CITIZEN SCIENCE:
THEORY AND PRACTICE

Exploring Conditions for Designing Citizen Observatories in Sri Lanka: The Case of Air Quality in Rural Areas

RESEARCH PAPER

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ABSTRACT

Citizen observatories (COs) are socio-technical initiatives that seek to engage citizens interested in environmental issues via digital applications to gather ecological data, drawing on participatory approaches. While CO projects conducted in the Global North have successfully engaged citizens, less is known about how they engage with citizens in rural areas in the Global South. Herein, we address this knowledge gap by exploring conditions for designing COs in rural areas in Sri Lanka. We conducted a case study to examine how rural communities that reside close to industrial centers make sense of their surroundings, with a specific focus on air quality. With the aid of qualitative analysis of ten semi-structured interviews, we identify primary collective community practices that contribute to local air quality knowledge. The study contributes to discourses on conditions for designing COs by suggesting potential design features for community science participation and sense-making. Our findings indicate that most often, the citizen science practices identified and discussed by the literature on COs and human-computer interaction are at odds with rural communities' priorities and sensing praxis in countries such as Sri Lanka. Thus, we argue for engaging with communities and their specific collective practices rather than with individuals to design COs in rural areas in Sri Lanka and in similar contexts. To give socio-technical initiatives such as COs a chance outside of the Global North, attention must be paid to how citizens experience, sense, and make sense of the local environment as part of a collective effort.

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INTRODUCTION

There is wide interest in socio-technical initiatives such as citizen observatories (COs), mainly led by citizens using citizen science strategies to monitor and act upon issues concerning the local environment (Alfonso, Gharesifard, and When 2022; Woods et al. 2022). COs have, since 2012, been deployed primarily in Europe (Montargil and Santos 2017). COs are defined as social and technical platforms constituted by people, technological solutions, and community participatory governance methods that complement environmental observation systems and improve local decision-making (Wehn and Evers 2015). COs can be viewed as an instance of citizen science aiming to engage citizens in collecting data about the environment and seeking to make an impact at the level of environmental policies. The individuals involved in COs are often volunteers who go beyond collecting data to do work such as analysing data, refining the project design, co-creating projects, and disseminating findings (Palacin-Silva et al. 2016). Those engaging in COs are citizens who care about the ecological environment and are motivated to learn about scientific methods, tools, and environmental data to act upon the local environment.

Previously, we conducted a systematic literature review on citizen observatories (Rathnayake, Joshi, and Cerratto-Pargman 2020). Through it, we gained compelling insight regarding the current landscape of citizen-driven environment monitoring worldwide. Our analysis, which reviewed 57 articles, revealed the imbalance of geographical spread of these projects; most of the studies skewed toward the Global North. It also highlighted that most COs focus on testing the citizen-science approach as an affordable method of acquiring ample environmental data, including related tools; and it underscored the need for more attention to issues regarding the sustainability of citizen science projects with continuous citizen participation.

Citizen participation has largely been confined to data gathering by individuals to increase the number of data points aggregated and discussed afterward. While individual participation of citizens may lead to achieving crowdsourcing goals, such as gathering large volumes of data at an affordable cost, there appears to be a need for more research examining the social aspects of citizen participation and engagement in data science campaigns (Bonney et al. 2014). Such observations align with findings shared by other systematic literature surveys, such as the one published in 2016 that reviewed academic articles about citizen science between 2007 and 2019 to identify global and European trends in environmental applications, practices, engagement techniques, and technology uses (Palacin-Silva et al. 2016). This second study shows the Global North dominance of the COs, with the USA, UK, and Canada being named the most active countries, with 38%, 16%, and 8% respective project percentages out of 108 studies. Furthermore, it reveals that more than 16 European countries are actively involved in environmental COs.

While acknowledging the spread of Citizen science and using citizen-centric data collection at the global level, including the Global South, the direct implementation of COs in the regions beyond the Global North is relatively rare (Rathnayake, Joshi, and Cerratto Pargman 2020). For example, the Citizen Science Africa Association (CitSci Africa) spearheads experience sharing and helps Africa set up its own citizen science initiative in Africa (SciStarter, no date). Similarly, in the Latin American context, though there are citizen science projects, they are mostly confined to the academic domain, with the call to seek attempts to induce positive outcomes in the environment, society, and governance. (Ortega-Álvarez and Casas 2022; Maillard et al. 2024). Further, a study conducted on water quality monitoring using citizen science states that despite the great potential of citizen science, it is still underutilized in low- and middle-income countries (Castro, Mateo-Sagasta, and Nowicki 2024).

