Journal of Environmental Studies and Sciences
https://doi.org/10.1007/s13412-022-00769-7

ORIGINAL ARTICLE

Minding the gap: socio-demographic factors linked to the perception of environmental pollution, water harvesting infrastructure, and gardening characteristics

Arthur Moses[1] · **Jean E. T. McLain**[1,2] · **Aminata Kilungo**[3] · **Robert A. Root**[1] · **Leif Abrell**[1,4] · **Sanlyn Buxner**[5] · **Flor Sandoval**[6] · **Theresa Foley**[6] · **Miriam Jones**[1] · **Mónica D. Ramírez-Andreotta**[1,3]

Accepted: 18 May 2022

Abstract

With the ongoing need for water conservation, the American Southwest has worked to increase harvested rainwater efforts to meet municipal needs. Concomitantly, environmental pollution is prevalent, leading to concerns regarding the quality of harvested rainwater. *Project Harvest*, a co-created community science project, was initiated with communities that neighbor sources of pollution. To better understand how a participant's socio-demographic factors affect home characteristics and rainwater harvesting infrastructure, pinpoint gardening practices, and determine participant perception of environmental pollution, a 145-question "Home Description Survey" was administered to *Project Harvest* participants ($n = 167$) by project *promotoras* (community health workers). Race/ethnicity and community were significantly associated ($p < 0.05$) with participant responses regarding proximity to potential sources of pollution, roof material, water harvesting device material, harvesting device capacity, harvesting device age, garden amendments, supplemental irrigation, and previous contaminant testing. Further, the study has illuminated the idiosyncratic differences in how underserved communities perceive environmental pollution and historical past land uses in their community. We propose that the collection of such data will inform the field on how to tailor environmental monitoring efforts and results for constituent use, how community members may alter activities to reduce environmental hazard exposure, and how future studies can be designed to meet the needs of environmentally disadvantaged communities.

Keywords Rainwater harvesting · Citizen science · Socio-demographic data · Climate change · Environmental perception · Environmental justice · Vulnerable populations · Community science

Introduction

Arizona water use

The average Arizona resident uses 120 gallons (454.2 L) of water per day, and that municipal use makes up an additional 20% of the state's water budget, with the remainder allocated for industry use (Arizona Department of Water Resources (ADWR) n.d.). Up to 70% of residential water is utilized for outdoor use, including activities such as gardening and filling pools, with that number increasing during the warmer summer and monsoon months (ADWR n.d.)

Alternative water sources at the local level are increasingly touted as a conservation method to meet the growing residential water demand, and to ease the conflict between urban and agricultural water use (Tamaddun et al. 2018). One method that has seen a resurgence is the practice of

---

✉ Mónica D. Ramírez-Andreotta
mdramire@arizona.edu

[1] Department of Environmental Science, University of Arizona, 1177 E. Fourth St, Tucson, AZ 85721, USA

[2] Water Resources Research Center, University of Arizona, 350 N. Campbell Ave, Tucson, AZ 85719, USA

[3] Mel and Enid Zuckerman College of Public Health, Environmental Health Sciences, University of Arizona, 1295 N. Martin Ave, Tucson, AZ 85721, USA

[4] Department of Chemistry and Biochemistry, University of Arizona, 1306 E. University Blvd., Tucson, AZ 85721, USA

[5] Department of Teaching, Learning and Sociocultural Studies, University of Arizona, 1430 E. Second St, Tucson, AZ 85721, USA

[6] Sonora Environmental Research Institute, Inc, P. O. Box 65782, Tucson, AZ 85728, USA

harvesting rainwater at home, even amid the "megadrought" conditions that the American Southwest is currently facing (Williams et al. 2020). Rainwater harvesting has become very important in many Arizona communities, to the point that municipalities have begun offering tax incentives (Radonic 2019; Bretsen 2018). Rainwater harvesting can support home gardeners and provides a successful method of irrigating even water intensive crops, such as lettuce or citrus, in one's backyard, while also reducing their water utility costs. Furthermore, to address urban heat island effect, which is being experienced disproportionately in environmental justice communities, organizations are working to provide low-cost interventions and climate change adaptations like active and passive rainwater harvesting to support the increase of tree canopy in these areas (Sandhaus et al. 2018).

Arizona industries and toxic release sites

Due to environmental justice challenges where low-income populations and populations of color continue to live in communities that suffer from the exposure and burden of environmental hazards (Wilson et al. 2012) combined with families exploring alternative water sources, it is important to understand what could threaten harvested rainwater quality. Though it does not capture all potential sources of contaminants that could affect harvested rainwater quality, the U.S. Environmental Protection Agency's (EPA) Toxic Release Inventory (TRI) Program (established under the Emergency Planning and Community Right-to-know Act of 1986) was created to help communities plan for chemical emergencies and requires industry to report on the storage, use, and releases of hazardous substances to federal, state, and local governments. However, it has been shown that there are racial and socio-demographic disparities in the burden of TRI facilities (Wilson et al. 2012).

Residents who are aware of environmental pollution are able to take action according to their previous knowledge and value systems (Shi and He 2012). Unfortunately, families may not be aware of their proximity to TRI sites or potential sources of pollution and as a consequence, may not be able to take action to protect themselves, family, or community. In 2018 (around the inception of this work), Arizona had 263 reported TRI sites, which are typically large-scale facilities that handle hazardous chemicals known to have adverse human or environmental health effects (U.S. EPA, 2020a). Of the 263 sites in Arizona, the five facilities with the largest releases are mining and smelting sites (U.S. EPA, 2020a). For over 150 years, Arizona has been producing and refining raw ore, and Arizona is the second largest mineral-producing state, and the leading producer of copper in the USA (U.S. Geological Survey 2017). Recently, in 2020, there were 257 TRI facilities and the total on- and off-site disposal or other releases added up to 53,679,896 lbs (24,348,791 kg) in the state of AZ, with copper, lead, and zinc elements and/or compounds as the top chemicals (U.S. EPA, 2022). Despite potential negative health outcomes (Ahmed et al. 2016; Jones and Ransome 1920), facilities with high releases of toxic chemicals are often located in close proximity to Arizona communities (U.S. EPA, 2022). While the TRI is an effort to increase the public's awareness of toxic release sites near their residential area, the data takes over a year to publish (2018 data was published in 2020, 2020 data published in 2022), leading to a lag time and a lack of site-specific, real-time data.

To address this gap as well as the overall structural challenges associated with environmental contamination, participatory research methods have been employed across the globe to monitor, track, and address environmental pollution and degradation (Davis and Ramírez-Andreotta 2021). A term that falls under participatory research is citizen science, defined as scientific research conducted with nonprofessionals, who may contribute to the research question, generation of theory or hypothesis, data collection, data analysis, data interpretation, and/or translating research to action (O'Fallon and Finn 2015; Bonney et al. 2014). Public participation in research, like citizen science, is a valuable model for scientific investigations across various disciplines and can serve as the bridge that connects science and practice to people and policy (Kobori et al. 2016; Fairclough et al. 2014; Pandya 2012). However, institutionally-only led citizen science practices have been critiqued for their lack of accessibility, diversity, justice, equity, and inclusion; to address these challenges, intentional action and "centering in the margins" are required for change (Cooper et al. 2021).

Introduction to Project Harvest

In response to climate change, water scarcity, and environmental pollution, urban and rural community members are gardening locally and conserving water by using rainwater harvesting systems. Communities seeking to adopt this kind of environmental stewardship have concerns regarding environmental quality (Sandhaus et al. 2018) and asked, "What is the quality of my harvested rainwater?". In response, The University of Arizona in partnership with Sonora Environmental Research Institute, Inc. (SERI), designed *Project Harvest* a co-created community science project focused on, evaluating potential microbiological, organic, and inorganic (i.e., metal(loid)) pollutants in harvested rainwater, soil, and garden plants irrigated with harvested rainwater, learning outcomes, and social action (for program details, see Davis et al. 2018, 2020; Ramírez-Andreotta et al. 2020; Project Harvest n.d.). Through co-creation, *Project Harvest* has generated 2.5 years (2017–2020) of environmental quality data and through a community-first reporting model (Emmett and Desai 2010; Emmett et al. 2009) and extensive engagement and data sharing activities (Kaufmann et al. 2021; Davis et al. 2020), continues to champion placed-based topics and local experts, address community questions regarding environmental quality, inform participant decision-making, improve environmental health literacy, and link research to action in underserved Arizona communities health literacy, community (Davis et al. 2020, 2018).

Communities neighboring TRI sites, as well as other sources of pollution, are susceptible to negative public health outcomes due to exposure to environmental pollution. An understanding of rainwater harvesting infrastructure and gardening practices, and determining participant perception of environmental pollution is critical for understanding what could be contributing to the contaminant concentrations observed in environmental samples and how to design public health intervention and prevention measures. Due to the community and socio-demographic diversity of *Project Harvest*, this study aims to understand if and how socio-demographic data are associated with (1) gardening behavior, (2) home and rainwater collection characteristics, and (3) participant's awareness and perception of potential sources of pollution. To do this, at the inception of *Project Harvest*, a home description survey (HDS) was administered. The descriptive information collected was used in conjunction with socio-demographic data to determine if certain features or behaviors are associated with specific socio-demographic characteristics.

Methods

Community selection and recruitment

Four Arizona communities were included in *Project Harvest:* the rural towns of Dewey-Humboldt, Globe/Miami, and Hayden/Winkelman and the urban city of Tucson. These communities were selected based on existing personal/organizational relationships, a clear connection between identified community issue(s) and/or perceived risks and the research, and their proximity to TRI and National Priorities Listed/Superfund sites (See Davis et al. 2020 for site details). The majority of participants in this study are from environmental justice communities based on socio-demographic information, proximity to contamination sites, median household income, race/ethnicity representation, and primary language (Davis et al. 2020, 2018). Community health workers with strong relationships in their respective communities, also known as *promotoras*, were selected in each community to help disseminate information, train participants, and collect data for the project.

