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FULL-LENGTH ARTICLES

Co-created Citizen Science Creates Space for Dialogue Around Environmental Challenges Faced by Urban Residents in the Global South

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In the Global South, rapid, unplanned urbanisation is associated with environmental degradation, pollution, and poor basic services, in particular for resource poor and vulnerable communities. With insufficient resources available for standardised monitoring of these issues, citizen science (CS) approaches have the potential to address evidence gaps and inform mitigation strategies and environmental policies. The majority of CS projects reported in the scientific literature are contributory, involving members of the public only in the data collection aspects of projects. There is growing recognition of the benefits of co-created CS, where participants are engaged in multiple or all stages of the scientific process. However, descriptions and evaluations of such projects are rarely reported in the literature, which is needed in order to refine and grow the use of co-created CS. Here, a review of the co-created CS literature is presented, followed by a six-step, researcher-initiated co-created CS methodology which was implemented with vulnerable communities within two cities in the Global South – Nakuru, Kenya and Udon Thani, Thailand. Successes and challenges experienced in these projects are discussed and recommendations for future co-created CS are presented. As for contributory CS, data generated in projects concretely identified environmental challenges faced by each community. However, using the six-step co-created CS methodology, participating citizens were uniquely able to leverage their data on behalf of their communities to establish dialogue with local authorities, generating meaningful shared understanding and priorities.

How can co-created citizen science (CS) approaches generate datasets which both identify environmental challenges experienced by marginalised communities and are also used to promote change? This question was explored by the authors in two co-created CS pilot projects in cities in the Global South, Nakuru in Kenya and Udon Thani in Thailand. In such contexts, rapid, unplanned urbanisation is associated with environmental degradation, pollution and poor basic services. These changes negatively impact residents' health and wellbeing, in particular in marginalised communities, but the data required to understand and monitor these challenges and inform mitigation strategies and environmental policy are

often missing or limited in scope (Fritz et al., 2019). As co-created CS focuses less on applying standardised monitoring methodologies, for which resources may not be available, and more on empowering communities to tell their stories and evidence their experiences in ways that are meaningful to them (see Gabrys et al., 2016), this approach has the potential to play a key role in addressing these evidence gaps and giving communities a voice in decision-making processes.

In recent years, there has been growing interest in and use of co-created CS methodologies, with calls amongst the CS community for all projects to offer the opportunity for participants to be involved in multiple or all stages of the scientific process (Ballard et al., 2018; Cooper & Lewenstein, 2016). However, compared with contributory CS projects (i.e. those where participants are only engaged in collecting and/or processing data), the number of co-created projects reported in the literature is small (Kelly et al., 2020; Mačiulienė et al., 2021). While this may, in part, be due to the nature of these projects lending themselves to outputs being reported in the grey (i.e. non-academic) rather than academic literature (Pateman, Tuhkanen, et al., 2021) and also overlapping terminologies with other participatory research processes, this imbalance is likely to reflect a real dominance of contributory over co-created CS, perhaps due to some of the challenges associated with these approaches. As such, descriptions of co-created CS methodologies are uncommon, as are discussions of challenges faced and lessons learnt by those involved in projects implementing these methods. This is particularly true in the Global South (Pateman, Tuhkanen, et al., 2021). Sharing of methods and experiences, including successes and challenges, is required in order for CS practitioners and researchers to learn from each other, to understand the expected outcomes from such projects, and to be able to make general recommendations about project design in order to grow and refine this methodology (Gray et al., 2017).

In this paper, therefore, an overview of co-created CS is presented, focusing on its characteristics, potential benefits and reported challenges. A methodology for implementing co-created CS projects is then described. This was developed by drawing on the literature and the authors' own experiences of designing and running co-created CS projects. The application of this method is then described in two pilot projects which sought to identify urban environmental challenges facing marginalised communities and to support and bridge local knowledge with processes of change. Finally, successes and challenges in applying the method in practice are reflected on, including the potential for the method to both generate missing data and create dialogue between marginalised urban communities and local authorities in efforts to tackle environmental challenges.

Co-created citizen science

Citizen science (CS) is the active involvement of people in the scientific process outside of a professional capacity (Pocock et al., 2015). While approaches are varied, and there is debate amongst scholars and practitioners

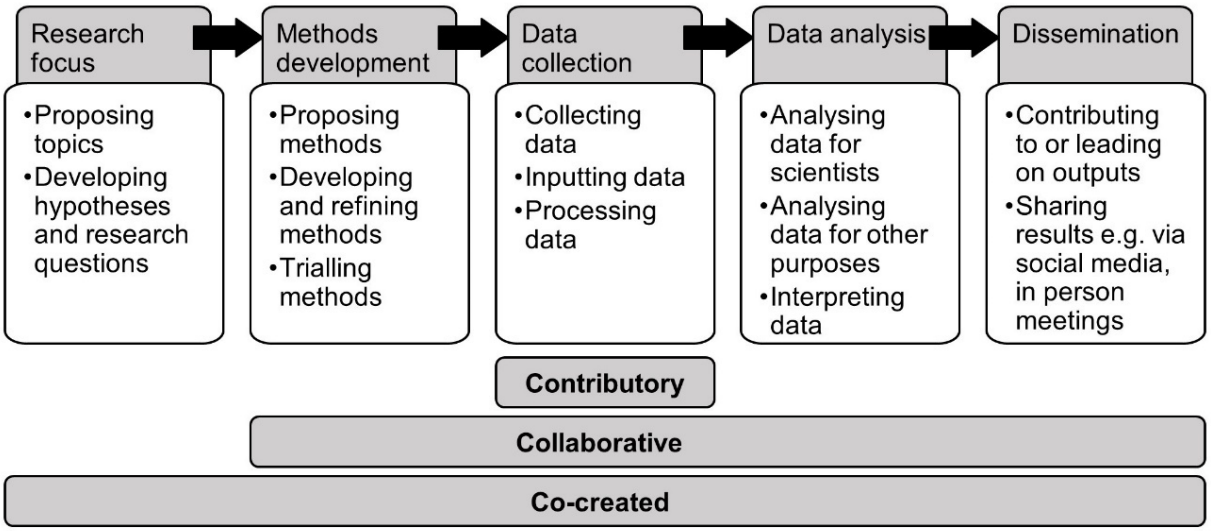

Figure 1. Levels of Participant Involvement in Different Types of Citizen Science Project.

about what should and should not be considered CS (Haklay et al., 2021), the European Citizen Science Association provides some guiding principles. These include that projects should generate new knowledge or understanding and have a genuine scientific outcome (in contrast to public education or engagement initiatives); and that participants are actively and meaningfully involved in projects and receive some benefit (compared with initiatives where data about people are used without their knowledge) (Robinson et al., 2018). In other words, the emphasis lies in creating relevance both for scientists as well as for participants.

The extent to which participants are centred, however, differs between projects depending on their aims. A common way of categorising CS initiatives is by identifying the stages of the research process in which participants are involved (Shirk et al., 2012) (Figure 1). Contributory projects tend to be led by scientists and involve participants only in data collection or processing. Collaborative projects engage participants in other stages, such as developing methods, analysing data and disseminating results. Co-created CS projects are those where participants have the opportunity to be involved in all stages of the scientific process, from developing research questions to analysing data and sharing results. Whereas contributory CS projects have often been seen to adopt instrumental philosophies, with a focus on serving the needs of science, co-created CS approaches can be seen as more democratic and aligned with a definition of CS given by Alan Irwin (Gray et al., 2017; J. L. Gunnell et al., 2021) i.e. that science should serve the needs of citizens as well as being designed and implemented by citizens themselves (Irwin, 2002).

Co-created projects are often (although not always) conducted at a local or community level, focusing on issues such as environmental risks or health concerns (Bedessem & Ruphy, 2020) and are motivated by bringing about change (Van Brussel & Huyse, 2019). Within these projects, different

stakeholders, including individuals from target communities, community organisations, professional scientists and decision-makers, unite around a shared concern (Hovis et al., 2020). Crucially, the aim is to give the perspectives and needs of community members equal, if not greater, weight to those of professional partners in recognition of the needs and knowledge of these individuals and communities (J. Gunnell, 2021). As such, compared with contributory projects, there is a transfer of power away from professional partners to the participants and communities involved (J. Gunnell, 2021; Ramirez-Andreotta et al., 2015), resulting in projects rooted in the cultural context of the community (Davis et al., 2020) which have meaning for all partners (Skarlatidou et al., 2019).