In this case study, we were interested in exploring conditions for designing COs in rural areas by studying how local environments are sensed and perceived to be at risk, and where, if at all, concepts like citizen science can contribute to communities in rural areas. While previous studies on COs target the participation of a specific community, the environmental data collection generally occurs individually (Kim, Mankoff, and Paulos 2013; Little, Hayashi, and Liang 2016). There are few studies discuss the interactions among citizens as part of a community and its practices (Wilderman 2007). Some studies highlight the need to use knowledge of the local communities and bring a sense of ownership to them for the long-term sustainability of the citizen commitment (Stephenson and Moller 2009; Gandiwa et al. 2014; Hecker et al. 2018).

Current literature covers the design issues of public participation in scientific research (PPSR), the core of the COs, and outlines vital takeaways in future designs. For example, Shirk et al. (2012) explore the contexts of conservation, ecology, and environmental management and provide a structured approach for public participation in scientific studies. They outline that PPSR project outcomes are influenced by (1) the degree of public participation in the research process and (2) the quality of public participation negotiated during project design. Accordingly, their work identifies three participation models: contributory, collaborative, and co-created projects. In contributory projects, the public mainly contributes

data, and the projects are designed chiefly by scientists. Scientists generally design collaborative projects, while the public contributes beyond data in project design, analysis, and dissemination of findings. The co-created projects are designed by scientists and by members of the public, with active involvement of the public in all aspects of the research process. Shirk et al. (2012) present a framework for PPSR to help project developers with five elements: inputs, activities, outputs, outcomes, and impacts; and further investigate how the three different models of participation fit within this framework, describing the level of participation in each element and fundamentally questioning whose and what interests are served. We return to these elements in our discussion section, reflecting on the design issues discovered in our study.

Our study contributes to a better understanding of the need to supply regional and local knowledge about the environment, particularly how such knowledge can improve the response to environmental challenges such as air pollution. For example, the Moms Clean Air Force report highlights the impact of air pollution and climate change on the indigenous tribes in the United States (USA) (Moms Clean Air Force, no date). This report finds different traditional approaches that Indigenous communities use to curb air pollution impacts on health. Other studies highlight the effectiveness of using local knowledge in addressing environmental issues. Another review covering 686 studies on pollution impacts on the Indigenous population concludes the need for input from local knowledge in environmental decision-making to address pollution control effectively (Fernández-Llamazares et al. 2020).

Taking stock of the studies mentioned above, the present work aims to address a gap in the study of COs by investigating conditions for designing and implementing COs and their citizen science practices in rural areas located in Sri Lanka. More specifically, this case study is focused on a rural community that has developed mechanisms to keep track of the air quality in their village. We studied how the community of 120 families in this village uses their sensory experiences and other practices for knowledge-creating about their local environment. Through interviews with the villagers, the study identifies under which conditions COs for rural communities concerned about air quality are valuable for the citizens in Sri Lanka.

The research questions leading this case study are:

(1) How do the villagers sense their local environment?
(2) How do the villagers make sense of their observations?
(3) How do the villagers legitimize their experiences within the context of their air pollution?

This case study sheds light on the role played by the community in creating local knowledge about the environment by and for the community. It presents implications for the design of socio-technical and participatory platforms for communities in rural areas.

CONTEXT OF THE CASE STUDY

This study focuses on air pollution, which constitutes an environmental concern globally, particularly in rural Sri Lanka. According to the World Health Organization, nine out of ten people are exposed to harmful air pollution, with an estimated seven million deaths annually (World Health Organization 2020). Globally, it is the fourth highest overall risk factor for human health, behind high blood pressure, dietary issues, and smoking (Rafaj et al. 2018). A significant disparity exists in the spread and the health effects of global air pollution. For example, reports regarding the air quality of North America (United States Environmental Protection Agency n.d.) and Europe (European Environment Agency 2022) showed declining air pollution in those regions. However, values in Asia have risen sharply, which has balanced the lesser values of other world regions in between. The health burden of ambient air pollution significantly affects low- and middle-income countries. According to the WHO, 89% of premature deaths from air pollution occur in such countries, especially in Southeast Asia and Western Pacific regions annually (World Health Organization 2020).