To ensure inclusivity in the targeted communities, we used a variety of recruitment methods. *Project Harvest* participants were recruited through (1) media press releases; (2) local newspapers and newsletters; (3) school leaders; (4) municipal utility programs; (5) master gardener programs; (6) community events; (7) Superfund site community advisory meetings; (8) the project website: projectharvest.arizona.edu; (9) other community advisory boards and town halls; and (10) *promotoras*. Though *Project Harvest* had a consistent message and recruitment campaign, the majority of participants were recruited by the SERI and University of Arizona *promotoras*, highlighting the *promotoras*' paramount role in bridging the gap between institutions and the public (Davis et al. 2020). For example, 82.1% of the participants in Tucson were part of SERI's limited income rainwater harvesting program and/or participants of SERI's past programs. In contrast, 17.9% of participants in Tucson were recruited through the City of Tucson's rebate program and list-serv. The *Project Harvest promotoras*, research team, and participants consisted of English, Spanish, and bilingual speaking individuals who are from the targeted communities. To ensure all participants had an equal opportunity for participating in the project and to accurately collect information, all recruitment materials were available in both English and Spanish.

Survey description and administration

The HDS, along with a demographics survey, was administered to every *Project Harvest* participant to (1) understand the characteristics of a participant's home, rainwater harvesting infrastructure, and surrounding environment; (2) gain insight into a participant's perception of environmental quality and sources of contamination in their community; and (3) contextualize the environmental monitoring data collected between 2017 and 2020 (not discussed here). The surveys asked questions regarding participants' (1) home and roof type, (2) rainwater harvesting infrastructure and collection device, (3) known/perceived potential sources of contamination, (4) soil and gardening activities, (5) potential routes of environmental exposure (see Supplemental Material), and (6) socio-demographic data (age, zip code, gender, primary language, race/ethnicity, education level, household size, and income).

The HDS consisted of 145 multiple-choice (i.e., select one answer or "all that apply") and open-ended questions. All survey participants were consented under the University of Arizona Institutional Review Board. The survey and consent forms were administered by SERI and university *promotoras* in the participant's primary language, either English or Spanish. To prepare and certify the *promotoras* to assist in human research, they completed the Community Partner Research Ethics Training and Certification Program

(CPRET), prepared by the University of Pittsburgh (Yonas et al. 2016).

Participants were given the option to complete the HDS either on paper or electronically, and were not differentiated by survey administration type. The electronic version was administered using Qualtrics software (Qualtrics, Provo, UT, 2018). Skip-logic features were used to reduce participant burden, fatigue, and time needed to complete the survey by omitting non-applicable questions. Furthermore, these features reduced error by preventing users from accidently answering those non-applicable questions. Paper and electronic surveys were administered by a *promotora*, with the option for participants to complete the survey on their own time and later submit it to their *promotoras*. Self-paced surveys were subsequently submitted to the university research partners. In total (2017–2020), 167 unique HDS surveys were recorded.

Surveys completed digitally were uploaded directly to the Qualtrics platform and exported as.csv files to Microsoft Excel (Seattle, WA, 2016 Version 16.0). Surveys completed on paper were scanned and preserved as a digital copy, and the data was manually entered into the same .csv file. Spanish surveys were professionally translated into English, returned to the research team, and processed as described above. Survey responses to multiple-choice questions were then given numerical identifiers, in which each response identifier corresponded to its number choice in the survey. For fill-in-the-blank questions, answers were reviewed and categorized based on similarity.

Statistics

Each participant was assigned a unique kit number for the entire length of the project. The HDS and socio-demographic survey responses were synchronized using these kit numbers. Non-parametric chi-square tests of independence were conducted to identify statistical differences ($p < 0.05$) between the categorical variables of both survey responses and socio-demographic (e.g., income vs. cistern material). The null hypothesis (H_0) of the chi-square test was survey responses and socio-demographics variables are independent. Significant p values ($p < 0.05$) indicate that the variables are *dependent*, and there is an association between the respective socio-demographic variable and HDS response (Table 2). See Supplemental Material to view all possible categorical responses to each survey question.

To properly assess participant perception to pollution sources, we asked seven closed-ended questions on whether participants were within 10 miles (16.1 km) of any lead producing, active mining, legacy mining, phosphate manufacturing, commercial agriculture, tobacco farming, or waste disposal facility. The participant perception of proximity to contaminant sources were also tested by socio-demographic characteristics using the chi-square test of independence. This allowed us to determine if participant responses ("Yes", "No", and "I Don't Know") about their proximity to potential sources of pollution were significantly associated ($p < 0.05$) with socio-demographic groups. Significant p values demonstrate that participant responses to proximity questions and socio-demographics are *not independent* from one another. The participant demographics data, as well as the survey data on gardening behavior, home and rainwater collection characteristics, and awareness and perception of potential sources of pollution, were then organized in a database (Microsoft Excel) and imported into R Studio (Boston, MA, Ver. 3.6.3, 2020) for analysis.

Results and discussion

Participant socio-demographics

A total of 167 participants completed the HDS. The age, gender, ethnicity/race, income, education level, and community distribution of *Project Harvest* participants are detailed in Table 1. In general, over 50% of participants are from low-income households, do not have a college degree, self-identify as a minority race/ethnicity, and almost half of the participants are from rural communities. Implementing a peer education model, partnering with a community-based organizations, and having cultural knowledge brokers (Davis and Ramírez-Andreotta 2021) on the team led to overrepresentation of select underserved and underrepresented populations in the study. As reported in Table 1 of Davis et al. 2020, in general, *Project Harvest* had overrepresentation of low-income households in all communities and Hispanic/Latina/o/x from the Tucson area. Hispanic/Latina/o/x representation was nearly equal to the community at large in Hayden/Winkelman, but lower in Dewey-Humboldt and Globe/Miami. Hispanic/Latina/o/x participants from the rural towns of Dewey-Humboldt, Globe/Miami, Hayden/Winkelman, and the city of Tucson were zero (however, 16% identify as multiracial or other), 16, 76, and 88%, respectively and the percent of low income was 33, 16, 33, and 89%, respectively (Davis et al. 2020). When comparing the participants to the communities at large, the rural towns of Dewey-Humboldt, Globe/Miami, Hayden/Winkelman, and the city of Tucson are 12, 40/61, 92/75, 44% Hispanic/Latina/o/x, respectively and the percent of low income/persons below the poverty line is 12, 16/31, 26/9, and 23, respectively (U.S. Census Bureau 2021; Census Reporter, 2019). As stated above, 82% of the participants in Tucson were part of SERI's limited income rainwater harvesting program and/or participants of SERI's past programs, which targets the southern metropolitan area of Tucson, including the City of South Tucson. This "Pueblo Within a City"

Table 1 Self-reported socio-demographic information by *Project Harvest* participants

Age	Responses	Percent
18–24	0	0%
25–34	15	11%
35–44	21	16%
45–54	16	12%
55–64	45	34%
65–74	22	17%
75–84	9	7%
85+	3	2%
Totals (n)	131	100%
Gender	**Responses**	**Percent**
Male	53	40%
Female	78	59%
Non-binary	1	1%
Totals (*n*)	132	100%
Race/ethnicity	**Responses**	**Percent**
White	57	44%
Hispanic/Latino	62	48%
Black/African American	0	0%
Mixed race	4	3%
Other	2	2%
Asian/Pacific Islander	4	3%
Total (*n*)	129	100%
Income	**Responses**	**Percent**
Low-income	66	54%
Not low-income	57	46%
Total (*n*)	123	100%
Education level	**Responses**	**Percent**
Elementary/primary	5	5%
Middle/junior high	7	7%
High school/secondary	18	18%
Some college	20	20%
Trade/technical school	9	9%
College degree	28	28%
Post-secondary degree	14	14%
Total (*n*)	101	100%
Community	**Responses**	**Percent**
Dewey-Humboldt	14	9%
Hayden/Winkelman	17	11%
Globe/Miami	26	17%
Tucson	96	63%
Total (*n*)	153	100%

Data reflects participants that completed a portion of both the home Description and socio-demographic surveys

is 70% Hispanic/Latina/o/x and 44% are below the poverty line; this is more than double the rate in the Tucson metropolitan area and entire state of Arizona (Census Reporter, 2019).

Comparing home and garden characteristics with socioeconomic factors

Survey results demonstrated that cistern material and size are associated with race/ethnicity and location ($p < 0.05$; Table 2), and these variables are important as cistern material may contribute to potential contamination over time and the size can impact contaminant concentrations. Both White and Hispanic/Latino individuals were more likely than other racial groups to own plastic cisterns; in addition, Whites were more likely to own larger cisterns. Capacity was also associated with income; low-income individuals were more likely to own cisterns smaller than a 1500-gallon (5678 L) capacity, and those designated as not low-income had cistern sizes that were evenly distributed, varying from 0 gallons (0 L) to 2500+ gallons (9464+L).

