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RESEARCH ARTICLE

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Mapping the current landscape of citizen-driven environmental monitoring: a systematic literature review

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ABSTRACT

Citizen observatories can be defined as socio-technical constellations designed to make people who are nonprofessional scientists empowered entities. By enabling citizens to monitor their environment via collection and sharing of data, citizen observatories can be viewed as an application or iteration of citizen science. This article contributes to mapping out the current landscape of citizen engagement and participation in environmental monitoring. We draw on a systematic analysis of 57 peer-reviewed papers and argue that citizen observatories have the potential to make a substantial social impact by bringing together different stakeholders and digital technologies. We also discuss the challenges of civic participation, quality of the data gathered, and long-term sustainability. The article identifies several critical gaps in the field that provide a guide for future studies on citizen observatories. Furthermore, it encourages deeper engagement within developing nations and investigates the impact of this approach on nurturing sustainable societies globally.

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Introduction

Citizen science is becoming a prominent and valuable approach to gathering data in an array of disciplines including the environment. Developing, implementing, and evaluating the impact of citizen science projects is a complex endeavor (Dickinson et al. 2012) and the interest is visible in both academic studies and practical applications. Citizen science refers to engaging individuals such as volunteers who are not trained scientists in collecting, categorizing, transcribing, or analyzing scientific data (Bonney et al. 2014). Engagement of this nature, with communities striving for a common purpose, can provide meaningful social and community outcomes, which may not be possible or expeditious within existing social or government systems. Citizen-science initiatives are currently gaining wider recognition due to the varying insights that citizen science provides to stakeholders including citizens, decision-makers, and academia. In conservation science, for instance, where resources are often limited in comparison to the scale of the questions, the involvement of the nonscientific community in academic research has become increasingly important; while for citizens, the contribution to scientific understanding and decision-making processes becomes a motivation (Tulloch et al. 2013).

Crowdsourcing, civic engagement, and digital civics are linked to citizen science initiatives. Crowdsourcing refers to the use of the latent talent of the crowd, where labor costs a lot less than utilizing traditional employees and can even be free (Howe 2006). Crowdsourcing today appears to be highly aided by digital and mobile technologies and has broader implications including in the field of business. Many online and mobile-based authoring tools are being utilized, allowing researchers to collect data from a large pool of participants who move around in various public spaces (Sasao et al. 2015).

Crowdsourcing initiatives can also be used to integrate the collective knowledge of citizens, empowering them to take an active role in civic decision making (Harding et al. 2015). On one hand, this can also help to improve the conditions of a community and is often referred to as civic engagement (Adler and Goggin 2005). Digital civics, on the other hand, try to understand how digital technologies can facilitate these engagements (Vlachokyriakos et al. 2016).

At present, attention to environmental factors is very high on the agenda in many leading world bodies such as the United Nations and the European Union (European Commission 2015).

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This has made implementing citizen-science for sustainability more visible in international discourse and a tangible target around which to orient. Many stakeholders including universities and nongovernmental organizations (NGOs) are becoming increasingly involved in citizen-science projects on sustainability (Bonney et al. 2014; Cunha et al. 2017). The unique role of information-systems design in stimulating a framework of sustainable environmental interactive technology based on social and economic sustainability is becoming increasingly apparent and an urgent concern (Nathan, Friedman, and Hendry 2009; Joshi and Cerratto-Pargman 2018; Cerratto-Pargman and Joshi 2015). This has encouraged citizen-science projects to provide information and communications technology (ICT)-enabled tools, making technologically supported crowdsourced environmental monitoring projects widely available. Citizen observatories are one such manifestation of this trend and are defined as communities of citizens sharing tools and applications as well as community participatory governance methods that are aided by social media streams (Wehn et al. 2018). Their objective is to complement environmental observation systems and improve local decision making (European Commission 2014a).

Citizen observatories and citizen science can be distinguished via the following indicators. While citizen observatories focus on two-way communication between citizens and stakeholders, citizen science is relatively confined to collecting data to support participation in study design or data analysis. What makes citizen observatories distinct from other citizen-science endeavors is their dual attention to both the facilitation of governance and decision making, on one hand, with the ultimate intention to bring change in society on the other. Citizen science engages with scientists or citizens participating in scientific projects for the purpose of contributing to discussions of scientific questions while citizen observatories entail a broader range of stakeholders that include policymakers, civil society representatives, and members of the private sector for the purpose of facilitating dialogue at the political level (Liu et al. 2017).