The benefits of co-created CS are widely discussed in the literature and include those for individual participants and communities; data and knowledge generation; decision-making and action; and science and society (Figure 2). For the individuals and communities involved, benefits come from research being conducted that is of direct relevance to their lives which may otherwise be neglected by traditional research methods (Ramirez-Andreotta et al., 2015). Along with a transfer of power to project participants, this can lead to greater autonomy and ownership of the research by communities (Asingizwe et al., 2019; Bedessem & Ruphy, 2020; Hecker et al., 2018). In depth engagement can also increase the likelihood of commonly proposed benefits of CS being realised, such as participants gaining new knowledge and skills (Ballard et al., 2018; Danielsen et al., 2009).

In terms of data and knowledge generation, inclusion of community members in the planning stages can lead to more locally appropriate and reliable methodologies being employed and, in the data collection stage, to a more representative dataset being generated (Corburn, 2007; J. Gunnell, 2021; Hoover, 2016). Drawing on the local knowledge of participants and their heterogeneity of experiences when interpreting findings can help to elucidate meanings that scientists would not otherwise be aware of (Bedessem & Ruphy, 2020; Chesser et al., 2020; J. Gunnell, 2021).

Action and change may be more likely outcomes from co-created than other forms of CS, where evidence for this is limited (Conrad & Hilchey, 2011; Gray et al., 2017). Often this will occur at a local level and have direct relevance to the communities participating (Corburn, 2007; J. Gunnell, 2021), although there is the potential for this to be scaled up. Change may come about through individuals altering their behaviour as a result of in-depth involvement in and understanding of the research and its findings (Asingizwe et al., 2019). Alternatively, projects may strengthen, build capacity and empower communities to directly address the issues they are facing, through direct action or influencing decision-makers (J. Gunnell, 2021 and references therein). In addition, projects may include decision-makers within their project team and directly seek to influence policy agendas and implementation (Van Brussel & Huyse, 2019).

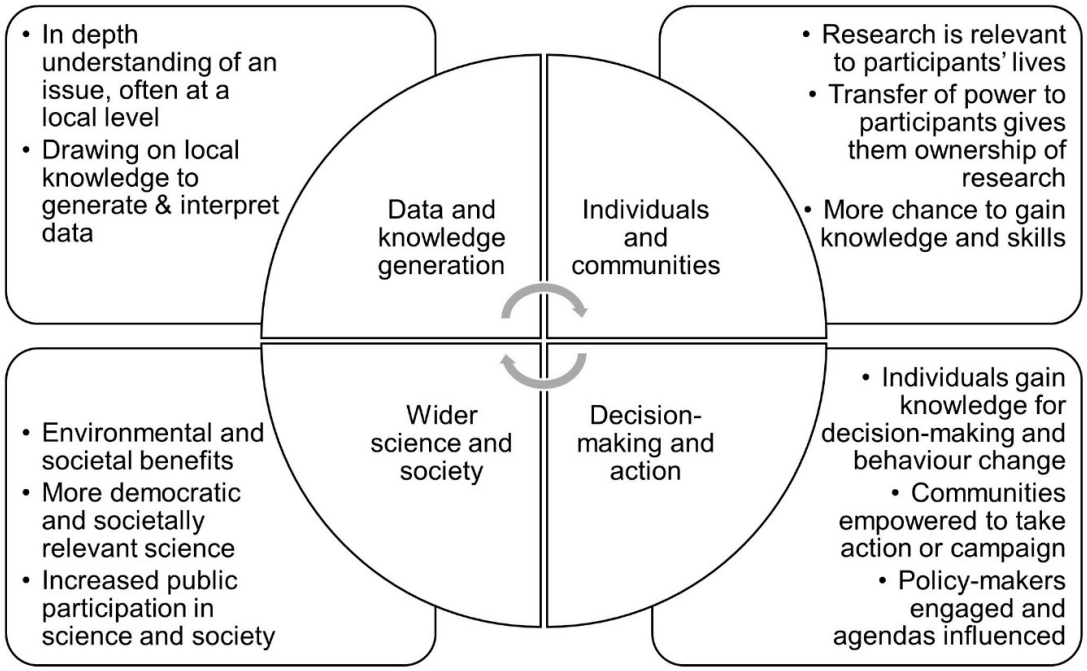

Figure 2. Reported Benefits of Co-Created Citizen Science Methods

Co-created CS can also play a role in addressing challenges science faces in terms of who it serves and how it is perceived by society (J. Gunnell, 2021). Many scholars have challenged whether conventional science does enough to ensure research is of relevance and benefit to its participants (e.g., Smith, 2021; Tuck & Yang, 2014) which might contribute to research fatigue (Clark, 2008). This is especially relevant for more marginalised communities and research in the Global South conducted by researchers in the Global North. Chesser et al. (2020) argue that co-created CS is a more ethical approach to engaging participants in research, particularly when working with marginalised groups who may have reservations about working with researchers and those from outside their communities. As such, these approaches can help build trust and collaboration between science and communities (Kelly et al., 2020). This increased collaboration can lead to shared understanding between communities and scientists and generate new research questions and avenues of scientific enquiry that are more relevant to society, in turn leading to a greater valuing of science by society (Bedessem & Ruphy, 2020).

Alongside these potential benefits, barriers to co-created CS have also been reported in the literature. These include challenges in securing research funding and institutional support for programmes if research methods and outputs are not well defined at the offset (J. Gunnell, 2021) and a reluctance to give up control of the direction of research (Bedessem & Ruphy, 2020). Co-created approaches can also be resource intensive because of the time and personnel needed to build and maintain relationships with communities (Davis et al., 2020), meaning the cost effectiveness of such approaches may be questioned (Hoover, 2016). Challenges within projects relating to

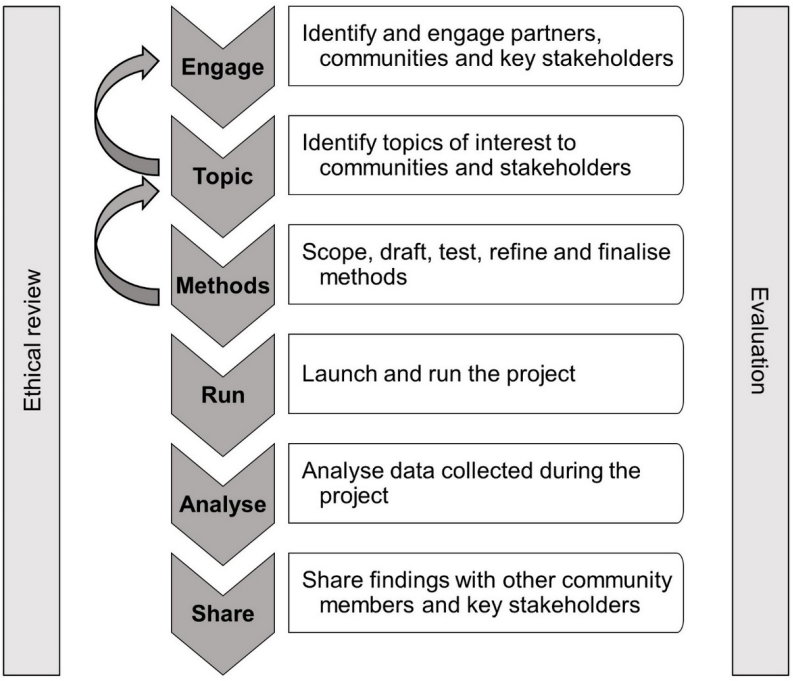

Figure 3. Co-Created Citizen Science Project Methodology

recruitment and inclusion; buy-in from and meaningful transfer of power to community participants; and managing the uncertainty that arises from co-created methods have also been reported (Collins et al., 2020; Heinisch, 2021).