Cistern material and capacity could have been influenced by rebate programs, such as in the City of Tucson. Tucson Water, a utility company, offers a rebate of up to $2000 USD for cistern systems up to 799 gallons (3025 L), an equivalent of $0.25/gal ($0.07/L), or $1.00/gal ($0.26/L) for 800+ gallons (3028+L) (City of Tucson 2020). SERI and the City of Tucson created a Limited-Income Rainwater Harvesting Program, which offers grants and loans to qualifying households. SERI also offered low cost, 55-gallon plastic rainwater barrels to participants in Dewey-Humboldt, Globe/Miami, and Hayden/Winkelman, costing between $40 and 65 USD depending on the participant's income (SERI, n.d.). This effort provided at least 21 participants with a SERI rain barrel, contributing to "11–55 gallons" (42–208 L) being the greatest cistern capacity category. The fact that SERI's limited-income program primarily installs 1500-gallon (5678 L) cisterns, with no cisterns smaller than 600 gallons (2271 L) may explain why low-income individuals were more likely to own cisterns smaller than 1500 gallons (5678 L). Interestingly, the data reveals that nearly the same number of low-income individuals and higher-income individuals own the largest capacity cisterns (2500+ gallons (9464+L)). As 50% of participants with the largest cisterns declined to answer income information, there may be some bias with those ($n = 14$) who own 2500+ gallon (9464+L) cisterns as 28.5% ($n = 4$) did not answer the demographics information at all, and a further 42.9% ($n = 6$) did not fully complete the demographics information on income. The description of the type of participant with the largest cisterns (2500+ gallons (9464+L)) and least likely to answer income information was male (71.4%), white (85.7%), at least some college (100%), and an average of 46 years of age (median = 59 years old).

Roofing material was associated with age, race/ethnicity, and location. Flat, built-up roofs were the most common roof material, and associated with White and Latino/Hispanic participants who were older (55+) and living in

Table 2 Select survey questions, socio-demographic categories, and calculated *P* values

Survey question	Age	Race/ethnicity	Education level	Gender	Income	Community
What is your roof made out of (Check all that apply)?	**0.010**	**< 0.001**	0.594	0.989	0.213	**< 0.001**
Approximately, when was your home built?	0.279	0.101	0.220	0.569	0.964	0.049
Have you ever tested your home indoor/outdoor paint for lead?	0.416	0.413	0.132	**0.040**	0.085	0.196
Has your home ever tested positive for lead in the paint?	0.610	0.839	0.274	0.287	0.676	0.502
Is the home/community garden located within two blocks of a major roadway, freeway, elevated highway, or other transportation structures?	**0.045**	0.178	**0.002**	0.453	0.852	0.106
Do you have pets/animals living on your property	0.066	0.846	**0.002**	0.622	0.084	0.362
What is your cistern made out of?	0.622	**< 0.001**	0.791	0.976	0.431	**0.009**
What is the capacity of your cistern (in gallons)? If you don't know, please estimate	**0.037**	**< 0.001**	0.384	0.216	**< 0.001**	**< 0.001**
How old is your cistern?	0.310	**0.023**	0.322	0.671	**0.034**	**< 0.001**
How often do you plant a vegetable garden at home?	0.239	0.351	0.475	0.988	**0.024**	**< 0.001**
Will you add nutrients or amendments to your garden this year?	0.492	**0.002**	0.094	0.626	0.223	**0.017**
What do you do when you no longer have harvested rainwater for your plants? (i.e., what is the other water source?)	0.082	**< 0.001**	0.056	**0.002**	0.116	**0.002**
Has soil in your community been impacted with an external source(s) of pollutants?	0.111	0.532	0.591	0.793	0.640	**< 0.001**
Have you done any water testing for contaminants on your land or garden?	0.200	**0.012**	0.292	0.882	1	**< 0.001**
How much of your daily vegetables come from your garden?	0.808	0.946	0.720	0.768	0.297	0.561
Do you share your garden/farm produce?	0.465	0.647	**0.022**	0.393	1	**0.002**
If yes (to sharing garden produce), who else eats the vegetables grown from your garden (Check all that apply)?	**0.012**	0.126	0.574	0.112	0.509	0.141

Socio-demographic categories are from Table 1. Bold indicates a significant association (*p* value of < 0.05) between the socio-demographic category and survey question. See full survey and categories in Supplemental Material

Tucson. In cities and suburban areas, tract housing, where one developer develops many properties, are common. This may translate into houses being built with similar, if not the same, materials in urban communities such as Tucson.

Planting frequency was associated with community and income. Several participants from each community (25 total) were planting for the first time (possibly due to project participation). Of those who answered the question on gardening frequency, Hayden/Winkelman participants were most likely to garden every year (61%), while Tucson participants were most likely not to garden at all (only 19% self-reported gardening). This likely presents the dichotomy between urban and suburban/rural living, as the percentage of those who said they gardened some edible food crop (to include first year gardeners) in the rural communities ($n = 55$, 82% of rural respondents) was significantly ($p < 0.05$) greater than in Tucson ($n = 64$, 64%). Low-income urban areas such as Tucson are associated with green space inequality, which could explain the high number of participants not gardening in Tucson (Foley et al. 2019; Nesbitt et al. 2018). On the other hand, Tucson is also home to community gardening co-ops, which may provide a space for would-be gardeners on a smaller scale. Low-income individuals were less likely to garden, possibly related to price barriers, lack of access to community space, or time commitments.

The consumption of produce from a participant's garden was not associated with any of the socio-demographics variables. While white women with at least some college education were more likely to eat from their garden, this was not significant ($p > 0.05$). Overall, *Project Harvest* participants were not very dependent on crops from their gardens as a substantial source of produce, though participants did report sharing produce with others outside their home. While edible food crops were popularly grown in this study, the small portion of participants relying on garden produce may be due to low crop yields, the perception and association of contamination in each community, which is a partial motivator for study participation, as well as people gardening as a hobby or catalyst for improving mental health (Soga et al. 2017).

Participant perception of potential pollution sources

Community, age, education, and race were associated with the perception of proximity to pollution (Table 3). Conversely, gender and income were not associated with the

Table 3 Association between socio-demographic category and self-reported proximity to potential sources of pollution

Category	*p* value
Age	**< 0.001**
Gender	0.377
Race/ethnicity	**0.003**
Income	0.146
Education level	**0.001**
Community	**< 0.001**

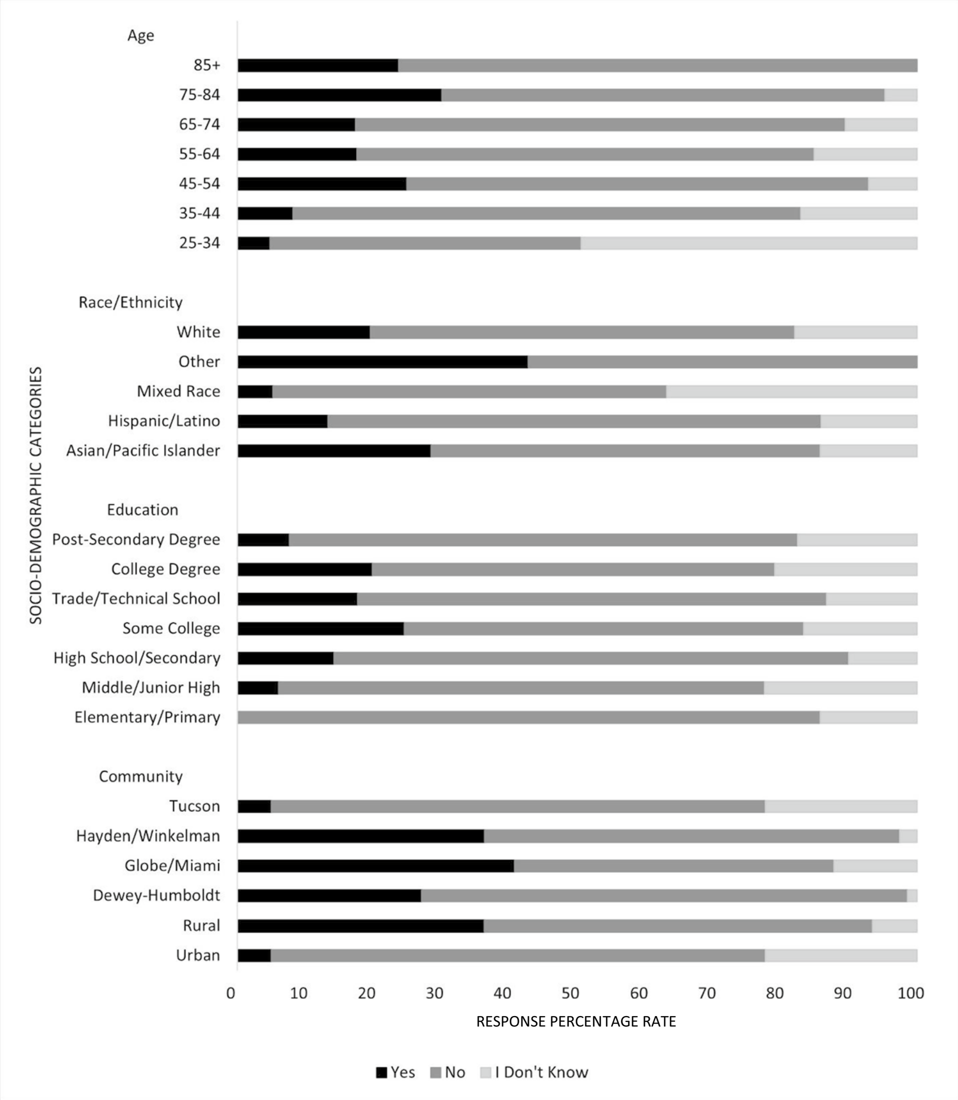
Bold indicates a significant association (*p* value of <0.05)

perception of proximity to pollution. The socio-demographic groups related to responses to pollution proximity questions (those with a *p* value of < 0.05) were further broken down in Fig. 1, which displays the percentage of participants who answered "Yes", "No", and "I Don't Know" on whether they were within 10 miles (16.1 km) of the polluting sites. Figure 2 further displays perceived proximity of their garden to industrial pollution sources.