Against this backdrop, we have selected the case of air pollution in a village in Sri Lanka, a low-income country and an island at the tip of the Indian subcontinent, in the Indian Ocean, focusing on design aspects of COs in the Global South. The island has a total area of 65,610 km^2, including 2,905 km^2 of inland water bodies (Marambe et al. 2015) Even though Sri Lanka is ranked low in terms of economies in the world, Sri Lanka's physical life quality index remains high, and is one of the highest in South Asia. According to previous findings, air quality levels and pollution may be considered a neglected public health problem in Sri Lanka (Nandasena, Wickremasinghe and Sathiakumar 2010).

The village under study has several established factories. The availability of skilled labour and usable wood waste as materials in this area are targets for installing new factories. Some of these factories use the waste of carpentry work, such as sawdust, as their materials to make different products, such as export-quality fire rods. Recently, Sri Lanka has seen citizens mobilize, sometimes in protests by rural communities, when factories are set up. For example, in 2013, citizens in the village of Rathupaswala experienced an incident that made visible the absence of

communication between the government and the citizens, on the one hand, and the citizens' legitimate concerns about the water quality in this region on the other hand (Imtiaz 2017). In this context, our study provides a relevant platform to explore conditions for setting up COs and citizens' understanding of air quality deterioration.

METHOD

CASE STUDY

We conducted a case study to investigate conditions for COs, focusing on air quality in Sri Lanka in a rural area. We chose a case study research methodology to better understand individuals' and communities' mechanisms, relationships, and processes by capturing data about the local air environment (Denscombe 2017).

STUDY DESIGN

Because we required detailed knowledge about air quality experiences, we selected 11 village family members living in closer proximity using purposive sampling. This sampling technique involves selecting an ideal individual or group from the phenomenon of interest (Palinkas et al. 2015). Those 11 villagers had lived in the area for more than 20 years. We have included six males and five females. These eleven local citizens shared their experiences and practices regarding air quality management (Aceves-Bueno et al. 2017; Young and Casey 2018; Subedi 2021).

The in-depth interviews were semi-structured and conducted in the first author's local language. They were recorded, transcribed, coded, and analyzed by the first author in consultation with the second and third authors. We took several steps to protect this study's quality integrity by using good research practices. The study adheres to Stockholm University's Research Integrity and Ethics policy, which clarifies the University's overall view regarding protecting and promoting good research practice (Stockholm University's Research Integrity and Ethics policy – Staff, no date). Firstly, the study did not involve high-risk procedures or vulnerable populations and is unrelated to any health-related investigation. We consulted with relevant individuals who oversee research ethics at our university, and availed ourselves of the online research ethics tool available on the university intranet to determine the requirements for ethical approval. We ensured the participants were fully informed about the study's aims and how their data was treated through formal letters in their local language. Further, we intend to share a copy of the study in their native language with the community.

We used a five-phased cycle of qualitative data analysis (YIN 2015), applying a grounded theory approach. The phases consisted of (1) compiling, (2) disassembling, (3) reassembling (and arraying), (4) interpreting, and (5) concluding. We used qualitative data analysis software to organize, transcribe, and code the data. In the initial compiling phase, we interviewed the villages and organised the data by transcribing the interviews, which were "cleaned" for analysis by reviewing the transcriptions for errors or inconsistencies. In the disassembling phase, we coded the organised data and identified key themes by applying thematic analysis (Braun and Clarke 2006). Our next step was reassembling. We constructed more prominent themes by implementing the codes to get a comprehensive view of underlying data. Then we determined the connections between the research questions and the resampled data to interperet, or make sense of the data. Finally, we summarized our findings.

The interview consisted of the following questions:

1. How concerned are you about the air quality?
2. What do you feel about the current air quality of your village?
3. How do you learn and make sense of the air quality of your village?
4. What follow-up actions would you take regarding air pollution in your living area?

We analyzed the data collected in ten out of eleven interviews (one was excluded because of its lack of relevance to this study). The next section presents findings based on our analysis of the collected data, and is structured by the study's research questions.

FINDINGS

HOW DO THE VILLAGERS SENSE THE AIR QUALITY IN THEIR LOCAL ENVIRONMENT?