Co-created Citizen Science Methodology

A methodology for designing and running co-created CS projects was developed based on the literature and the authors' own experiences as CS practitioners and researchers. This methodology can be used to guide the direction of co-created CS projects and structure the work of a project team. However, as with any co-created process, the needs of community members and other project stakeholders, the sociocultural, economic and political context, and unforeseen changes and challenges will guide the specific direction a project takes.

As with many other co-created CS projects (e.g. Asingizwe et al., 2019), this method focuses on researchers as initiators of the project, approaching a community to collaborate with, with at least a broad topic area in mind. An alternative starting point is for individuals, communities or community-based organisations to seek out scientific partners to assist them in addressing a particular concern. While in some ways this may seem ideal, as communities lead the process from the start, this would depend on communities having the knowledge, support and resources needed to initiate these processes. As such, there is value in researchers approaching communities and instigating the process, while anchoring each of the six steps of the method in the focal communities, and focusing on creating benefits for these communities, as well as for other partners and local stakeholders.

The first stage of the methodology is *Engage*, i.e. identify and develop a partnership between researchers, community members and local organisations to design and deliver a local project. Many CS practitioners and researchers have noted the importance of building the right team with a clear shared concern (Segev et al., 2021) and the skills needed for the specific project and desired outcomes (Ramirez-Andreotta et al., 2015). Skarlatidou et al. (2019) specifically advocate for the use of stakeholder mapping and other tools to understand stakeholder needs when developing this partnership. Partnerships should include participants from communities affected by the issue, ideally ensuring representation of diverse group members. It should also include organisations or individuals with experience of running CS projects as well as those with the required research skills and knowledge for the project. Also recognised in the literature is the importance of individuals (champions) and/or community organisations already embedded in the community to help build trust and understanding between the community and research partners (Asingizwe et al., 2019; Chesser et al., 2020; Davis et al., 2020; Ramirez-Andreotta et al., 2015; Segev et al., 2021). It is also important to engage partners who can use the data or results from the project, such as local authorities or service providers, as the goal is to facilitate processes of change in relation to the project findings.

Once a team has been formed, the second stage is *Topic*, i.e. identify the focal topic for the project. In some cases, researchers can approach a community with a broad topic area in mind (Collins et al., 2020) and utilise activities such as facilitated discussions, ranking and voting exercises to narrow down the focus. In other cases, a narrower topic is pre-determined by researchers (e.g. Asingizwe et al., 2019) or the community (e.g. Hoover, 2016) and this stage focuses on agreeing on the finer details of the topic of the project. It is essential that the topic identified is relevant for the community members participating, carries some scientific value and, ideally, that there are processes of change that can be foreseen. Following this stage, the project might also partner with additional stakeholders depending on research skills or networks needed to address the focal topic.

This is followed by stage 3, *Methods*, i.e. development of the research methods the project will use. Co-design of methods involving all different project partners is important to ensure the methods are suitable for community members to use and in line with time and resources they have available (Asingizwe et al., 2019). In addition, the method should produce robust and actionable data (Bedessem & Ruphy, 2020; Jasanoff, 2017) usable by stakeholders with the power to address the issues identified. This stage should include time and space for training of community members and trialling of methods (Chesser et al., 2020; Davis et al., 2020; Ramirez-Andreotta et al., 2015). There is often a feedback loop taking place between the three first stages of the methodology, as the project is shaped around

community priorities, available skills and knowledge, budget and what is possible in the current political and social climate (Figure 3). Sufficient time is, therefore, required to allow for these iterations to occur.

Stage 4 is *Run*, i.e. the period in which community members collect data. During this stage, continued communication with, and support of, community members using channels that are appropriate for them is critical (Davis et al., 2020; Ramirez-Andreotta et al., 2015). Following this is stage 5, *Analyse*, i.e. analysis and interpretation of data collected during the project. Including community members here is of importance as it will maintain their ownership of the research, incentivise them to act on the results (if appropriate) and also give them the opportunity to develop additional skills (Davis et al., 2020; J. Gunnell, 2021). Stage 6 is *Share*, i.e. sharing results with community members, project partners and potentially beyond to other members of the public or relevant organisations. A variety of methods may be needed in order to reach these different audiences and to ensure positive action results from the project.

Ethical review should take place following careful consideration of ethical implications of projects. In co-created projects, this may need to occur more than once as the project progresses through its different stages and the research methods become clearer. *Evaluation* of projects is also an essential process, as well as sharing of lessons learned with the wider CS community. Here, because projects were run over a relatively short period of time, summative evaluation was the focus. However, for longer projects it would be more appropriate to integrate formative evaluation elements into the project design as well. Longer projects may have more feedback loops in general, for example, ongoing data analysis and results feeding back into refining of methods.

Co-created Citizen Science Pilot Projects

Project Context and Aims

Projects were initiated by the authors of this article, a team of researchers based at the Stockholm Environment Institute (SEI), an international non-profit research and policy organisation for sustainability policy and practice. The team included urban health and wellbeing researchers based at SEI's Africa centre in Nairobi, Kenya and Asia centre in Bangkok, Thailand, as well as citizen science practitioners and researchers at SEI's centre at the University of York, UK. The projects formed part of a wider SEI City Health and Wellbeing Initiative funded by the Swedish International Development Cooperation Agency which focused on these two cities. For in depth engagement and to bring about meaningful change, ideally co-created CS projects would run over long time periods (Davis et al., 2020). However, the funding available in this case permitted only a rather limited time-frame for engagement (up to 12 months). As such, we viewed these as pilot projects, with an emphasis on testing and potentially refining the co-created CS methodology methodology, as well as offering the opportunity to understand

how even short, more resource-limited co-created CS projects could generate valuable data and create a dialogue for change. We envisage, however, the approach being suitable for longer, more extensive projects, and encourage other researches and citizen scientists to utilise and adapt the methodology in their co-created CS projects.

Projects took place in Nakuru in Kenya and Udon Thani in Thailand (Figure 4). Nakuru is the fourth-largest city in Kenya and the capital of Nakuru County located within the Great Rift Valley. Nakuru city has an estimated population of 570,674 (KNBS, 2020, p. 241). Rapid growth is putting development pressure on green and blue spaces, increasing demand on existing resources and amenities, and exacerbating issues of water shortage, poor sanitation, waste management and unplanned informal settlements. Udon Thani in northeast Thailand is a small city of 120,000 residents (2020[1]). While the city has experienced a declining population over the last 20 years, partly due to the movement of residents to residential suburbs outside the municipal boundary, the city is facing rapid development due to its strategic location near the Laos border and investments in the ASEAN Economic Corridor[2]. However, the population of the whole province is declining and this is projected to continue, with the growth rate falling from 0.3 to 0.16 percent (Ministry of Public Health, 2021). Udon Thani is exposed to both flooding and drought, and is heavily reliant on one reservoir for its water supply.

Ethics approval was gained through the University of York Department of Environment and Geography Ethics Committee, as this was the institution of the project leads. As we used a co-design process, initial applications for ethical approval were made based on the process set out in Figure 3. As the details of the CS activities became clear, supplementary applications were made and approved.