Interpreting participant perception of proximity to pollution

The Arizona State Mine Inspector estimates that there are more than 100,000 abandoned mines in the state (Arizona State Mine Inspector n.d.) and ~ 380 active mines or development projects in the state of Arizona (Richardson et al. 2019). Many of these sites are located in, or near, communities throughout the state, and largely contribute to why community and pollution perception are significantly associated. Active mining and legacy mining had the most "Yes" (*n* = 44; *n* = 49 respectively) responses to being within the vicinity of community members' gardens. Participants were asked if they were within 10 miles (16.1 km) of active and legacy mining sites. The majority of participants in Tucson

Fig. 1 Participant self-reported proximity to potential sources of pollution by socio-demographic groups. Associations among categories are given in Table 3. A "Yes" response indicates that the participant is aware of polluting industries within 10 miles (16.1 km)



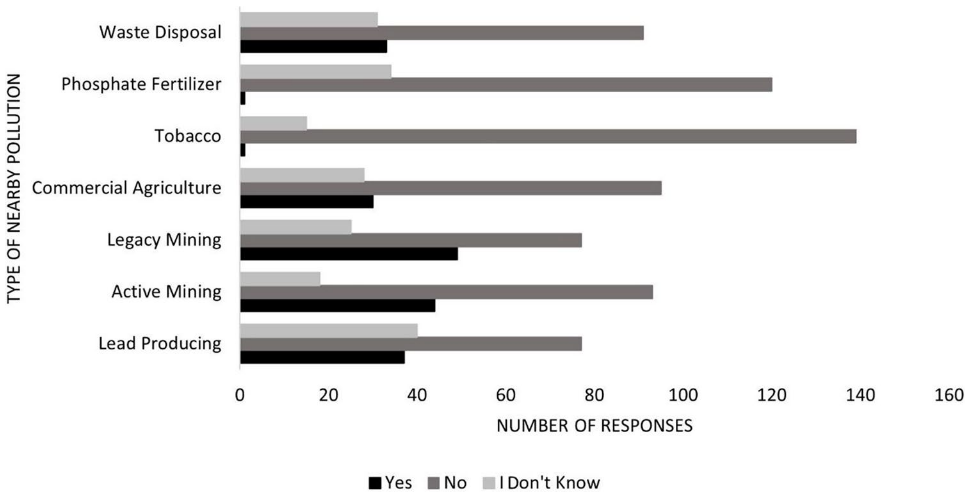


Fig. 2 Participant responses when asked about various types of potential pollution sources located within 10 miles (16.1 km) of their garden

responded that there was no, or they were not sure of, any legacy ($n=83$, 92.2%) or active ($n=91$, 96.8%) mining nearby. While Tucson does have a history of short-lived mining exploits that include Mile Wide Mine, Gould Mine, and the Old Yuma Mine in the northern part of the city, participants may not live nearby (U.S. National Park Service n.d.). There are no active mines within the Tucson city limits; however, there are construction (gravel, sand, and crushed stone) aggregate facilities (Richardson et al. 2019). For the rural communities, the majority of participants in Dewey-Humboldt ($n=13$, 76.5%), Globe/Miami ($n=23$, 92.0%), and Hayden/Winkelman ($n=14$, 73.7%) stated that they were aware of active mining. Globe/Miami has active mining (Pinto Valley Mine), quarry operations (Lime Quarry), and aggregate plants being operated within the town's vicinity. One of Globe/Miami's most recent active mines, the Miami Open Pit Mine run by Freeport-McMoRan, ceased active mining operations in 2015, though leaching still occurs on extracted resource mounds. Hayden/Winkelman residents were correct in their perception of Ray Mine; it is currently active in nearby Kearny, in addition to an aggregate plant nearby. Hayden is also home to the ASARCO Hayden Plant, another facility processing ore, where remediation efforts are being addressed through a Superfund Alternative Approach, which is an alternative to listing the site on the National Priorities List; but not an alternative to the Superfund process. The majority of participants in both Dewey-Humboldt ($n=17$, 100%) and Globe/Miami ($n=21$, 84.0%) stated that they were aware of being near legacy mining. Globe/Miami participants were correct in identifying legacy mining; legacy mines include, but may not be limited to, Old Dominion Mine and the now closed Miami Open Pit Mine. Dewey-Humboldt residents were also acutely aware of legacy mining as the Iron King Mine is a registered Superfund site (Ramírez-Andreotta et al. 2015).

When asked about proximity to waste centers, transfer stations, incinerators, and dumps (Fig. 2), only one participant from Dewey-Humboldt mentioned a nearby disposal facility. The Gray Wolf Regional Landfill is nearby Dewey, Arizona, though it may be outside the 10 miles (16.1 km) radius for some participants. About half of Globe/Miami ($n=14$, 56.0%) and Hayden/Winkelman ($n=10$, 52.6%) participants stated that such a facility was nearby. Between the two municipalities of Globe and Miami is the Russell Gulch Landfill in Globe, Arizona. Near Hayden/Winkelman there is the Dudleyville Landfill in Winkelman, Arizona. Interestingly, a quarter of Tucson responses ($n=25$, 26.6%) stated that they were unsure about whether a disposal facility was within ten miles (16.1 km) of their property, a large departure from the high frequency of "No" responses received from that community. Tucson is home to seven waste facilities that include Los Reales Landfill, Speedway Recycling & Landfill Facility, two transfer stations, two reclamation centers, and the now-closed Tangerine Landfill (as of 2013) (Pima County Department of Environmental Quality, 2020; Pima County, 2013).

Apart from association with community location, when asked about proximity to potential sources of pollution, responses were dependent on race/ethnicity, age, and education level (Fig. 2). The one apparent variation in responses between age categories came from the 25–34 age group. Those in the 25–34-year-old category were far more likely to answer, "I Don't Know" (49.4%) and the least likely to respond "Yes" (4.8%) to their being near pollution sources. Neither gender nor income was significant in differentiating responses to potential pollution sources. While all participants, regardless of race/ethnicity, had a tendency to answer "No" to potential sources of pollution being nearby, Latino/Hispanics were more likely to answer no (72.5%), than White (62.3%) and Asian (57.1%) community members. Overall, those with a trade/apprenticeship education (59%)

were far more likely than other groups to identify potential sources of nearby pollution, specifically when asked about mining and waste disposal, both of which are industries where trade/apprenticeship education are common. For education overall, some college (24.6%), college degree (19.9%), trade education (17.8%), and high school graduates (14.3%) were more likely to answer "Yes" when compared to those with middle school (6.1%) and post-secondary graduate (7.7%) education. Interestingly, federal hazardous waste worker training programs, such as the U.S. EPA's Superfund Job Training Initiative and Brownfields Job Training and the National Institute of Environmental Health Sciences (NIEHS) Environmental Career Worker Training, emerged with the environmental justice movement to provide those disproportionately impacted by environmental hazards with the needed training to receive equitable opportunities for jobs related to remediation/redevelopment/revitalization, including assessment and reuse (U.S. EPA, 2021a; NIEHS, 2021, 2010). In addition to preparing individuals for a career in environmental cleanup or construction, the training programs also aim to address critical components of environmental justice, e.g., social issues, economic issues, employment opportunities, and public health (NIEHS, 2010). As a case in point, in 2021, the U.S. EPA supported a Superfund Job Training Initiative in association with the ASARCO Hayden Plant and provided environmental trainings and certifications to community members living in the area and broader "copper corridor." In January 2022, U.S. EPA hosted their graduation ceremony. Our findings support the knowledge base and role that those with trade/apprenticeship education can play in environmental awareness, leadership, sustainability, and justice. Potential next steps include reaching out to this newly trained cohort to explore and possibly expand their role in the associated communities.

Environmental justice and risk perception

Black, indigenous, and people of color (BIPOC) have been advocating for environmental health and opposing environmental threats for decades. Indigenous Environmental Justice recognizes that Native American tribes are governments, have connections to traditional homelands, and continue to suffer from the impacts of genocide and colonization that is tied to land removal, resource exploitation, and toxic exposures (Jarratt-Snider and Nielsen 2020). The environmental justice movement acknowledges the grassroots efforts and struggles of BIPOC. Initial keystone efforts include those of immigrant and migrant farmworkers led by Caesar Chavez (1965–1970), the Memphis Sanitation Strike led by Dr. Martin Luther King, Jr. (1968)—both advocating for workplace rights and safer working conditions, and the formation of Northeast Community Action Group, a group of African American homeowners who fought the placement of a landfill in Houston, TX (*Bean v. Southwestern Waste Management Corp, 1979*) (U.S. EPA, 2021b; Bullard 2001). In 1982, the movement gained significant momentum after the sit-in against Warren County, NC, where over 500 environmentalists and civil rights activists were arrested for attempting to halt the transfer of soil contaminated with polychlorinated biphenyls (PCBs) to a landfill located in Warren County (U.S. EPA, 2021b). The relationship between race/ethnicity and environmental quality (Bullard 2001, 1996, 1993, 1990, 1987; United Church of Christ, Commission for Racial Justice, 1987; U.S. General Accounting Office 1983) continues to be studied. Additionally, scholars have expanded on the term "environmental justice, including "A Taxonomy of Environmental Justice," outlining the need for distributive, procedural, corrective, and social justice (Kuehn 2000) and Critical Environmental Justice studies, which uses a multidisciplinary approach, highlighting ecological violence as a form of social violence and the problem of state violence (Pellow 2018, 2016). It is clear that environmental injustices require structural change and that conventional health intervention/promotion strategies have largely failed to mitigate the sources of environmental health risks for environmental justice communities. This is likely because the strategies often address health at the individual behavior level, rather than interacting with relevant social, cultural, and political contexts (Masuda et al. 2010). However, within these contexts, what factors influence environmental perception or awareness? The literature is varied on whether Whites or underrepresented groups are more likely to perceive environmental risks. In our study, Hispanic/Latina/o/x individuals were the most likely to respond "No" to the presence of nearby environmental pollution sources (note that most Hispanic/Latina/o/x were located in the City of Tucson or South Tucson). Sansom et al. (2019) suggests that generations of exposure and long-term cultural norms could account for differences in environmental risk perception between races. Their study found that non-whites were more likely to underestimate environmental risks while living in the same community (Sansom et al. 2019). Conversely, Macias (2016) and Flynn et al. (1994) found that non-whites are more likely to perceive risks than Whites in the USA. This study also suggests that literature likely varies greatly due to the plethora of limitations on these studies such as dichotomous racial groupings (as is the case in the Sansom study), community-centric lenses (which this study utilizes), and not controlling for other influencing factors such as socioeconomic status, education, etc. (Macias 2016). Even within ethnic groups, sub-groups may display differences such as Latino/Hispanics with different primary languages and places of birth (Macias 2016).