Reliable and objective overviews of citizen observatories and their impact are not yet readily available. Systematic literature reviews of the field either focus on a broader area of citizen science covering different applications (Chandler et al. 2017) or discuss the success and longevity of citizen-science projects (Cunha et al. 2017). Moreover, as the scope of these studies spreads across various fields, it tends to limit the depth of focus on environmental monitoring. This arguably results in a situation where the

conclusions are helpful mostly for broader issues in citizen science than specifically for citizen observatories. This gap forms the foundation and motivation for this article's scrutiny and effort to narrow the scope and specifically to devote attention to citizen observatories.

We describe the current landscape pertaining to citizen observatories for various environmental monitoring activities around the world through a systematic literature review. The goal is, first, to systematically summarize a corpus of research papers directly related to citizen observatories using scientific searching criteria. Second, we aim to determine the rubrics that will provide the lens to further analyze the selected studies. This literature review builds methodologically on previous systematic reviews conducted in the field of human-computer interaction and sustainability (DiSalvo, Sengers, and Brynjarsdóttir 2010). It provides pathways to identify rubrics that are the building blocks of a literature review. We expect that the insights gained from this analysis will help to inform our understanding of the role of public awareness within natural resource management.

Materials and methods

Systematic literature review

The study, conducted in March 2019, utilized three electronically accessible and widely used databases: Scopus, ACM Digital Library Full-Text Collection, and Web of Science. As citizen observatory is a relatively new concept, articles published before the year 2007 were excluded. Only full-text peer-reviewed articles written in the English language were included. Arguably, this ensures that the final set of papers is relevant, and the review is comprehensive, logical, and effective. The preliminary search was performed in three iterations using three different queries forwarded to each database. The first set of queries was based on the following search strings.

Search string A: "citizen observatory" OR "citizen observatories"

Search string B: "citizen science" AND "monitoring"

Search string C: ("citizen science" OR "crowdsourcing" OR "citizen participation" OR "citizen engagement") AND ("sustainable" OR "sustainability")

Search string D: "digital civics"

The Scopus database search produced 13, 477, 31, and 220 results, respectively, for each query. The results were exported as a list into the spreadsheets. We subsequently amalgamated these results while removing duplicates and entries in which the full-

Table 1. Spread of papers in each inclusion and exclusion step.

Search String	Web of Science	Scopus	ACM
A	73	13	0
B	446	471	75
C	558	31	28
D	172	220	30
Exclude duplicate	670	504	42
Exclude duplicate	980		
Include environment-related	512		
Exclude biodiversity	151		
Include main focus on citizen science	88		

text was not available. The resulting total number was 504 entries. The ACM database search provided a smaller output, with 0, 75, 28, and 30 results, respectively. After applying the same process, we ended up with a total of 42 entries. The Web of Science database returned 73, 446, 558, and 172 papers, respectively, and the removal of duplicates resulted in 670 total entries. These three databases were imported to the same spreadsheet and subjected to another round of duplicate removal, which produced an overall set of 980 papers (see Table 1).

Thereafter, specific criteria for the inclusion and exclusion of papers were applied. The first was to examine the titles and include only environment-related studies. This exclusion brought us to a total of 512 papers. We then applied two key levels of exclusion. The first exclusion was any study related to biodiversity. Previous studies show that citizen-science literature is dominated by studies related to biodiversity, 96 out of 126 studies (Cunha et al. 2017), which suggests that this is an exclusive area. Furthermore, this application of citizen science mainly involves survey-type studies such as censuses of wild animal populations. The focus of this study is to explore decision-making and environmental observations in the context of social impact by uniting stakeholders that are not usually part of the equation of decision making, rather than focusing on population ecologies. Thus, all records covering biodiversity were excluded, bringing the total to 151.