Project Descriptions

Step 1: Engage

Nakuru. In Nakuru, the process was initiated by the research team at SEI's Africa Centre. The research team held three meetings with the County Government of Nakuru, Department of Water, Environment and Natural Resources to understand their perspectives on key environmental issues and priorities in the city. The research team collaborated with local rights-based organisation Umande Trust, which has experience of working with communities in low income areas of Nakuru. Together they visited several of the city's neighbourhoods and settlements. Following this, two low-income and informal neighbourhoods were approached for their involvement in a pilot project - Kaptembwo and Free Area (Figure 4). These two

1 https://stat.bora.dopa.go.th/new_stat/webPage/statByYear.php

2 http://www.tei.or.th/thaicityclimate/public/document-4.pdf

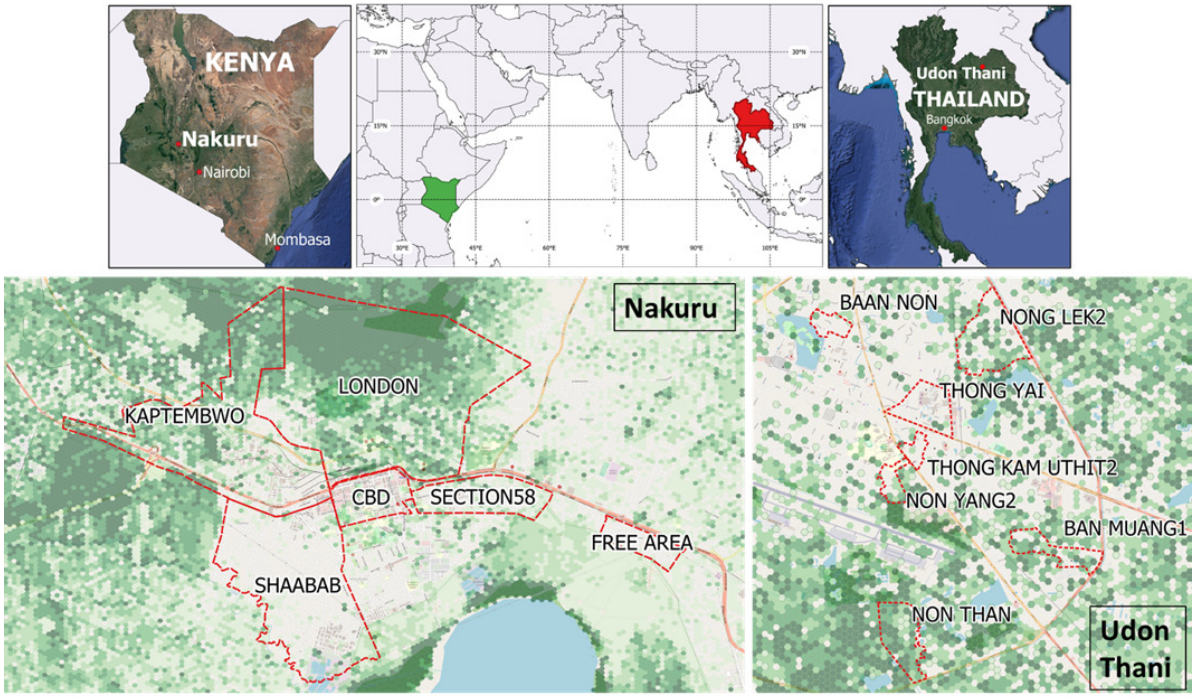

Figure 4. Location of Case Study Cities, Nakuru in Kenya and Udon Thani in Thailand and focal communities within these

neighbourhoods were both experiencing environmental challenges and poor living conditions and had strong existing connections with the Umande Trust.

Udon Thani. The research team at SEI's Asia Centre were supported by a consultant from Udon Thani who facilitated the team's engagement with city stakeholders throughout the project. The research team also employed undergraduate university students as fieldworkers for the initial stages of the project. The research team had previously engaged several communities in the city in research activities and approached three communities where a relationship existed with community leaders: Baan None, which consists mainly of residential streets with some shophouses; None Than, an area on the municipal outskirts where the majority of residents are government officials and the surrounding area is largely undeveloped; and Nong Lek 2 which has larger detached houses and includes an area upgraded as part of the national slum upgrading initiative (Figure 4).

Step 2: Topic

Nakuru. In December 2018, the research team held scoping workshops in Kaptembwo and Free Area to elucidate residents' perspectives on key environmental issues in the neighbourhoods. Umande Trust invited community members, with 45 attending in Free Area and 46 in Kaptembwo, representing a mix of ages, genders and socioeconomic statuses. Workshops were held in community spaces and a mixture of Swahili and English was spoken. The research team asked the community members, "What are the environmental problems in your neighbourhood and Nakuru?". Community

Table 1. Priority Issues of Concern to Residents in Free Area and Kaptembwo, Nakuru

	Number of people raising issue		Total ranking points for theme	
Theme and priority issues	**Free area**	**Kaptembwo**	**Free area**	**Kaptembwo**
Waste			16	34
Lack of garbage collection points	7	-		
Lack of garbage bins	3	-		
Blockage of drains due to plastic waste	6	-		
Domestic and industrial waste	-	7		
Water			93	57
Water contamination	21	23		
Water shortage	66	30		
Water wastage	6	-		
Surface water management	-	4		
Sanitation			46	36
Blockage/absence of sewer/drainage system	23	10		
Shortage of toilets	11	-		
Seasonal overflowing of drainage	2	-		
Poor disposal of diapers, sanitary napkins etc.	4	-		
Flying toilets	6	-		
Poor sanitation	-	26		
Pollution			11	10
Noise pollution	2	-		
Soil pollution	1	-		
Air pollution	-	10		

Note. Dashes denote that the issue was not raised in the neighbourhood. Flying toilets are plastic bags filled with human faeces which are discarded by throwing them in open areas. They are commonly found in areas which lack adequate provision of sanitation services, including informal settlements.

members first answered individually on sticky notes and after the workshop the research team used these to calculate the number of people who mentioned each priority issue in each neighbourhood (Table 1). The research team, Umande Trust and community members then collectively grouped issues to identify themes and potential causes of these problems. At the end of the workshop, participants voted for which of these themes they felt were most urgent to address through a ranking system, giving three points to the most urgent theme, two to the second and one to the third most urgent. These points were summed to give the total number of ranking points for each theme in each neighbourhood (Table 1).

In February 2019, the research team, Umande Trust and community members met again in follow-up workshops in Kaptembwo and Free Area to confirm the issues prioritised during the first workshops. At the workshop in Free Area, community members showed great enthusiasm for the project and the issues already raised, and a clear way forward on how to adopt the CS method was discussed. During the workshop, participants reaffirmed the issues that had been prioritised and in groups discussed potential ways of solving them, before sharing suggestions with the rest of the group. Not one subject was considered more urgent than the others; rather, the issues were seen as interconnected and an effect of lack of planning and maintenance

Table 2. Priority Issues of Concern to Residents in None Than, Baan None and Nong Lek 2, Udon Thani

	Total votes		
Priority issue	None Than	Baan None	Nong Lek 2
Waste and fly tipping	3	9	4
Stray cats and dogs	9	1	3
Narrow roads	2	-	-
Fires	1	-	-
Cable wires	1	-	-
Poor playground facilities	1	-	-
Smells	-	-	-
Traffic	-	-	0
Flooding during heavy rain	-	-	-
Noise	-	-	-
Dirty water	-	-	1
Poor air quality	-	-	-

Note. Dashes denote that the issue was not raised in the neighbourhood whereas zeros denote that the issue was raised but not voted for as a priority. Fly tipping is the act of dumping waste on land which is not intended for waste disposal.

of basic services, as well as an increased pressure from rapid urbanisation. For instance, participants highlighted problems with poor drainage systems, insufficient garbage collection and collection points and increased pressure on the water supply. As such, some community members proposed to map and monitor issues related to all the priority issues in the community. This information could then be shared with relevant authorities, to raise awareness of the issues affecting the community. By contrast, in Kaptembwo, new community members attended who had not participated in the first workshop and this lack of continuity made it much more difficult to revisit and confirm what was discussed at the first workshop. Therefore, the research team decided to focus activities in Free Area.

Udon Thani. In February 2019, the research team and local communities met in focus group discussions in each of the communities. Eleven people participated in Baan None, ten in None Than and four in Nong Lek 2. Workshops were held in Thai. As in Nakuru, community members were asked "What are the environmental issues in your neighbourhood and city?" and individually wrote these down on sticky notes. Community members then explained these issues to others around the table before grouping them into themes. Participants discussed what information they would find useful to tackle these issues as well as the information they thought the municipality needed. Finally, the community members voted for their top three perceived problems. Unlike in Nakuru they gave one vote to each of their three top issues which were then summed to give a total for each issue (Table 2).