Aminrad et al. (2011) found that age and educational attainment had a significant influence on environmental awareness and attitude in Malaysia. While that study specifically examined individuals pursuing either a bachelors, masters, or doctorate degree, we examined similar, though not completely synonymous trends. In our study, those who had post-secondary education were more likely to identify potential sources of pollution than those without. However, we did not examine an increasing trend in awareness among the categories of post-secondary education (trade, some college, college, degree, post-graduate). Similarly, literature finds that education and age are associated with pro-environmental behaviors and concern (Meyer 2015; De Silva and Pownall 2014; Abdul-Wahab and Abdo 2010). Meyer (2015) suggests that in Europe, compulsory education, which has also increased in the USA, is one of the influential factors for individuals becoming more environmentally friendly, explaining the bias within age and education.

Previous studies have noted that urban residents generally have a higher perception of pollution sources and risks than rural communities (Yang 2020; Sarker et al. 2018). However, our study has revealed that our rural communities have a higher awareness of nearby potential pollution sources (Fig. 1). This difference in awareness could possibly arise from a few factors such as the registering and advertising of National Priorities List sites, previous scientific studies in the communities, and the importance of these industries in the local job economy. Conversely, the urban community TRI sites tend to be on the outskirts of town. While Tucson does have a Superfund site (e.g., Tucson International Airport Area site-TIAA), it is not readily visible from either the city center or downtown area as compared to tailing piles and smelter stacks in rural communities (Fig. 3). The lack of awareness, specifically in the urban community, likely demonstrates that the information-based regulations, such as the TRI database, are not reaching the public. Additionally, secondary sources of information such as news/government reports/townhalls (e.g., TIAA's Unified Community Advisory Board Meetings) to learn about potential sources of pollution within their community are being underutilized.

The TRI was implemented to improve public awareness of toxic chemicals and their emitting facilities, thereby improving environmental and public health (Johnson et al. 2016). TRI sites are more likely to be associated with high population urban areas and disproportionately impact minorities and low-income individuals (Johnson et al. 2016; Aoyagi and Ogunseitan 2015; Wilson et al. 2012). While communities who are unduly impacted by TRI sites have the most to gain from increased access to information-based regulations such as the TRI, communities that have more economic and social power tend to see more reductions in TRI emissions and toxicity leading to improvements in overall environmental quality (Aoyagi and Ogunseitan 2015). The EPA currently lists several categories of groups who may be interested in utilizing the TRI data including citizen/communities/NGOs, government, academia, industry, and the media (U.S. EPA 2020b). If TRI were functioning in our selected communities, empowering the public and community members as intended, we would expect a higher proportion of "Yes" responses to many of our proximity response questions, particularly in the areas of mining, lead producing, and waste management industries. Simply posting this information on the TRI website is not wide-reaching; it shifts the burden to the end user who is required to be aware of, locate, and explore this data. One thing seen in this study, especially among the youngest generation who grew up in the

Fig. 3 The Iron King Mine tailings pile. This property is part of a National Priorities List site since 2008 and is adjacent to residential properties in Dewey-Humboldt, AZ. Photo By: Robert Root

digital age, is that "I Don't Know" was a common response to pollution proximity questions, underscoring that more appropriate methods of information distribution are necessary. TRI should focus on increasing information campaigns, such as better using social media platforms, incorporating this information into schools, town halls, or working with community leaders to spread this information to the public. While simply posting the information online is within the letter of the law, the spirit of the Emergency Planning and Community Right-to-Know Act was to better inform communities of toxic chemicals managed or released nearby, and that is not being fulfilled in our highlighted communities.

Understanding how various communities perceive potential sources of pollution is highly relevant for environmental monitoring studies. One practical application of this information is to better tailor result dissemination events, educational materials, and best practices associated with CS project participation and targeted at-risk communities. This information would help researchers better identify cultural norms and practices in their partnered or target communities. For example, in an at-risk community where gardening is a cultural norm, researchers could suggest culturally relevant crops that are less likely to bioaccumulate contaminants of concern. This in turn would likely lead to a larger practical application than simply suggesting no garden activity at all. Alternatively, materials could be properly tailored if you understand that perhaps the younger generation has different water harvesting habits than older participants, or those who speak Spanish primarily differ from those who speak English primarily, allowing you to prioritize targeted print versus digital media, or alternative language campaigns.

Participant understanding of historical garden area use

Participants were asked if they knew the historical use of their garden area, where they learned that information, and if they desired to learn more about the history. The only community that had a majority answer "Yes" to knowing the historical use of the garden area was Dewey-Humboldt ($n = 14$, 82%). This community is adjacent to the Iron King Mine and Humboldt Smelter Superfund sites and has experienced EPA projects such as residential soil removal, as well as another co-created science project, called *Gardenroots* (Averett 2017; Ramírez-Andreotta et al. 2013, 2015). The combination of these factors likely contributes to the community being aware of what they are choosing to grow in the soil (Ramírez-Andreotta., et al., 2013). Responses from the other three communities indicated less prior knowledge of land use; Tucson ($n = 31$, 34%), Globe/Miami ($n = 4$, 19%), and Hayden/Winkelman ($n = 3$, 16%).

When participants were asked whether they *wanted* more information about their garden area, most answered "Yes." However, 84% of Hayden/Winkelman participants did not know the historical use of their gardening land and 93% were not interested in the learning about it. Hayden/Winkelman currently has both an active nearby mining site (Ray Mine in Kearny, Arizona) as well as an active smelter, which may influence a participant's desire to know more; the mine and smelter report employing 1417 and 607 employees respectively in an area with just over a thousand permanent residents (as of 2014) (ASARCO n.d; U.S Census Bureau 2012). Additionally, participants in Hayden/Winkelman may not be interested in learning about historical use of their garden area because they may be experiencing regulatory exhaustion; that is, this community has dealt with state and federal government oversight and enforcement actions regarding pollution for over a decade (Heusinkveld et al. 2021). It is important to mention that two-thirds of Hayden/Winkelman participants cited that they garden every year, the most likely of any community. Due to legacy hazardous waste sites and ongoing emissions, it is valuable to have knowledge regarding historical past land uses.

Survey design and limitations

Internal validity

Survey design is paramount to receiving both sufficient and correct data from participants, and directly informs the internal validity of the study. Based on feedback from participants and *promotora*s as well as discussions in team meetings, it became clear at the inception of the project that select HDS questions were not functioning. In 2018, the HDS survey was modified to address critical questions that received low response rates and/or modify questions that did not have an "I Don't Know," "None," "Not Applicable," or "Other: Please Specify" option. For example, additional detail and descriptions were added to questions regarding: "What is your roof made of" and "What is the capacity of your cistern." This revised survey updated 31 questions and included 8 new questions. This modification improved the validity of the survey instrument; however, some challenges remained, which are consistent with most evaluation instruments. Our use of open-ended questions presented some difficulty. *Project Harvest* received more handwritten surveys than online survey completions due to the *promotoras* and/or participants' lower comfort level with technology and the ease with completing surveys administered in person. On written surveys, some participants' handwriting was not fully legible, creating difficulty in recording results and translation. We also observed differences in respondents' descriptions of homes and gardens. This was particularly evident in naming produce, for example, *Eruca vesicaria* was referred to as "arugula," or "rocket." Similarly, some participants categorized herbs as "leafy" plants while others placed herbs in the "other" category. In other instances, animals were referred to by name such as "dog" or "horse," while others used breed names such as "chihuahua." While this may not necessarily be a serious concern for researchers, it must be considered when creating questions to ensure data utility. This also speaks to the importance of creating highly specific questions during survey development, and potentially adding sample responses while taking care to not introduce bias, as questions may be interpreted differently by respondents.

Closed-ended questions can be useful for gathering specific information; however, without comprehensive categories for responses, they may exclude certain respondents (Krosnick and Presser, 2010). It has been demonstrated that closed-ended questions are more likely to be answered with incorrect information versus open-ended questions (Krosnick and Presser, 2010). For surveys administered via paper, participants would, on occasion, write down alternative options to close-ended questions when no response applied to them. It is advised to provide options for additional writing in both digital surveys and written surveys.

Another limitation may have been the length of survey, which could have led to participant fatigue and under-reporting (Backor et al., 2007). In most cases, *Promotoras* administered the surveys in person at the participant's home, which allowed them to tailor the pace of survey delivery. While a purely online system may lower the effort for researchers, it almost certainly shifts the burden of participation onto prospective participants. In 2018, 24% of rural, 13% of urban, and 9% of suburban respondents stated that access to high-speed internet is a major obstacle to online survey completion (Parker et al. 2018).

This study design may be further limited by participant's recollection, reporting biases, and the dependency on a participant's current or readily available knowledge. Some questions may have been difficult to answer, such as "Do you know the historical use of your garden/farm?", without the context of a specific timeframe. Also, it can be anticipated that due to participation in, and the extensive data sharing efforts in *Project Harvest* (Kaufmann et al. 2021 and Ramírez-Andreotta et al., unpublished results), their knowledge may have improved. This concept supports the implementation of both a pre- and post-survey where efforts to account for and capture history and maturation (Cook and Campbell 1979; Campbell and Stanley 1963) need to be implemented. *Project Harvest* has been conducting extensive learning research (e.g., Davis et al. 2020, 2018) and is currently wrapping up post-assessments that will be reported at a later date. Regardless, this highlights the importance of community gatherings and data sharing, as participants may be inclined to learn more about sources of pollution after receiving environmental sample results (Ramírez-Andreotta et al. 2016a, 2016b; Brody et al. 2014; 2007).