We subsequently read the resulting corpus of papers and further examined them to check whether they were related to the area of citizen observatory or monitoring of the environment using a citizen-science approach. This was determined by whether the primary goal of the research was to study citizen observatories or to use citizen science to address sustainability issues by monitoring the environment in crowdsourcing. This step resulted in the inclusion of papers only related to citizen observatories or citizen-science concepts and environmental monitoring. Accordingly, we excluded studies such as a paper on the Japanese smart-city concept where citizen science was a subarea of research. This selection criterion further narrowed down our results to 88.

Finally, the single corpus of articles was divided into two subsets: (1) 31 papers discussing general issues on citizen observatories through reviews and theoretical models and (2) 57 papers describing studies on the direct application of citizen observatories.

Research questions

From the above subset of 31 articles, we identified certain common thematic areas.

These subtopics served as a lens to determine the rubrics for discussion in this article. Participation, quality of data, and societal implications emerged as key themes where research objectives and discussions were clustered.

Participation

The first set of rubrics revolved around factors determining citizen participation. It called for an analysis of the following issues: (1) What was the environmental aspect monitored, and in which location? (2) Why was a citizen-science approach used? (3) How were citizens invited and what was the type of engagement?

An understanding of these aspects is important to reveal patterns of existing experiences within citizen observatories. This is key to realizing the potential of implementing similar initiatives in other locations (Tulloch et al. 2013).

Quality of data

The second set of rubrics relates to data and their quality: What are the innovative data gathering techniques used? How was data quality maintained?

Answers to these questions are important for the sustainability of citizen observatories as they are not universally regarded as scientific investigation (Bonney et al. 2014). Furthermore, as innovative data-collection methods are applied, such as web-based applications, such scrutiny about data quality is important as they have not previously been used.

Societal implications

The final set of rubrics focused on study outcomes and impact on society by examining: What was the outcome of the study for the community? What are the frameworks that determine social implications?

These rubrics capture the potential social impact of the studies. Moreover, they are important in understanding to what extent citizen-science projects increase crowd participation for environmental monitoring.

Limitations

This review was confined to three electronically available databases. Although several combinations of keywords were used to search these databases, a search of additional databases could produce a wider array of articles. Furthermore, the study includes only articles published in the English language which limits the scope of our review. Finally, each decision to include or exclude a particular publication was taken by a single reviewer, and this may have affected the outcome of the results and conclusions.

Results

Participation

With respect to the question of the environmental aspect and location, the data indicated that air and water quality was the dominant issue. Examples ranged from air-pollution monitoring such as studies to create community-empowered air quality-monitoring systems (Hsu et al. 2017) and water-testing systems (Shupe 2017) that illustrated the citizen-observatory approach. These represented 20 studies out of a total of 57. A subtotal of 18 was conducted as a sea- or ocean-related tests, such as monitoring phytoplankton seawater discolorations (Siano et al. 2020). The next interest area, including 16 studies, dealt with emergency environmental issues such as floods (Lanfranchi et al. 2014). The other six studies focused on other environmental concerns such as noise pollution. Most of the studies were conducted in the United States (47%) and this group was exemplified by a research project designed to understand volunteer motivations to participate in citizen-science projects covering eight major cities in the country (Alender 2016). The next major geographic area was Europe with 41% of the articles. These studies were spread across countries such as Norway (Castell et al. 2015), France (Siano et al. 2020), the UK, Netherlands, and Italy (Lanfranchi et al. 2014). It is important to note that only 7% of these citizen observatories or science studies focused on countries in the global South, such as one carried out in India (Dutta et al. 2017) and another in Tanzania (Gomani et al. 2010).

Further analysis of this gap is essential. While the disparity is not surprising, given our choice to focus exclusively on English-language articles, we believe that this discrepancy may indicate broader regional differences. Given the fact that the origins of this construct lie predominantly in Europe, it is possible that the concept may bear structural inequities or varied architectural dimensions that may create

inadvertent unequal access. We plan to address this question in future research.

In terms of the reasons behind using the citizen-science approach, it was evident that the motivation to adopt a citizen observatory was not confined to citizen empowerment or related objectives. The comprehensiveness of the data with the added citizen component is one of the key motivations for most of the projects (35%). Their focus was to access data or information that is difficult to obtain by other means (Jarvis et al. 2015). In addition, 28% of the publications reported on the impact that this research strategy can have on the community with respect to empowerment (Alender 2016). Further, cost-effectiveness and the ability to run long-term studies were another reason to adopt this approach.

