies and Chemical Bonds*. Durham: Duke University Press.

Zhang, S., N. Shapiro, G. Gehrke, J. Castner, Z. Liu, B. Guo, R. Prasad, et al. 2019. "Smartphone App for Residential Testing of Formaldehyde (SmART-Form)." *Building and Environment* 148 (January): 567–578. https://doi.org/10.1016/j.buildenv.2018.11.029.