Waste management was a common theme across all three communities, though it differed slightly in each case. In None Than, which is on the outskirts of the city centre, fly tipping by outsiders is a major issue while community leaders encourage waste recycling, composting and other activities to improve waste management. In Baan None and Nong Lek 2,

rubbish is left around bins and not sorted by residents, attracting stray animals and leaving the streets foul-smelling and dirty. Initial community consultations and discussions with the municipality also identified waste management as an issue affecting the overall liveability of the city, creating community-level tensions and potentially having health implications. Furthermore, waste management is a problem community members might have some influence and control over, in comparison to other issues identified such as stray animals and safety concerns from electrical wires. It was also an area the research team felt they could provide support on. As such, waste management was decided as the focal topic for the pilot project.

Step 3: Methods

Nakuru. At the workshop held in Free Area described above, the research team introduced participants to CS, sharing examples of CS projects and discussing potential activities that could tackle the issues identified. It was agreed to form a committee of 15 community members (referring to themselves as Environmental Champions) selected from the workshop participants to lead the work. These members were chosen to represent the wider community, covering all five areas of Free Area, and a mixture of genders, ages and vulnerabilities (e.g. representatives of persons living with disabilities).

Based on these discussions, the research team drafted a design for an environmental monitoring activity including a survey form in the app Epicollect (https://five.epicollect.net/) to document and georeference environmental issues. The survey included the following questions: What type of issue is it? What caused it? Has the community raised concerns? To whom have concerns been raised? Has any action been taken? Has there been any positive change? It also included fields to record the date, time and location and upload a photo of the issue.

In March 2019, the research team, Umande Trust and Environmental Champions met again in a workshop with the aim of the Environmental Champions providing feedback to the research team on the suggested project design. The researchers showed the Environmental Champions how to use the Epicollect app on tablets. The community members then took a walk in the neighbourhood to try the tool and collect test data, after which they provided feedback to the researchers. The form was then updated by the researchers based on this feedback and a review of the test data to ensure its quality and relevance to the overall goal of the project.

The team then held a follow up workshop in April 2019 to finalise the methodology. The researchers shared the updated Epicollect form and discussed a data collection protocol, as well as how the results could be communicated and visualised. The Environmental Champions decided they would conduct systematic mapping of environmental issues twice a month along transect routes they identified on a satellite map covering the five areas of Free Area.

Udon Thani. The research team held a second round of workshops with communities in late March 2019 to discuss issues around waste management at the household and community level and to explore how household- and community-level data could contribute to better waste management. By this stage, the project focused on two communities, Baan None and None Than, as the researchers were unable to arrange further meetings with community members in Nong Lek 2. The possibility of community members keeping waste diaries was suggested by the research team as a way of improving understanding of consumption patterns and informing a community action plan for recycling and composting to reduce overall landfill waste. There was, however, a feeling amongst community members that a waste diary would be a burden in households that are already busy and pressed for time.

Instead, community members suggested a mapping exercise to understand likely sources of waste and where it tends to accumulate. Following the workshop, the research team developed a brief survey using the Epicollect app which allowed a photograph of waste items to be geo-referenced, and some short multiple-choice questions for each photographed item. The questions were: Is the waste recyclable? What is its likely source? What is the location of the waste? The information collected was fully anonymised and the survey questions were in Thai.

Step 4: Run

Nakuru. Environmental Champions collected data on tablets provided by the research team on five occasions between April and June 2019. They formed five groups (three people per group) to walk the transect routes through the five neighbourhoods of Free Area. This systematic mapping was supplemented by sporadic monitoring by the Environmental Champions using their smartphones. Data was collected and stored offline and uploaded later.

Udon Thani. The waste mapping activity was carried out in Baan None and None Than in May 2019. Community members in each location were split into small groups, allocated streets in their neighbourhood and given a tablet, and asked to walk around to document the waste they came across. Throughout the activity the research team supported the community members in using the tool and in identifying different types of waste.

Step 5: Analyse

Nakuru. The research team used Microsoft Excel to clean and analyse the data from Epicollect and used R studio to generate a map illustrating the spatial distribution of issues identified to then discuss with the community members. The community members recorded environmental issues in a total of 246 locations (Figure 5). Waste, including solid and waste water, was the most common issue reported, followed by drainage-related issues, for example due to accumulation of waste, poor drainage systems or leaking sewerage systems (Figure 6). Manholes being uncovered or poorly made were the next

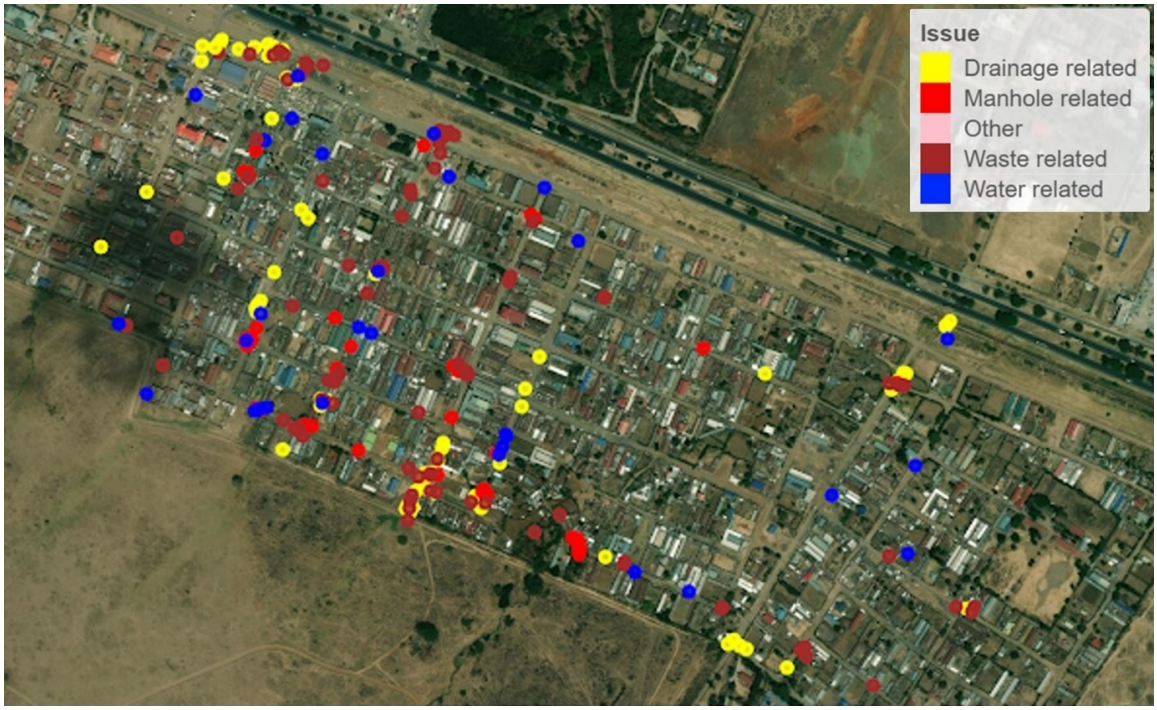

Figure 5. Location of Environmental Issues Mapped by Participants in Free Area, Nakuru

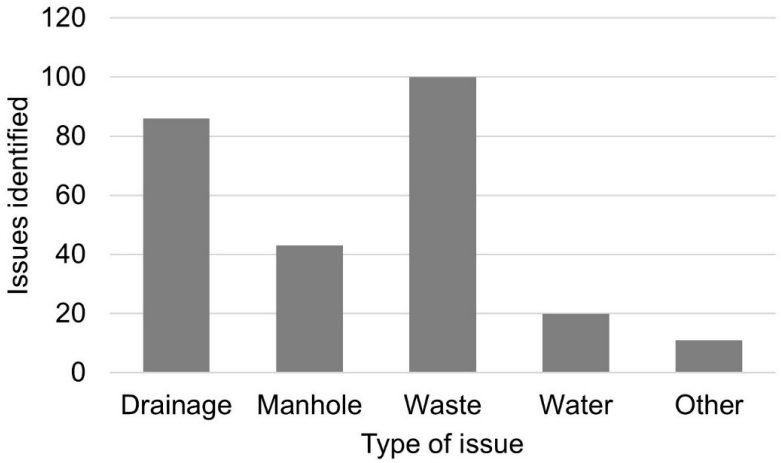

Figure 6. Frequency of different types of environmental issues identified in Free Area, Nakuru

Note. Each data point could be related to more than one type of issue.

most common issues. Reasons suggested for these issues included poor urban planning, lack of maintenance by the County Government, careless dumping of waste, and poor service from providers in the private sector.