External validity

Can these study results be applied and generalizable to the broader population? Factors that impact the external validity of the study are the experimental design and the possible interactive effects between the selection biases and experimental variables (Cook and Campbell 1979; Campbell and Stanley 1963). Meaning, that since this work leveraged existing relationships, aligned the research question with community concern and perceived risk, partnered with community organizations, and employed cultural knowledge brokers, the experimental arrangement was impacted and introduced selection bias. As stated above, *Project Harvest* had overrepresentation of low-income households in all communities and Hispanic/Latina/o/x from the Tucson area. Hispanic/Latina/o/x representation was somewhat equal in Hayden/Winkelman, but lower in Dewey-Humboldt and Globe/Miami. Specifically, in Tucson, SERI recruited from their organization's existing programming designed to reach and address the needs of those underserved and underrepresented in the Tucson metropolitan area. Though *Project Harvest* had a consistent message and recruitment campaign and used a myriad of bilingual strategies (listed in "Community selection and recruitment" section), the majority of participants were recruited by the local *promotoras*, highlighting the *promotoras*' paramount role; however, this could have led to a section bias based on the *promotora*'*s* social position and network.

Regardless of the limitations stated above, *Project Harvest* is incredibly proud of the recruitment methods and engagement. *Project Harvest* works with predominately environmental justice communities that do not have equal access to the environmental decision-making processes and are disproportionately exposed to pollution and suffer from environmental health disparities. We anticipate that these results can be generalizable beyond the study population, but more importantly, the study experimental design and selection bias created the necessary space for those living in "sacrifice zones" (Bullard 1993) whose voice are considered those of the "side effects" (Beck 1992)—to be heard and represented to successfully inform environmental decision-making.

Community participation and improving recruitment

As highlighted above, *Project Harvest* study design and recruitment were more inclusive of, and provided opportunities for, those who are most effected by environmental pollution to be heard and represented. Historically, non-White minority groups have been underrepresented in citizen science projects (National Academies of Sciences 2018; Pandya 2012). Participants in *Project Harvest* are economically and racially diverse, with just over 50% self-identifying as low-income or below (based on U.S. Department of Housing and Urban Development guidelines) and non-White race/ethnicity (predominantly Hispanic/Latina/o/x); and reporting that they do not have a college degree (Table 1) (Davis et al. 2020). While we do have overrepresented participation from Hispanic/Latina/o/x identifying participants (when compared to the state demographics), this highlights the importance of engagement and recruitment methodologies, indicating that minority recruitment is readily achievable. A full comparison between the state of Arizona's race/ethnicity breakdown versus *Project Harvest* participants can be seen in Table 4. The lack of educational and racial representation in citizen science efforts is attributed to research design, which can impact recruitment methods. In contrast to co-created community science described here, traditional citizen science programs are sometimes missing community input at the inception of the program, lack reciprocity, and mutual or shared responsibility and accountability. Traditional citizen science programs may also lack inclusive practices and do not address the interests, concerns, and needs of members of society historically and currently underserved by science (Cooper et al. 2021). In addition, some citizen science programs have inclusion and exclusion vetting processes to participate that are not inclusively designed and welcoming to a diverse body of learners and forms of knowledge. The primary mechanism of *Project Harvest* recruitment was via *promotoras*, who are known within their respective communities. One shortcoming was the recruitment of Black or African Americans and American or Alaskan Natives (Indigenous populations). Potential ways to overcome this for future projects are to continue building community-academic relationships and to increase the number of *promotoras*, community members in leadership roles, and partnerships with community champions and community-based organizations throughout the targeted communities (Davis and Ramírez-Andreotta 2021; Davis et al. 2020).

Table 4 Distribution of Race/Ethnicity in Arizona, USA and Project Harvest Participants

Race/ethnicity	Arizona*	Project Harvest
Black or African American	5.1%	0.0%
American or Alaskan Native	5.3%	0.0%
Asian/Pacific Islander	4.0%	3.1%
Two or more	2.9%	3.8%
Hispanic/Latino	31.6%	47.7%
White, not Hispanic/Latino	54.4%	44.6%
Other	N/A	0.8%

*U.S Census Bureau 2013. The 2010 U.S. Census Survey does not offer an "other" option; therefore, that category is listed as "N/A". Project Harvest participant data is only calculated for those who have submitted all surveys

Conclusion

Project Harvest engaged traditionally underserved and underrepresented groups and has co-generated a dataset that provides novel insights into residential conservation infrastructures, environmental awareness, and perception of pollution. In this work, we have demonstrated the importance of collecting socio-demographic information in addition to relevant site description and environmental perception data. Understanding the harvesting rainwater infrastructures, gardening trends, and participant awareness by community, income, race/ethnicity, age, and gender, allows us to better understand if any home characteristics could be impacting a participant's environmental quality and inform policy design. This information can be used to formulate evidence- and place-based responses to environmental health concerns and inform future climate change adaptation policies and communication strategies to build community resiliency. Multiple climatic drivers cause numerous hazards leading to social and environmental risk (Zscheischler et al. 2018). Increased temperatures and drought in the southwest (Williams et al. 2020) highlight the need for more effective water management and approaches to address urban heat island effect. With an understanding of how cistern size and material is associated with race and income, policies can be designed to ensure equal access to materials, especially for urban environmental justice communities who may benefit more from a larger cistern that can support the irrigation of shade trees to address urban heat island effect and reduce electricity costs. These efforts could effectively increase a family's capacity to build a sustainable home and successfully adapt to climate change stressors. These findings also highlight the need for a tiered loan-based approach to ensure all have equal access to and can benefit from rebate programs. Limited income families traditionally have fewer resources to purchase and install rainwater harvesting systems and maintain trees (SERI n.d.). The effort led by SERI in collaboration with the City of Tucson clearly demonstrates how a loan and grant program along with cultural-informed teaching workshops for limited-income families can increase the number of rainwater harvesting systems in environmental justice communities.

We also have demonstrated the successful recruitment and participation of traditionally underrepresented and underserved groups by ensuring the project is accessible and working with community partners and *promotoras*. Interestingly, those with a trade/apprenticeship education (59%) were far more likely to identify potential sources of nearby pollution, specifically mining and waste disposal. These findings highlight that those who are in trade professions can play a pivotal role in environmental and risk communication efforts and should be considered for knowledge broker and *promotora* type roles. This finding additionally coincides with the mission of federally funded worker training programs to build capacity within environmental justice communities. These worker training programs have been able to successfully deliver both pre-employment and life skills training and increase sustainable employment opportunities, promote economic development, address occupational health disparities, and advance environmental justice (NIEHS, 2021).

Currently, information-based regulations like the TRI are missing the mark and perpetuating information disparities. Policy and intervention programs need to include a peer education model and be more deliberate and transparent about sources of environmental pollution, how these sources can impact environmental quality, and provide culturally-tailored information regarding public heath prevention/intervention and mitigation/remediation practices. For example, the worker trainer programs highlighted above partner with community leaders, employers, community-based organizations, state and local governments, former students, and union representatives (NIEHS, 2021). Informed by formative and process evaluation methods, *Project Harvest* has reported all the data back to participants in English and Spanish using novel data sharing techniques, such as print media, data visualizations, environmental art, and an interactive digital platform, all which included relevant information and existing water quality standards/advisory levels to inform families on how to safety use their harvested rainwater (Project Harvest n.d.; Kaufmann et al. 2021; Ramírez-Andreotta et al., unpublished results).

Both community and race/ethnicity were common themes for not only gardening and water harvesting preferences of participants, but for how they perceive potential sources of pollution. These two socio-demographic categories together indicate that there is a socio-cultural influence on participants' relationship with their local environment. This relationship can inform policy design and should be considered by both researchers and policymakers prior to environmental public health efforts. Understanding cultural relevance helps identify the unique socio-demographic characteristics that influence individual and community exposures, risk, and perception of environmental pollution. In *Project Harvest*, it became clear that rain is not "pure" and in most cases, a participant's potential exposure to environmental pollutants is beyond their control (Palawat et al., unpublished results). To elicit structural change for environmental justice, participatory research efforts need to ensure community members hold formal leadership roles, include decision-makers and policy goals, and sustain long term partnerships (Davis and Ramírez-Andreotta 2021). Policy interventions need to be informed by Critical Environmental Justice studies (Pellow 2018, 2016) and efforts need to be invested in distributive, procedural, corrective, and social justice to thoroughly identify the common causes of and solutions to environmental injustices (Kuehn 2000).

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13412-022-00769-7.

Acknowledgements We would like to thank all Project Harvest participants for their time and the co-generation of data. We would like to thank all the *promotoras* and those not listed as co-authors, Margaret Dewey, Lisa Ochoa, Palmira Henriquez, Aviva O'Neil, Imelda Cortez, and Armida Boneo for their facilitation in participant recruitment, training, and ongoing commitment to the project and community. Special thank you to program coordinator/lab manager, Shana Sandhaus for support of multiple project activities which enabled this research. We thank Ann Marie Wolf and the entire Sonora Environmental Research Institute, Inc for their partnership and essential role in *Project Harvest*. We would like to acknowledge Maria Del Rocío Estrella Sanchez for translation of the surveys and responses. Finally, we would like to thank our anonymous reviewers for helping to improve the paper.

Author contribution Study conceptualization: M.D.R-A. Study design: M.D.R-A., A.M., J.E.T.M., A.K., L.A., R.A.R., F.S., methodology: A.M., M.D.R-A.; investigation: A.M., M.J., T.F., M.D.R-A.; formal analysis: A.M.; validation: A.M.; writing-original draft preparation: A.M.; writing-review and editing: A.M., M.D.R-A., J.E.T.M., A.K., L.A., S.B., R.A.R; F.S., M.J., T.F.; supervision: M.D.R.-A.; project administration: M.D.R-A.; funding acquisition: M.D.R-A., J.E.T.M., A.K., L.A, R.A.R, F.S.