The villagers participating in this study have yet to have access to any other scientific data on air pollution in their area. There is no regional mechanism to measure such data, nor do they have any scientific or technological tool to measure air quality installed by the authorities. Their concerns about their environment are the product of their perceived changes in the local environment over time. More specifically, we identified the recurrent and dominant themes of "smoke," "noise," "smell," and "heat" in the villagers' discourse. In particular, these themes constitute the semantic nodes that organize the villagers' explanation regarding how they collectively negotiate and construct evidence about air pollution that they use in their conversations with others and communication with authorities. In what follows, we describe how the villagers make sense of the challenge of air pollution by using their senses and local knowledge about their environment.

Smoke

In the corpus constructed, smoke is one of the predominant themes that emerged, described in the villagers' words as the visible change in the air, typically one emitted from a burning substance observed by the inhabitants. All the interviewees used this term explicitly, which is one of the recent noticeable changes they have observed. They mentioned their perception of smoke or cloud of smoke, covering a radius of two to three kilometers from the factories when the factories are operating.

They added different examples to indicate concerns about the air quality issue. For instance, they said, *"We sometimes can't see things inside our home due to smoke*." In this type of phrase, they were trying to add depth to the issue through the darkness of the smoke. Some used different words to indicate the seriousness. One interviewee said, "*They have put a chimney, but the smoke is coming down heavily*" to indicate this seriousness by mentioning that the flow was uncontrollable. Most of them used similar phrases such as, *"When they (the factories) start working, only then the smoke gets down,"* to relate the impact of factories on air quality deterioration directly.

We, therefore, find that the sensing of smoke acts as a vital indicator of the air quality, and there are also several sub-indications of its density and relationship to the factory activity.

Smell

The villagers also explained that there was a distinctive unpleasant smell. It was evident that the smell was the first indicator attributed to their concerns about air pollution. For example, they said, *"It was this smell that first made me feel something wrong was taking place in our area."* Some of them used terms like *"strong smell"* and *"smell of burning of wires"* to explain the same experience. For example, one villager said, "*I felt a smell and checked if anything is burning in our house or if there's an electrical leak, and then asked others in the neighborhood if they felt the same*." Smell prompted them to gather informally to conduct an inquiry with others. Further, they use phrases such as "*it eases out at night*" to indicate the relationship to the factories by comparing the smell between the operating hours of the factories and the rest of the time.

"Heat"

The interviewees also mentioned heat to describe the relatively higher temperature they felt in the air during factory operations. They described this as a warmer experience in their environment, which they feel when they move outside their homes. Additional descriptions indicated they *"feel like the heat is generating around us"* and "*I don't feel comfortable when going outside*." These phrases were to describe the intensity of this experience. They also used phrases to link heat with the factories; for example, one interviewee described the experience in detail: *"We feel different heat in our environment during the daytime when the factory machines turn on, and it is not as night time."* Here, we observed villagers relating this heat sensory experience to the factories by mentioning the "daytime" experience.

Therefore, we identified heat as another indicator for villagers of air quality deterioration in the area. It, too, has several sub-indicators or parameters to show the gravity of the issue. The community used time and geographical-based comparisons to attribute what they sensed to the surrounding factories.

Noise

The villagers described loud or unpleasant sounds that cause disturbances to inhabitants. One interviewee used the phrase *"sound of rubble,"* coded as noise, while others used the term "noise" itself. There were eight instances where the interviewees used the words we coded as noise. They complained that the sound disturbed their day-to-day activities, and they connected it to environmental pollution. For example, one interviewee mentioned, *"We all can hear the loud and continuous noise which starts early morning with the factory's opening, polluting the environment."* Another interviewee related their childhood and compared the difference. *"When we were small, the whole area was quiet and very clean. But now, with these noises, our entire neighborhood is shattered, and all are exposed to pollution."* Here, we found a clear indication of a narrative that linked the community along the axis of time to disruptions such as the advent of factories and a loss of agency in the community, who were passively left to witness the detrimental effects. Thus, the perceived noise is another indicator that these communities are sensing pollution and disruption of their environment.

Altogether, these themes indicate the community's dependency solely on general observations from the human senses to determine the air quality. Our analysis of the interviews didn't reveal any willingness of the villagers to get any expert comment or assistance to assess their assumptions. Although the lack of equipment and resource persons are obstacles to such measures, villagers themselves were not enthusiastic about such action. They use key indicators linked to their sense of air quality and observed changes over time (historical progression), translated into sensory inputs such as smell, smoke, heat, and noise.