For 69% of the issues identified, Environmental Champions were aware of the community having previously raised concerns, for example, to Public Health Officers, County Government, Members of Nakuru County Assembly, the Nakuru Water and Sewerage Company, Ward Administrators, Garbage Collectors, and the Area Chief. However, there was no clear connection between the type of issue and to whom it was reported. Environmental Champions were aware of actions being taken to address only

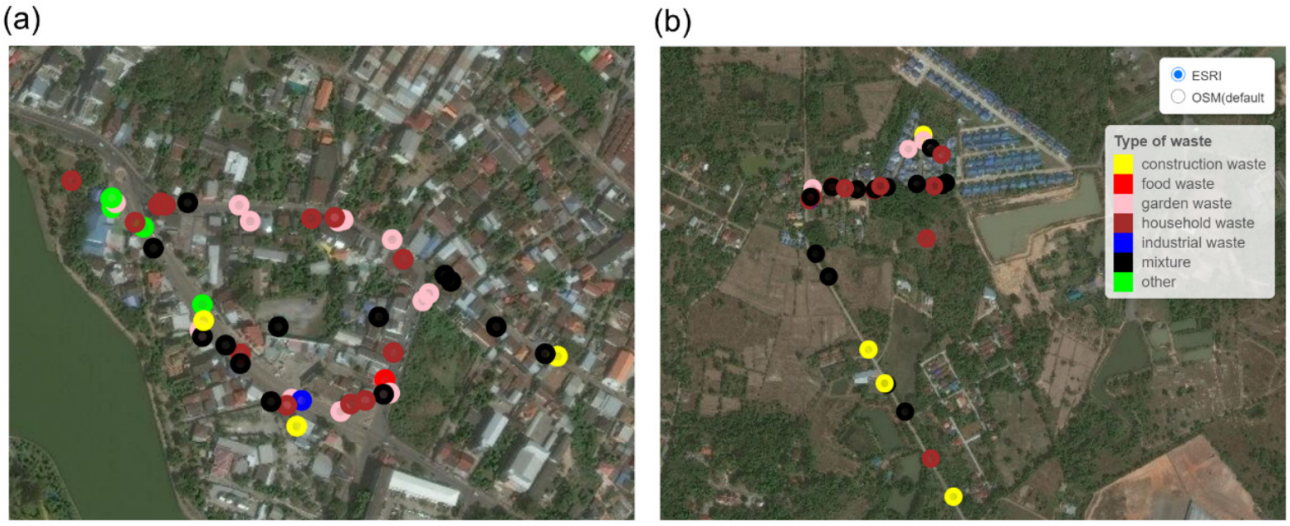

Figure 7. Location of waste related issues mapped by participants. (a) Baan None. (b) None Than.

39% of the issues identified. Most actions had been taken by the community, the County Government or had involved several stakeholders, including community-based organisations. Only 6% of the reported issues had shown clear positive change, while for 27% of reported issues, some positive change was observed, in most cases due to action by the County Government.

Udon Thani. The research team cleaned and analysed data in Excel. In total, 92 instances of waste were mapped: 42 in None Than and 50 in Baan None (Figure 7). The majority were either on the 'side of the road' or on the 'pavement' (35 and 21 responses respectively), suggesting that a lot of waste is deposited by passers-by, whether on foot or in a vehicle. Similarly, for the likely source of waste, the most frequent response was 'passing pedestrian(s)' (30 responses), though 'illegal dumping by households' was also common (29 responses) and was dominant in Baan None; 'wind blowing waste' and 'other' were third with 20 responses each (Figure 8). The majority of waste encountered was classified as 'household waste' (43 responses); 'garden waste' was the second highest category (branches, leaves) followed by 'a mixture' and 'construction waste' (Figure 8). Most of the waste mapped was regarded as not being recyclable (48 responses) but for those considered to have recyclable content, this included plastic bags and plastic bottles.

Step 6: Share

Nakuru. The research team, Umande Trust and Environmental Champions held a knowledge sharing and validation workshop in July 2019 where the team, led by the community members, shared and discussed project findings with Nakuru County Government Department of Water, Environment and Natural Resources officials, and other community members. Those present at the meeting concluded the data was useful for highlighting environmental problems and responses. The group identified challenges with the environmental governance structure; for example, a lack of clarity about to whom issues should be reported had previously resulted

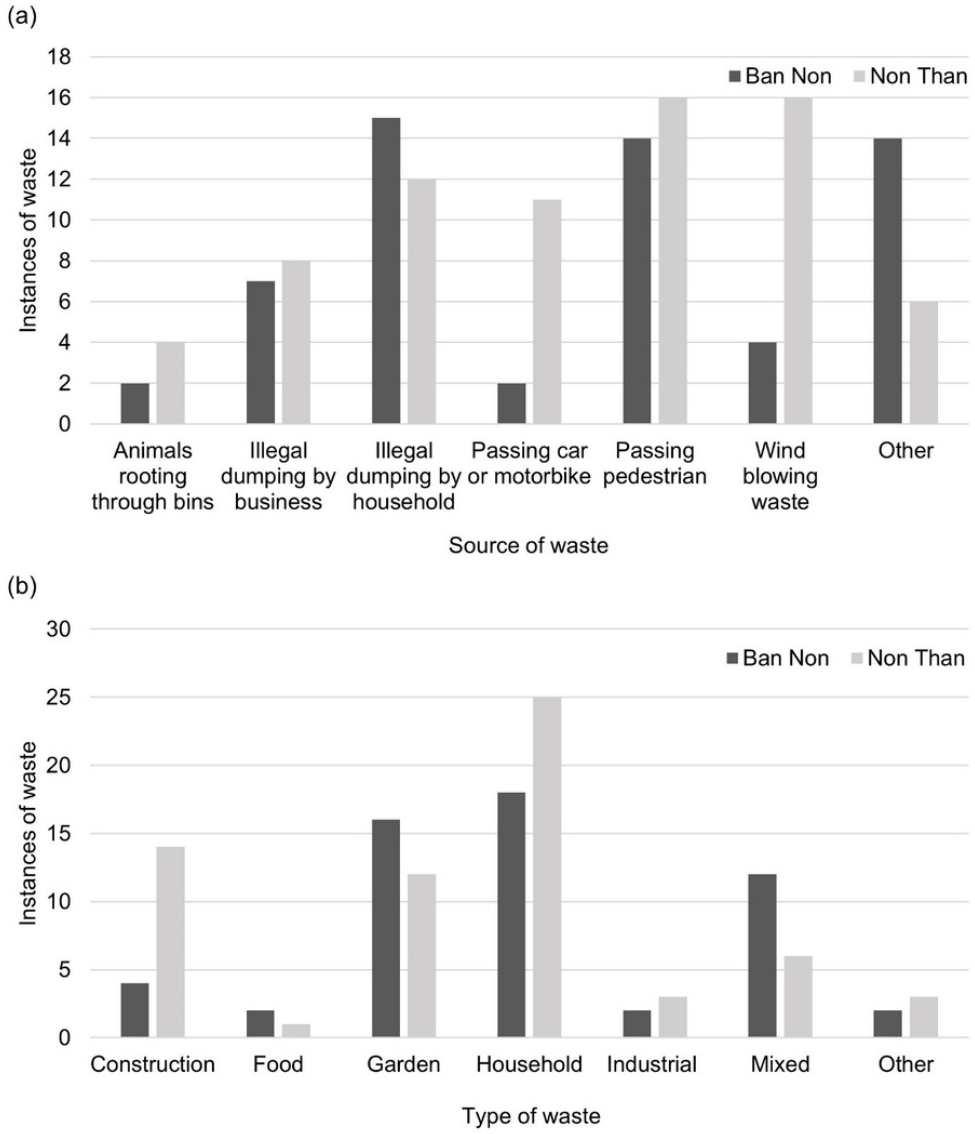

Figure 8. Categorisation of waste in Baan None and None Than. (a) Source of waste. (b) Type of waste.

in delays in the relevant offices taking necessary actions to resolve them. It was also recognised that despite efforts from the County Government and community, waste management remains a major challenge due to limited resources, poor urban planning and waste infrastructure provision. Discussions highlighted synergies between the County and the community's actions and, therefore, opportunities for more integrated waste management. For example, it was suggested that the Environmental Champions could act as ambassadors to monitor environmental issues and support any improvements in their local environment. The need to widen communication to include other key stakeholders was also recognised, such as County officers for infrastructure and drainage, water utility and public health.