Funding This research was funded by the National Science Foundation's Division of Research and Learning—Advancing Informal STEM Learning Program, Alexandria, VA [Grant No. 1612554] and the National Science Foundation's Division of Human Resource Development-Alliances-Minority Participation, Alexandria, VA [Grant No. 1809591].

Declarations

Human research All survey participants were consented under the University of Arizona Institutional Review Board, which ensures the rights and welfare of human participants in research.

Competing interests The authors declare no competing interests.

References

Abdul-Wahab SA, Abdo J (2010) The effects of demographic factors on the environmental awareness of Omani citizens. Hum Ecol Risk Assess Int J 16(2):380–401

Ahmed IM, Nayl AA, Daoud JA (2016) Leaching and recovery of zinc and copper from brass slag by sulfuric acid. J Saudi Chem Soc 20:S280–S285

Aminrad Z, Zakaria SZBS, Hadi AS (2011) Influence of age and level of education on environmental awareness and attitude: case study on Iranian students in Malaysian Universities. The Social Sciences 6(1):15–19

Aoyagi H, Ogunseitan OA (2015) Toxic releases and risk disparity: a spatiotemporal model of industrial ecology and social empowerment. Int J Environ Res Public Health 12(6):6300–6318

Arizona Department of Agriculture (AZDA). (2018). "Guide to Arizona Agriculture." *Arizona Department of Agriculture*

Arizona Department of Water Resources (ADWR). (n.d.). Public resources | Arizona Department of Water Resources. Retrieved 23 January 2021, from https://new.azwater.gov/conservation/public-resources

Arizona State Mine Inspector. (n.d.). How many mines are there in Arizona. asmi.az.gov/how-many-mines.

Arizona Office of the Governor. (2019). New census report ranks Arizona third in percentage growth rate. Retrieved 23 January 2021, from https://azgovernor.gov/governor/news/2019/12/new-census-report-ranks-arizona-third-percentage-growth-rate

ASARCO. (n.d.). Grupo Mexico Mining. https://www.asarco.com/mines/

Averett, N. (2017). New blood: The promise of environmental health citizen science projects. National Institute of Environmental Health Sciences, U.S. Department of Health and Human Services, ehp.niehs.nih.gov/doi/full/https://doi.org/10.1289/EHP2484.

Backor K, Golde S, Nie N (2007) Estimating survey fatigue in time use study. In international association for time use research conference, Washington, DC

Beck. (1992). Risk society : towards a new modernity. Sage Publications.

Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ et al (2014) Next steps for citizen science. Science 343(6178):1436–1437. https://doi.org/10.1126/science.1251554

Bullard RD (2001) Environmental justice in the 21st century: race still matters. Phylon (1960-) 49(3/4):151–171. https://doi.org/10.2307/3132626

Bullard RD (1987) Invisible Houston: the Black experience in boom and bust. Texas A&M University Press, College Station, p 1987

Bullard RD (1990) Dumping in Dixie: race, class and environmental quality, 1st edn. Westview Press, Boulder

Bullard RD. (1993). Confronting environmental racism: voices from the grassroots (1st ed.). South End Press.

Bullard RD (1996) UNEQUAL PROTECTION: ENVIRONMENTAL JUSTICE AND COMMUNITIES OF COLOR, 2nd edn. Sierra Club Books, San Francisco

Bretsen SN (2018) Rainwater harvesting in Colorado and the quandary of a taking. Tex a&m J Prop l 4:165

Brody JG, Morello-Frosch R, Brown P, Rudel RA, Altman RG, Frye M et al (2007) Improving disclosure and consent: "Is it safe?": new ethics for reporting personal exposures to environmental chemicals. Am J Public Health 97(9):1547–1554

Brody JG, Dunagan SC, Morello-Frosch R, Brown P, Patton S, Rudel RA (2014) Reporting individual results for biomonitoring and environmental exposures: lessons learned from environmental communication case studies. Environ Health 13:40

Campbell D, Stanley J (1963) Experimental and quasi-experimental designs for research. Rand-McNally, Chicago, IL

Cook TD, Campbell DT (1979) Quasi-experimentation: design and analysis issues for field settings. Houghton Mifflin Company, Boston, MA

City of Tucson. (2020). "Rainwater harvesting rebate." *Official Website of the City of Tucson*, City of Tucson, www.tucsonaz.gov/water/rainwater-harvesting-rebate.

Cooper CB, Hawn CL, Larson LR, Parrish JK, Bowser G, Cavalier D, Dunn RR, Haklay M, Gupta KK, Jelks NO, Johnson VA, Katti M, Leggett Z, Wilson OR, Wilson S (2021) Inclusion in citizen science: the conundrum of rebranding. Science 372(6549):1386–1388. https://doi.org/10.1126/science.abi6487

Davis LF, Ramírez-Andreotta MD, McLain JE, Kilungo A, Abrell L, Buxner S (2018) Increasing environmental health literacy through contextual learning in communities at risk. Int J Environ Res Public Health 15(10):2203

Davis LF, Ramírez-Andreotta MD, Buxner SR (2020) Engaging diverse citizen scientists for environmental health: recommendations from participants and promotoras. Citizen Science: Theory and Practice 5:1

Davis, L. and Ramírez-Andreotta, M. (2021). Participatory research for environmental justice: a critical interpretive synthesis. [online] Environmental Health Perspectives. Available at: https://ehp.niehs.nih.gov/doi/https://doi.org/10.1289/EHP6274

De Silva DG, Pownall RA (2014) Going green: does it depend on education, gender or income? Appl Econ 46(5):573–586

Emmett EA, Desai C (2010) Community first communication: Reversing information disparities to achieve environmental justice. Environ Justice 3(3):79–84

Emmett EA, Zhang H, Shofer FS, Rodway N, Desai C, Freeman D, Hufford M (2009) Development and successful application of a "community-first" communication model for community-based environmental health research. J Occup Environ Med 51(2):146–156

Fairclough DV, Brown JI, Carlish BJ, Crisafulli BM, Keay IS (2014) Breathing life into fisheries stock assessments with citizen science. Sci Rep 4(1):1–10

Flynn J, Slovic P, Mertz CK (1994) Gender, race, and perception of environmental health risks. Risk Anal 14(6):1101–1108. https://doi.org/10.1111/j.1539-6924.1994.tb00082.x

Foley T et al (2019) Low income urban forestry program in Tucson, Arizona, USA. Cities and the Environ (CATE) 12(2):2

Geoghegan, H., Dyke, A., Pateman, R., West, S. and Everett, G. (2016). Understanding motivations for citizen science. Final report on behalf of UKEOF, University of Reading, Stockholm Environment Institute (University of York) and University of the West of England.

Heusinkveld D, Ramírez-Andreotta MD, Rodriguez-Chavez Saez EA, Betterton E, Rine K (2021) Assessing a children's integrated exposure model in an active mining town. Expos Health 13(3):517–533. https://doi.org/10.1007/s12403-021-00400-0

Johnson R, Ramsey-White K, Fuller CH (2016) Socio-demographic differences in toxic release inventory siting and emissions in metro Atlanta. Int J Environ Res Public Health 13(8):747

Jarratt-Snider K, Nielsen MO (2020) Indigenous environmental justice. University of Arizona Press. https://doi.org/10.2307/j.ctv10qqwrm

Jones, E L, and F L Ransome. (1920). "Deposits of manganese ore in Arizona." U.S. Geological Survey, U.S. Geological Survey.

Kaufmann DB, Hamidi N, Palawat K, Ramírez-Andreotta MD (2021) Ripple effect: communicating water quality data through sonic vibrations. In Creativity and Cognition (C&C '21). Assoc Comput Machine, New York, NY, USA, Article 64:1–7. https://doi.org/10.1145/3450741.3464947

Kobori H, Dickinson JL, Washitani I, Sakurai R, Amano T, Komatsu N, ... and Miller-Rushing AJ (2016) Citizen science: a new approach to advance ecology, education, and conservation. Ecological research, 31(1), 1-19

Kuehn, Robert R (2000) "A taxonomy of environmental justice". Aboriginal Policy Research Consortium International (APRCi). 307. https://ir.lib.uwo.ca/aprci/307

Krosnick JA and Presser S. (2010). Questionnaire design. In J. D. Wright & P. V. Marsden (Eds.), Handbook of Survey Research (Second Edition). West Yorkshire, England: Emerald Group.

Macias T (2016) Environmental risk perception among race and ethnic groups in the United States. Ethnicities 16(1):111–129

Martin WE, Kulakowski S (1991) Water price as a policy variable in managing urban water use: Tucson, Arizona. Water Resour Res 27(2):157–166

Masuda JR, Poland B, Baxter J (2010) Reaching for environmental health justice: Canadian experiences for a comprehensive research, policy and advocacy agenda in health promotion. Health Promot Int 25(4):453–463. https://doi.org/10.1093/heapro/daq041

Meyer A (2015) Does education increase pro-environmental behavior? Evidence from Europe. Ecol Econ 116:108–121

Miller, Allisa. (2019). “Amarillo ASARCO copper refinery reportedly shutting down operations.” Https://Www.newschannel10.Com , News Channel 10, www.newschannel10.com/2019/10/24/amarillo-asarco-copper-refinery-reportedly-shutting-down-operations/

Moore, Derrick. (2018). “Homeownership remains below 2006 levels for all age groups.” The United States Census Bureau, www.census.gov/library/stories/2018/08/homeownership-by-age.html.

Mortimer Farms. (n.d.). “What's Pickin'.” *Mortimer Farms AZ*, Mortimer Farms AZ, www.mortimerfarmsaz.com/CountryStore.