HOW DO THE VILLAGERS MAKE SENSE OF THEIR ENVIRONMENT?

Our second question relates to how the diverse sensory inputs discussed above integrated into a shared experience

of the community making sense of their environment. How did *the villagers* process their sensory inputs? Here, we identified "gathering" and "sharing" as critical codes or indicators. We first unpack the meanings of the codes and then proceed to explore the themes to determine the answers to this question.

Gathering

Gathering indicates the informal meetings in the community concerning their personally sensed air quality observations. These occurred in the neighborhood without organized structure, time, or methods. In particular, these are informal interactions within the community where they seek others' opinions and experiences to compare with their own. Some of the phrases used by the interviewees are mentioned below.

> *"I rushed to my neighbor to talk about the smoke cover."*

> *"There were few people who came there asking if we feel a smell."*

> *"We got together to discuss with neighbors."*

The respondents indicated the tendency of physical gathering as a primary step of collecting sensed information, negotiating understanding, and making sense of their environment after sensing individually.

> *"Sharing sensed experiences"*

Sharing refers to the mutual discussion about the experiences of air quality between one another. Sharing included describing the sensed experiences, feelings, and ideas regarding the air quality. Verbal sharing was standard, while occasionally, they used chat-based mobile applications or mobile calls. Here, we see technology mediation from a purely sensory community experience for the first time. Via chat, they shared photos of smoke or videos containing noise as a sign of visible evidence. Interestingly, all the participants mentioned some form of digitally mediated communication to ascertain the air quality experience.

Some of the phrases used by the interviewees are mentioned below.

> *"I asked my neighbor if they feel the same."*

> *"We all discussed the smell."*

> *"We had this Whatsapp group and shared the photos of smoke."*

The sharing occurs as a way of sharing knowledge among community members to recount and ascertain their beliefs with others, agree on them, and draw conclusions. By actively sharing their experiences regarding air quality, the respondents verified their assumptions while building on them for knowledge co-creation. We learned that sharing their experiences or feelings supported by evidence such as photos contributed heavily to their following action, such as meeting to lodge complaints or report to the local assembly. It transpired that the respondents, as members of a rural community, even without any prior relationship, formed a strong network through sharing based on this environmental issue. It has given the community a firm belief or joint agreement on their arguments for deteriorating air quality. These results indicate that villagers make sense of the air quality in the community and document their observations using the mobile communication tools they have at their disposal. Scientific verification or measurements (epistemology of the Global North or the western scientific worldview) are inaccessible. Hence, they have deployed the only mechanism in their reach—each other, the community—to act as verifying agents and make decisions based on the collective meaning of those sensing experiences.

HOW DO THE VILLAGERS LEGITIMIZE THE SENSED EXPERIENCES ABOUT THEIR ENVIRONMENT?

The community relies on the Village Assembly (Civil Arakshaka Manadalya) to officially record their experiences based on their collective decisions. They treated this village-level committee as a trusted body in which their stories get into formal recordings as minutes. Those minutes are then discussed in monthly meetings, and the progress is monitored. The meeting is attended by the chief priest of the village temple, the gramasewake (the local government official in charge of the village), a police officer, and representatives from villages. Our interviewees expressed that the assembly is an institution that brings legitimacy to the decisions made by the villages.

> *"A team of villagers went to the assembly, and that's on record now."*

> *"We have entered the concerns about air quality to village assembly and can use it if needed as evidence."*

Participating in the Village Assembly occurs as a community, where they gather and report in the meeting. Evidence about the sensed experiences is created when the experiences are collectively shared, confirmed, and legitimized. The issue here is how much collectively

validated sensed experiences gain agency to provoke a response from the decision-makers in the region.

DISCUSSION

Our findings illustrate how a rural Sri Lankan community understands their environment, particularly air quality, by sensing it, individually and collectively, and documenting sensed observations with mobile phones (e.g., photos, notes). In this section, we reflect on these findings while integrating relevant previous research, models, and frameworks to contextualize the results for further studies.

Previous studies in demography of participation conclude that although a sharp increase is visible in citizen science and related practices, barriers exist when it comes to participation for many social groups. Thus, participation exists at the same exclusion level reflected at the general societal level, limiting participants to educated, academically skilled male participants (Cooper et al. 2021; Vasiliades et al. 2021).