Udon Thani. The research team discussed findings from the project with the Udon Thani municipality team in charge of waste management following the first round of focus groups. Discussions included recognition that waste sorting at home is not very common in Thailand and behaviour changes are

required to make this the norm. How people can be encouraged to pick up rubbish was discussed, for example through 'plogging' (jogging and waste collecting combined). Once the team had collected and analysed the data, the research team presented the results at the November 2019 monthly meeting of the Udon Thani Municipality with the leaders of all 104 communities in the city. In addition, it was presented in an Udon Thani-focused session at the October 2019 Asia Pacific Urban Forum (APUF) where the Mayor also presented the city's initiatives on health, physical activity and wellbeing.

Evaluation. In November 2019, the research team held an internal reflections workshop to share perspectives on the process and outcomes of the pilot projects as well as to consider recommendations for the design of future projects. This included drawing on conversations researchers held with community members and stakeholders during each stage of the process. The lead author made notes on the discussion and, following the workshop, used these to identify and describe emerging themes relating to the successes and challenges of the projects, as well as resulting recommendations for others wishing to use similar methods. These themes and recommendations were shared with all co-authors for feedback and iterative editing until collective agreement was reached. In 2020 the research teams and community members met again in workshops in both cities where the research team presented results from the projects and asked community members for further reflections on the co-created CS process and its impact; and in 2022, researchers from SEI returned to the communities in Udon Thani and Nakuru to provide further feedback and gather additional reflections on the process. Notes were taken at these workshops and these were reviewed by the lead author in the context of the themes and recommendations identified from the original evaluation workshop. Again, an iterative process of discussion and editing followed until agreement was reached by all co-authors on the final key themes and recommendations emerging from the pilot projects which are presented in the following sections.

Reflections

Key reflections on the successes and challenges of projects fell under the four themes: recruitment and engagement, data collection methods, extent of co-creation and project outcomes.

Recruitment and Engagement

Recruitment and engagement of communities and the interconnected issue of the selection of focal topics in the initial stages of the projects emerged as a key challenge. A crucial proposed benefit of co-created CS is that it facilitates research of direct relevance to citizens' lives and tackles issues of public concern that might otherwise be neglected by traditional research methods. The extent to which this is achieved, however, depends on which communities and which members of these communities participate in projects and, therefore, whose views and experiences are considered and

addressed. As with CS in general (Pateman, Dyke, et al., 2021), previous co-created CS projects have experienced challenges with engaging diverse participants (e.g. Collins et al., 2020).

In Udon Thani, the entry point to communities was through community leaders and community committee members. While the research team requested that these individuals advertise the project to others within their communities, only the community committee members themselves attended meetings. The perspectives voiced in focus group discussions were, therefore, of those who already play an active role in community activities and initiatives, rather than of 'ordinary' household members. These individuals also tend to be retired rather than working members of the community or youths (workshops were held on weekends and so should not have excluded these groups) and attendees were also predominantly women.

There are several possible explanations for the failure to engage more widely. It was suggested by some community members that Udon's urban context, especially in areas with many tenants, makes it hard for people to have a strong sense of ownership of their community and hence there is a lack of motivation to join such initiatives, especially if the impacts of issues are not severe and felt across the whole community. Indeed, some of the priority topics identified by workshop participants were not straightforward or safe for the project team to launch project activities on, such as stray dogs and cats and messy electrical wires. As waste came up repeatedly in the workshop discussions, it was selected as the focus for the project. However, the fact that it was not everyone's top priority issue may have hampered engagement. While it is tempting to start by approaching communities with leaders who are engaged and approachable or communities who have been involved in similar projects before, a better approach may be to start with the issue and engage groups who are already working on related challenges.

Another challenge with engagement in Udon Thani was that the research team was based in Bangkok, a flight or overnight train ride away. While this does not always equate to a barrier to in depth engagement, in particular if frequent and lengthy visits are possible, within the resource constraints of our pilot projects, the research team were not able to engage with the communities in the deep and sustained manner that has been shown to facilitate the success of co-created CS projects (Ramirez-Andreotta et al., 2015). Without sustained engagement, it was difficult for the research team to build trust and relationships with communities and to know whether there were other underlying challenges or tensions in the community that might have affected interest in collective research.

In Nakuru, the research team's entry point was through the local non-governmental organisation Umande Trust, which has worked in the community and established strong relationships with community members previously. While urban low-income and informal settlement residents are typically not accessible to those not embedded within these communities, partnering with this local and trusted community organisation was very

successful. However, by asking people to attend meetings during the day, people recruited were largely those without jobs or in casual work. While participation in these types of projects is voluntary, in East Africa it is usually facilitated financially through a daily allowance (five to ten USD) to compensate individuals for time they could otherwise have used to earn a living. This form of remuneration can, however, have negative impacts on participation; with some people participating not because they care about the issues being addressed but because of the remuneration. However, the amount of time community members spent independently gathering data between workshops could be seen as an indication of their buy-in to the project. Furthermore, the research team felt the relationships built through several scoping workshops and the focus on issues most relevant to the community also helped build a strong rapport with and between participants.

Data collection methods

Another theme that emerged was around the compromises that had to be made when designing data collection methods. In Udon Thani, it was clear that participants' other priorities and demands, such as earning an income and their other voluntary commitments, limited what the research team could ask them to commit to. As such, data collection was limited to a single morning's activity and was not as extensive as originally planned. As others have recognised, it is important to be led by the commitment participants are able to make and adapt to this (Asingizwe et al., 2019). The process still created "just good enough data" (Gabrys et al., 2016, p. 2) to initiate dialogue with decision-makers and other stakeholders.

In both projects, there were some issues related to the technology used for data collection (tablet and Epicollect app) due to a lack of familiarity. In Udon Thani, this may have been less of a problem if the pilot project had been able to engage younger members of the population and if the research team felt it was appropriate to ask people to commit more time to training. Despite this, by accompanying the community members as they collected data, the research team were able to address technical problems as they arose, and the initial wariness about using an app seemed to dissolve. In Nakuru, people were more familiar with sharing and viewing information on a noticeboard or in a paper document rather than on an app but after training, participants felt comfortable using the tool.

Extent of co-creation

Another theme that emerged from the evaluation was the extent to which the pilot projects were truly 'co-created'. In both Nakuru and Udon Thani, for example, data collection methods were initially drafted by the researcher team, although as others have found, providing a starting point which community members can adapt and refine can be a useful approach (e.g. Asingizwe et al., 2019). Community members were not involved in the analysis of data, although they were engaged in validation of the results during workshops. Community members were also not involved in co-

authoring this manuscript. These limitations were largely due to skills and language barriers and a lack of capacity within these pilot projects for the research team to provide the training and support needed to overcome these. Whilst the environmental data generated was used to open up discussions between community members and decision makers, lack of engagement in every stage poses a risk that community members do not take full ownership of this process.

Furthermore, the research team recognise that the communities did not initiate the pilot projects. Rather they were initiated by the research teams who then approached the communities with an offer to work with them. As much as the research team tried to ensure the process was collaborative, because of this starting point and potentially the nature of previous research projects communities have experienced (i.e. being extractive rather than collaborative), this may have led community members to view researchers as leading the projects. For longer projects and collaborations, the transfer of power, ownership and capacity from researchers to the community that is desired of co-created CS might become more feasible. However, experiences here reflect those of other researchers in co-created CS projects (e.g. Collins et al., 2020), raising the question of how projects can achieve this transfer of power which is one of the core aims of the approach.