Nesbitt, Meitner MJ, Sheppard SR, Girling C (2018) The dimensions of urban green equity: a framework for analysis. Urban Forest Urban Green 34:240–248. https://doi.org/10.1016/j.ufug.2018.07.009

National Academies of Sciences (NAS), Engineering, and Medicine. (2018). *Learning Through Citizen Science: Enhancing Opportunities by Design*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25183.

National Institute of Environmental Health Services (NIEHS). (2010). Environmental Justice and Hazardous Waste Worker Training Programs. https://tools.niehs.nih.gov/wetp/public/hasl_get_blob.cfm?id=9014

National Institute of Environmental Health Services (NIEHS). (2021). Environmental Career Worker Training Program. https://www.niehs.nih.gov/careers/assets/docs/ecwtp_factsheet_2021.pdf

O’Fallon L, Finn S (2015) Citizen science and community-engaged research in environmental public health. Lab Matters 4:5

Palawat, K., Foley T., Root, R.A., Ramírez-Andreotta M.D. Patterns of contamination and burden of lead and arsenic in rooftop harvested rainwater collected in Arizona environmental justice communities. In review, unpublished results.

Pandya R (2012) A framework for engaging diverse communities in citizen science in the US. Front Ecol Environ 10(6):314–317

Parker K, Horowitz J, Brown A, Fry R, Cohn D, Igielnik R (2018) “Similarities and differences between urban, suburban and rural communities in America.” *Pew Research Center's Social & Demographic Trends Project*, Pew Research, www.pewsocialtrends.org/2018/05/22/what-unites-and-divides-urban-suburban-and-rural-communities/.

Pellow (2016) Toward a critical environmental justice studies. Du Bois Review 13(2):221–236. https://doi.org/10.1017/S1742058X1600014X

Pellow (2018) What is critical environmental justice? UK Polity Press, Cambridge

Pima County. (2013). “Tangerine landfill closing to the public.” Tangerine Landfill Closure - Pima County, Pima County, webcms.pima.gov/cms/One.aspx?pageId=60081.

Pima County Department of Environmental Quality (PDEQ). (2020). “Non-Pima County owned landfills, transfer stations & reclamation facilities in Pima County.” *Non-Pima County Owned Landfills, Transfer Stations & Reclam...*, Pima County Government, webcms.pima.gov/cms/one.aspx?portalId=169&pageId=196357.

Project Harvest website (n.d.) Available at: projectharvest.arizona.edu

Radonic L (2019) Becoming with rainwater: a study of hydrosocial relations and subjectivity in a Desert City. Economic Anthropology 6(2):291–303

Ramírez-Andreotta MD, Brusseau ML, Beamer P, Maier RM (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. Sci Total Environ 454:373–382

Ramírez-Andreotta, M. D., Brusseau, M. L., Artiola, J., Maier, R. M., and Gandolfi, A. J. (2015). Building a co-created citizen science program with gardeners neighboring a Superfund site: The Gardenroots case study. *International public health journal*, *7*(1).

Ramírez-Andreotta MD, Brody JG, Lothrop N, Loh M, Beamer PI, Brown P (2016a) Reporting back environmental exposure data and free choice learning. Environ Health 15(1):2

Ramírez-Andreotta MD, Brody J, Lothrop N, Loh M, Beamer P, Brown P (2016b) Improving environmental health literacy and justice through environmental exposure results communication. Int J Environ Res Public Health 13(7):690. https://doi.org/10.3390/ijerph13070690

Ramírez-Andreotta, M. D., et al. (2020). “Addressing environmental injustice through co-created citizen science.” *Department of Environmental Science*, Water Resources IMPACT, environmentalscience.cals.arizona.edu/news/2019/11/addressing-environmental-injustice-through-co-created-citizen-science.

Ramírez-Andreotta, M. D., Buxner S; Sandhaus, S. Co-created environmental health science: identifying community needs and co-generating knowledge to support science learning. In review, unpublished results.

Richardson, C.A., Swartzbaugh, L., Evans, T. and Conway F.M. (2019). Directory of active mines in Arizona: FY 2019. Arizona Geological Survey Open-File Report-19–04, 12 pages.

Sandhaus S, Ramírez-Andreotta MD, Kilungo A, Wolf AM, Sandoval F, Henriquez P (2018) Combating climate injustices: an informal science and popular education approach to addressing environmental health disparities. Pedagogy in Health Promotion 4(4):260–269

Sansom G, Berke P, McDonald T, Shipp E, Horney J (2019) Evaluating the impact of race and gender on environmental risk perceptions in the Houston neighborhood of Manchester. Environmental Justice 12(3):92–98

Sarker R, Yeasmin M, Rahman MA, Islam MA (2018) People’s perception and awareness on air pollution in rural and urban areas of Mymensingh Sadar upazila. Progress Agric 29(1):22–32

Shi X, He F (2012) The environmental pollution perception of residents in coal mining areas: a case study in the Hancheng mine area, Shaanxi Province, China. Environ Manage 50:505–513. https://doi.org/10.1007/s00267-012-9920-8

Soga, M., Gaston, K. J., and Yamaurac, Y. (2017). Gardening is beneficial for health: a meta-analysis., Preventive Medicine Reports, 5, 2017. ISSN 2211–3355, https://doi.org/10.1016/j.pmedr.2016.11.007.

Soga, M., Gaston, K. J., and Yamaurac, Y.. (n.d.). Rainwater Harvesting. https://seriaz.org/rainwater-harvesting/

Sonora Environmental Research Institute Inc. (n.d.) “Rainwater harvesting rain barrels.” seriaz.org/projects/rainwater-harvesting/discounted-rain-barrel-program

Tamaddun K, Kalra A, Ahmad S (2018) Potential of rooftop rainwater harvesting to meet outdoor water demand in arid regions. J Arid Land 10(1):68–83

Towne, D. C. (2002). Ambient groundwater quality of the Lower San Pedro Basin: a 1999–2000 baseline study. Arizona Department of Environmental Quality, Water Quality Division, Hydrologic Support & Assessment Section, Groundwater Monitoring Unit.

United Church of Christ, Commission for Racial Justice. (1987). Commission for Racial Justice. Toxic Waste and Race in the United States. https://www.nrc.gov/docs/ML1310/ML13109A339.pdf

U.S. Census Bureau. (2013). 2010 Census. http://www.census.gov/2010census/data/

U.S. Census Bureau. (2012). 2010 Census of population and housing, summary population and housing characteristics, CPH-1–4, Arizona U.S. Government Printing Office, Washington, DC.

U.S. Census Bureau. (2021). Quick Facts. https://www.census.gov/quickfacts/fact/table/US/PST045221.

Census reporter. (2019). https://censusreporter.org/.

U.S. Environmental Protection Agency (U.S. EPA). (2020a). Toxics release inventory (TRI) program. www.epa.gov/toxics-release-inventory-tri-program.

U.S. Environmental Protection Agency (U.S. EPA). (2020b). TRI data uses. www.epa.gov/toxics-release-inventory-tri-program/tri-data-uses.

U.S. Environmental Protection Agency (U.S. EPA). (2022). TRI toxics tracker, total disposal or other releases by chemical for 2020. https://www.epa.gov/toxics-release-inventory-tri-program.

U.S. Environmental Protection Agency (U.S. EPA). (2021a). Superfund job training initiative. https://www.epa.gov/superfund/superfund-job-training-initiative

U.S. Environmental Protection Agency (U.S. EPA). (2021b). Environmental justice timeline. https://www.epa.gov/environmentaljustice/environmental-justice-timeline

U.S. General Accounting Office. (1983). Siting of hazardous waste landfills and their correlation with racial and economic status of surrounding communities. https://www.gao.gov/products/rced-83-168

U. S. Geological Survey. (2017). The top 5 mineral-producing states. Retrieved 23 January 2021, from https://www.usgs.gov/news/top-5-mineral-producing-states

U.S. National Park Service. (n.d.). “History of mining in the Tucson Mountain district.” National Park Service, U.S. Department of the Interior, home.nps.gov/sagu/planyourvisit/upload/Tucson-Mining-for-Web.pdf.

Wendler D, Kington R, Madans J, Van Wye G, Christ-Schmidt H, Pratt LA, Brawley OW, Gross CP, Emanuel E (2006) Are racial and ethnic minorities less willing to participate in health research? PLoS Med 3(2):e19. https://doi.org/10.1371/journal.pmed.0030019

West SE and Pateman RM. (2016). Recruiting and retaining participants in citizen science: What can be learned from the volunteering literature?. *Citizen Science: Theory and Practice*.

Williams AP, Cook ER, Smerdon JE, Cook BI, Abatzoglou, JT, Bolles K, ... and Livneh, B. (2020). Large contribution from anthropogenic warming to an emerging North American megadrought. Science, 368 (6488), 314-318

Wilson SM, Fraser-Rahim H, Williams E et al (2012) Assessment of the distribution of toxic release inventory facilities in metropolitan Charleston: an environmental justice case study. Am J Public Health 102(10):1974–1980. https://doi.org/10.2105/AJPH.2012.300700

Yang T (2020) Association between perceived environmental pollution and health among urban and rural residents-a Chinese national study. BMC Public Health 20(1):194

Yonas MA, Jaime MC, Barone J, Valenti S, Documét P, Ryan CM, Miller E (2016) Community partnered research ethics training in practice: a collaborative approach to certification. J Empir Res Hum Res Ethics 11(2):97–105

Zscheischler WS, Van Den Hurk BJJ, Seneviratne SI, Ward PJ, Pitman A, Aghakouchak A, Bresch DN, Leonard M, Wahl T, Zhang X (2018) Future climate risk from compound events. Nat Clim Chang 8(6):469–477. https://doi.org/10.1038/s41558-018-0156-3