The findings help us understand alternative and valuable approaches for designing COs in a setting such as rural Sri Lanka. Such approaches are scrutinized through the knowledge we gained previously via a systematic literature review on COs in which we found the practice of scientific frameworks to monitor the environment (Dickinson et al. 2012; Palacin-Silva et al. 2016). Those scientific practices are driven by individualistic measuring equipment such as low-cost air quality monitoring kits and single-user interfaces (Hamm and Shibuya 2021). Any interactions or interdependency among the participants are seldom encouraged or not explicitly mentioned or studied.

Our case study reveals that this scientific approach may not be enough for the specific context of rural communities in Sri Lanka. Based on the findings obtained, villagers, like the ones interviewed here, make sense of their air quality through their senses and are most interesting as a community, not only as individuals. More specifically, they make sense of their air quality via three interrelated phases: individual sensing, collective meaning-making, and collective reporting**.**

INDIVIDUAL SENSING

Individual sensing refers to the villagers' observation and sensory understanding of their environment. Their observation spans smoke, smell, noise, and heat. Their confidence in trusting these sensory observations merely depends on comparing past events (our respondents have lived in the area for more than 20 years) and, in some cases, comparison of sensory observations between factory functional and non-operating times. Furthermore, we found their trust in these human sensors and observations more significant than in any scientific method. Without systems or expertise, this trust or confidence in their conclusions results from the actions that follow—gathering and sharing experiences. We, therefore, highlight the community's natural sensory ability and observations for noticing and sensing, such as smoke, noise, smell, and heat, as potential design features of COs when implemented in Sri Lanka.

There are successful implementations of environmental monitoring systems developed in the Global North supporting the input of heterogeneous data, such as these natural observations, that can inspire future development that suits the context and needs described here. For example, a study done in Pittsburgh, USA (Hsu et al. 2017) used a community-based air quality monitoring system that used smoke images, air quality indicators, and smell reports of the crowds. The study indicated that the system-generated scientific knowledge empowers the community to rebalance the power relationship with regulators and other stakeholders.

COLLECTIVE MEANING-MAKING

Collective meaning-making refers to the villagers' participation in conversations and negotiations where they share and take sensed information from others in the community to connect different pieces about the local air quality and make sense together. Here, we refer to informal interactions among individuals as smaller groups to share their sensed data, hypotheses (or speculations), and feelings. This occurs in gatherings, including general physical get-togethers and, in some instances, telephone conversations, WhatsApp, or Viber group chats. During the gathering, they share their ideas verbally or using mobile-based apps through photos or text. Via these informal gatherings, the villagers interested in air quality have created a community that interacts with each other to share what they notice and experience regarding the air in their village. The community the villagers participate in reflects the forming of a community of practice around local air quality (McDonald 2015; Sbrocchi et al. 2022). Community sense-making through gatherings and sharing experiences addresses essential criteria for fulfilling their decision-making process. They discussed and negotiated air quality sensory experiences and related events in groups to get a bigger picture. Most of their follow-up activities after the initial individual observations were of community form. Therefore, we understand the community's interdependent nature, reflected in the analysis, which forms a collective meaning-making. We consider such a collective meaning-making a condition and salient feature for designing COs for this region.

COLLECTIVE REPORTING

With sensing and collective meaning-making backed by a very informal gathering of practice, the knowledge the villagers have created gains further attention and legitimacy when they report it to the Village Assembly. Therefore, collective reporting becomes an essential element of understanding the locally gathered knowledge of the community. Thus, the Local Assembly serves as the place where the local knowledge was recorded in written form and legitimized. It serves as a nerve point where communities meet a relatively upper-hierarchical village segment with some form of decision-making. As a meeting point covering most of the village's social issues, the setup of the Village Assembly may identify as a native meeting place for localized governance in the village structure, which may serve as an effective arm to tackle routine issues. The Village Assembly lacks any scientific resources to capture environmental data, but it can forward formal complaints to the region's public health officials or Central Environment Authority.

This sequence highlights an already established mechanism in rural Sri Lanka where villages sense the air quality, make the decision as a community of practice, and report it to a local body to legitimize their observations. While citizen science and related socio-technical establishments such as COs are getting attention in the Global North, unregistered and seemingly invisible community-based air quality monitoring, at least for recording mechanisms, operates in rural places in the Global South. The mechanisms described herein may open up future research potential for better assessing the value of COs globally, including rural communities in the Global South.