One option, for example, is for projects to have an alternative starting point, where communities approach researchers for support in addressing a problem they face and for communities to lead the process throughout. While to some, this may be seen as the 'gold standard' of co-created CS, it is important to balance this aspiration with communities' knowledge and capacities. This approach depends on local communities having the necessary contacts available to them to instigate the process as well as having the time and resources necessary to be heavily engaged in the remainder of the process. While is some cases this may potentially be perceived as a reluctance of individuals and community members to take the power that is being offered to them, in some cases it may actually be more beneficial for researchers to provide greater input in consultation with community members.

Project outcomes

The final theme that emerged was the extent to which the project achieved tangible outcomes for the communities involved, research team and beyond. Looking back at the proposed benefits of co-created CS, the extent to which the pilot projects resulted in these different types of outcome can be assessed (Figure 9).

In terms of data and knowledge generation, both projects resulted in the generation of new datasets that concretely showed the environmental challenges faced by these communities. Sharing these datasets at facilitated workshops provided a starting point for valuable discussions to highlight these issues with decision-makers and the challenges they experience in them being addressed by the relevant persons, authorities or service providers. This points towards co-created CS projects, even when limited in time and

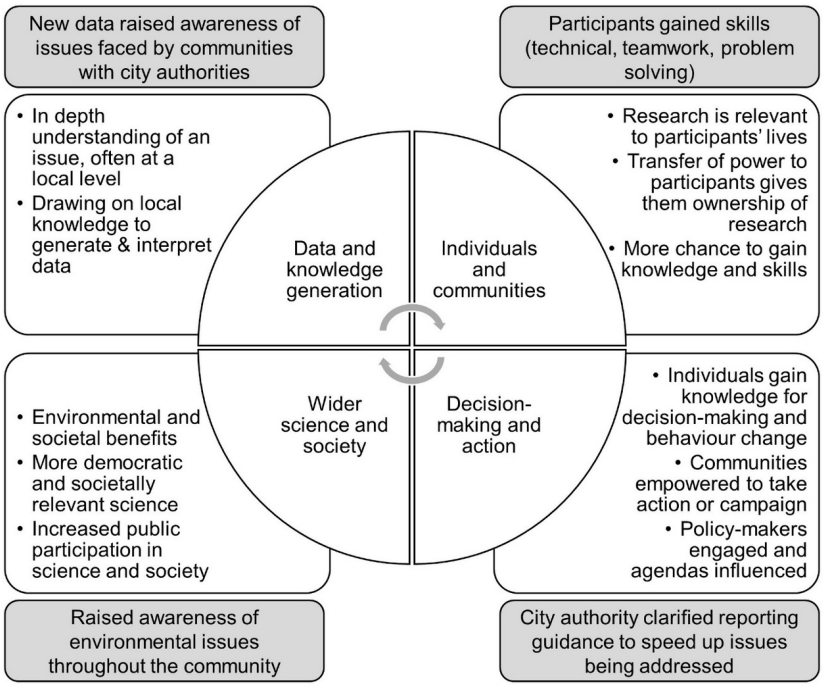

Figure 9. Project Outcomes Relating to Benefits of Co-created Citizen Science

resources as these pilot projects were, providing a way to generate data which both identifies environmental challenges experienced by marginalised communities and generating a starting point for promoting change.

Benefits for participants were also apparent; the research team in Nakuru in particular observed that the issues explored in this research had key relevance to the lives of the participating community members and how, to some extent, they took ownership of the research such as planning several of their own transect walks in Free Area. In the dissemination workshop in Nakuru, the community members also seemed confident in discussing these issues with the local authority, with the data and research team to support them. Community members also reported that they gained knowledge and new skills and that they instigated their own conversations with other community members about environmental conditions in their neighbourhood, which could be seen as a wider benefit for society.

Thus, the primary outcome of the pilot projects can be seen as supporting community members to create dialogues about the environmental challenges they face. However, the extent to which the pilot projects influenced any further change, in particular in decision-making by authorities, is limited. In Nakuru, data collected in the project also revealed there had previously been no clear structure regarding where different types of issue were reported. As a result, the communities were given clear signposting as to where different responsibilities lie and so where their issues should be directed. However, the research team did not see evidence of change beyond this. In both projects, workshops with stakeholders identified routes via which further action could be facilitated e.g. in Udon Thani integrating a reporting function into the existing Udon Thani municipality app was discussed. Longer term funding

(a challenge which has been identified elsewhere e.g. see Pateman, Tuhkanen, et al., 2021) and deeper engagement of key stakeholders including local authorities and charities could have, therefore, facilitated more tangible outcomes.

There are also larger structural issues at play which may limit the extent to which change can be achieved. In Nakuru, for example, while it was recognised that such methods could improve the efficiency of problem reporting and highlight problems faced by marginalised communities, the County Government highlighted the limitations they face in dealing with issues because of limited resources and poor urban planning and waste infrastructure provision. This raises the challenge for future initiatives of managing expectations of community members and the risk of generating research fatigue when projects do not result in change. As outcomes of CS projects can be difficult to predict, open and honest conversations between all partners at the start of projects and throughout about what can be realistically achieved are essential (Chesser et al., 2020).

Recommendations

Based on the above reflections, the authors' recommendations for co-created CS projects in similar contexts are:

- invest time in understanding the local context and culture, ideally in partnership with organisations that already have relationships with communities;
- have the resource and flexibility to bring in other organisations or individuals with the expertise to tackle the primary issues of concern to communities;
- take the time to increase the power and control participants have over the research process. This might include training to build participants' skills in designing research methods or designing activities to clearly demonstrate the equal power all partners have over decision-making within the project;
- try to ensure there is sufficient time, resource and training for participants to be involved in all stages of the research process but be guided by their capacities and priorities;
- allow sufficient time and resources at the start of a project to engage stakeholders to help to ensure projects align with their priorities and that data generated from the project are used in a meaningful way so citizens can see action from their efforts; and

- have open conversations about the realistic outcomes of projects based on resource availability and wider structural constraints. Co-design the project goals with all individuals and organisations involved with the project with these limitations in mind.

Conclusions

The six-step methodology for co-created CS research activities presented here can be used to understand and begin to address environmental challenges faced by marginalised urban communities, as evidenced by its application in two cities in the Global South, Nakuru, Kenya, and Udon Thani, Thailand, where co-created CS projects are notably sparse. The experiences within these projects, including successes and challenges and emerging recommendations, can be used to inform others wishing to use the approach and so to grow and refine this methodology.

In summary, the two pilot projects generated new knowledge with relevance to the community members and with genuine scientific outcomes. Whilst the projects were co-created, there were limitations as to how active participants were (e.g., taking ownership of the process, transferring of power) and to what degree they were engaged in all stages of the research processes (e.g., method development and analysis). Despite this, there is clear potential for co-created CS approaches to begin to address environmental challenges experienced by marginalised communities. In particular, the pilot projects created dialogue between marginalised urban communities and local authorities on the environmental challenges identified. For example, workshops with stakeholders in both projects identified routes via which further action could be facilitated such as where to report issues and how to improve reporting functions. However, the extent to which the pilot projects influenced any further change, in particular in decision-making by authorities, is limited, at least in part due to structural challenges beyond the control of projects.

This also raises the challenge for future initiatives of managing expectations of community members and the risk of generating research fatigue when projects do not result in change. Longer term funding could have resulted in deeper engagement of key stakeholders, including local authorities and charities, which could have, potentially, facilitated more tangible outcomes. Another approach may be to work with priority issues identified by local government or service providers but where data gaps exist, as well as officials who are responsive to alternative modes of data collection. During the initial stages of projects, local authorities and communities could be brought together to come up with shared priorities, although this depends on the local context and nature of the relationships. In this way, CS still has a great potential to create a platform for conversation between communities and authorities and stakeholders.

In addition, consideration needs to be given as to whether CS itself is the best method to address issues of concern to the communities. In these projects, the starting point was CS as a method and the research team then looked for a community to work with and an issue to apply the approach to. It may have been more appropriate to start by identifying issues and then to look for the best method to address them. Whilst these are certainly crucial issues that should be carefully considered by researchers wishing to use these methods, they do not negate the potential of the co-created CS to be an effective way of opening up dialogues about the issues faced by marginalised communities.

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