THE DESIGN FOR COMMUNITY PARTICIPATION

The broader objective of our study was to explore conditions for designing COs in Sri Lanka. In this sense, we aimed to understand existing community practices regarding the environmental monitoring of this rural community as a case in the Global South to address the knowledge gap in implementing COs in these contexts. The participation of the community members in the current case is mainly visible in three phases: individual sensing, collective meaning-making, and collective reporting. Shirk et al.'s (2012) study on public participation in scientific research provides us with further insights with a framework for deliberate design by using existing cases in the domain. We reflect on our findings by using the theoretical lens provided by Shirk's study, which enables us to better view the design issues related to the degree and the quality of public participation in our context.

First, our findings reveal the question about air quality is raised by individuals, discussed among communities, and reported to the authorities. The study highlights the nature of this community of building up the process of making sense of their environment without the support of the scientists or tools granted by the authorities to measure air quality. Their method is mainly based on natural senses such as sight and smell, and they took the matter to authorities from these data.

The actions of our rural community indicate the degree of participation identified as co-created projects in Shirk's study as a fitting model for future CO designs. Therefore, we recommend the active involvement of villages directly exposed to air quality issues in most or all aspects of the research process with scientists. Such an approach will also add value to their claims as more scientific data can be produced and reported when they report air pollution to the authorities.

Second, our findings resonate with the five elements outlined in Shirk et al.'s (2012) study, which can guide the quality of participation for future CO designs in this rural community. As the current setup is a self-born community practice, scientists are not involved in all three phases we identified. However, the role of the public in those three phases provides some insights into how the above five elements should be dealt with when designing the COs.

For instance, the "input" of the community's concerns and expectations of air pollution plays a significant role because they need a solution to their problem. As we discussed, their approach to addressing the issue didn't have any input from the scientists; it was only a self-born mechanism for which we can propose adding scientific methods to improve outcomes. Access to scientific expertise to conduct air quality monitoring of the village in a scientifically rigorous manner can add more authenticity to their sensing to reporting processes. However, we stress the need to keep the village's interest or desire to address their concern about air quality as the project's core and recommend the same approach when setting up COs in rural Sri Lanka.

Third, the community already engages in a set of "activities" related to air quality monitoring, from sensing to reporting, which they developed. They had their way of collecting and interpreting data, mainly through communication. We suggest that the activities element of future designs be created by using these community practices with scientists who can provide due guidance while maintaining the collective nature of work. There, the expert can assist in developing tools accepted by the scientific domain and members of the Village Assembly but co-created with the community, adhering to their needs,

way of communication, and facility to capture their general observations about the environment. In the "outputs" element, the villages need to analyze data and report on their observations to solve their concerns and to present to the Village Assembly or the authorities. The collective nature of participation encourages the analysis to take part as a group of villages by using tools and discussion platforms to share their ideas and present the case. Scientists can facilitate this analysis; it is essential to understand that the analysis depends on both environmental data and the experience of villages in identifying the reason for air pollution.

The rural community's expectation from their activities was to address their concern about air quality. We therefore suggest the primary outcomes in future designs should be to find an immediate solution to villagers' concerns about air quality. Hence, a design that effectively improves the current community practices and can efficiently address the air quality issue of the village is recommended. Finally, a project's impact element should prioritize the community's needs for timely, locally relevant, actionable data, which may not be of concern for academic research.

Fourth, we suggest the above as initial guidance for the degree of participation and quality of the villages' involvement when designing COs in the future. Later, specific interests may be reinforced based on the outcomes and experiences as initiatives evolve.

Against this backdrop, we propose a participatory and relational design strategy, including design features to support community-based air quality monitoring when designing COs for the Global South. Moreover, we argue for supporting the meaning-making of the individually sensed data via collective meaning-making and collective reporting design features. In a design project, it is essential to conceptualize whose interest should be addressed and how desired outcomes are defined (Shirk et al. 2012); therefore, the findings in this study will assist when designing future COs in the Global South.

Individual sensing and collective-meaning making go hand in hand and could be facilitated by generating multimodal data (pictures and text descriptions), sharing time stamps associated with the sensed observation, and comparing the present sensed observations with knowledge about air pollution from the past. Such design features facilitate communication between villagers, which remains crucial for forming a community that deals with air quality issues. In that respect, we turn to studies in the field of human-computer interaction that show how technologies can be used to communicate and resolve problems. For example, one such analysis is based on Dewey's notion of a public, defined as a dynamic organization of individuals formed by the desire or need to address an issue (Le Dantec et al. 2011). The study presents a context in which an information system is built for the staff and homeless residents at an emergency night shelter. In this context, two publics are the shelter staff and the residents. Accordingly, they deployed a community resource messenger (CRM) system to communicate between shelter staff and residents. This study indicated that selected standard technologies can assist two public members in expressing and developing new attachments, which help in effective communication.

Similarly, sensing will, for example, be more formalized by inviting villagers to write logs of their environment more systematically and compare impressions, photos, and feelings. And collective meaning-making can be made more meaningful by asking them to share a digital and social space to discuss the diaries, design sections in the dairies, and extract community knowledge from the logs. The collective reporting phase can be more public by gathering the community reports and discussing them, reflecting on them, and publicizing them via websites or social media, which can lead to public debates. Design features could help the villagers to archive multimodal data and make them searchable for easy comparisons throughout time and location.

Fifth, while our analysis highlights the existing practices within this community, it is also essential to foresee how the addition of technologies, a central component in modern COs, might enhance the impact of these practices. The role of technology in COs is spread across many aspects, including data collection, analysis, and sharing. With their efficiency and scalability, these technologies play a vital role in COs; previous studies have demonstrated how they impact the longevity of community concerns about the environment and the decisive role that technologies can play in environmental policy. Our study showed significantly less use of technologies in these communities; this opens the door to further studies to see if technologies improve impact. In some instances, communities become more empowered entities in society by using technology to monitor and keep evidence on their environment (Hsu et al. 2017).

Participatory science emphasises the collaborative approach to scientific research in which members of the public are actively engaged in the scientific process. While our study revealed the efforts of the community to address the environmental issue, the engagement seemingly lacked a scientific approach, which gives due recognition to the authorities. With the intervention of the technologies, the community has a better opportunity for such an engagement, and this study reflects the need for such an intervention to see its impact.

CONCLUSION

In their present form, citizen science and COs reflect design considerations predominantly from the Global North. While this might be a natural consideration given the origins of these socio-technical constructs, we argue herein for such platforms to be more deeply informed by the realities of the Global South. Very little is known about how rural communities in the Global South make sense of the environment, Our study addressed this knowledge gap by exploring a local village in Sri Lanka. Our findings contrasted the practices that may need to be considered when implementing COs in the Global South. Accordingly, we argue that individual and scientific frames most commonly used in the Global North are insufficient in a context such as rural Sri Lanka. A clear insight from our research was how air quality was sensed as a community and not as individuals, which created, in turn, civic knowledge and ownership of the issue. This can be made actionable via legitimation using frameworks and tools bridging the science-policy gap.

We acknowledge that collective sensing and meaning-making is not unique to the Global South but is a universal method globally. What we instead hope to highlight via our study is that collective meaning-making and collective reporting are two critical existing practices in the observed rural community that can be leveraged to heighten the legitimacy and agency of communities in the Global South, often left out of decision-making spaces.

The lack of literature on applying such methods in the Global South concerning citizen science is another reason we highlight it here (Rathnayake, Joshi, and Cerratto-Pargman 2020). While some data sharing exists via popular platforms such as WhatsApp and Vibe, the context of use is critical regarding how this data sharing can be used for environmental protection and increasing community agency. These results illustrate the need for a novel, relational, sense-based approach to developing COs that can be leveraged in countries like Sri Lanka.

This design should also keep the comparison of past and present observations. We argue that stories need to be documented as another feature in the design with searchable tags. Finally, we identified the Village Assembly as the central meeting point in which knowledge gathered is shared, discussed, and legitimized.

Overall, the study revealed that there are already established community practices in Sri Lanka that make sense of the environment, which has the potential to develop into citizen science initiatives. It also underscores the importance of adding technological sensory tools and sharing platforms to existing practices, which can bring immense benefits to the community that is already using the existing community-based practice. This study contributes to a better understanding of how responses to air quality challenges can be viewed, and encourages more exchanges of best practices between the Global North and South towards achieving the Sustainable Development Goals (United Nations n.d.).

COMPETING INTERESTS

The authors have no competing interests to declare.

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