These results also open another avenue of analysis of the global South, namely, to determine the usability of citizen-science projects beyond being a tool for data collection. It would be interesting to assess whether this approach can be used to achieve other positive objectives such as establishing interaction and co-participation between citizens and authorities during both emergencies and day-to-day management of natural resources (Lanfranchi et al. 2014).

Concerning the question of how citizens were recruited and their type of engagement, there were three key parties involved in the studies: citizens, NGO staff, private parties, and government representatives. There were 37 instances in which only citizens participated, such as the “SecondNose” project for air-quality testing (Leonardi et al. 2014), 15 instances with at least two parties involved, such as the ICT-enabled citizen observatories focusing on local flood-risk management (Wehn and Evers 2015), and only six studies involving the full range of parties. The purpose of these studies was to draw on the expertise of all stakeholders to support the co-management of natural resources (Aoki et al. 2017).

All studies of the observatories used a campaign to attract citizens who were mostly engaged as volunteers. These included online campaigns, newsletters, posters, and other media accessible to the relevant community. The majority of the studies (95%) attained the expected number of volunteers. A persistent feature is that most of the studies could not be sustained over a long period of time, making it difficult to determine the sustainability of participation trends. The motivation for engagement on the part of citizen participants was not captured in most of the studies. Only four publications (e.g., Aoki et al. 2017) out of 58 discussed such issues, which revealed motivations such as the desire to gather personally relevant information (e.g., air-quality issues

which can hold health risks), interest in the environment, environmental awareness, and the desire for environmental advocacy and education. It would be instructive to address this gap in our knowledge in order to better understand the expectations of communities for continuous participation, which will assist in the implementation of sustainable citizen observatories. This inquiry goes beyond citizen observatories per se and begs the question of how long-term participation can be sustained where citizens and diverse stakeholder groups can be engaged by a meaningful design principle. What incentives can be embedded and barriers removed to provide a robust environment for participation that transcends novelty? We will return to this question and further develop it in future studies.

Quality of data

For the research question on innovative data-gathering techniques, it was evident that data were assembled for most of the studies through technological instruments, where 36 studies were done using online or mobile-based means. One study, for example, enabled citizens to measure the noise in their everyday environment by using a global positioning system (GPS) equipped mobile phones as noise sensors (Maisonneuve et al. 2009). In some studies, the human became the sensor, and the data were entered into mobile or web applications, such as the color of water (Kobernus et al. 2013). Further, 17 studies used an improvised device supported by the Internet or mobile apps. For example, SecondNose, the air quality mobile crowd-sensing system, used a mechanism that included an air-pollution sensor, an Android mobile phone application, a backend with data collection, and an analytics component, and a web application to visualize the data (Leonardi et al. 2014). Another study examining air pollution from a factory used a live camera that could be oriented from a volunteer's home, supported by an open-source tool (Hsu et al. 2017). There were two studies where volunteers gathered data using traditional equipment and transmitted the data via conventional channels or by personal visits to laboratories (Sheppard, Wiggins, and Terveen 2014).

For the question of taxonomy regarding errors in citizen science, hardware, device handling, user activity such as making noise, and environmental conditions such as weather were identified in the analyses (Budde et al. 2017; Sheppard, Wiggins, and Terveen 2014; Kim, Mankoff, and Paulos 2015). Using a robust method of iterative testing over time, the studies were trying to build trust in data and to allow for the calibration of tools. For example, the

air quality-monitoring unit AirQino was put through a one-month monitoring campaign using such iterative testing (Zaldei et al. 2017).

Another study on community-based groundwater-monitoring networks using the citizen-science approach was in place for a five-year pilot period (Little, Hayashi, and Liang 2016). Hardware was tested with a selected group of users first to ensure accuracy (Hsu et al. 2017; Siano et al. 2020; Leonardi et al. 2014; Wakasa and Konomi 2015). Data gathered were validated by relevant "expert" staff (e.g., Sheppard and Terveen 2011).

Societal implications

One of the main aims of our study is to understand how citizen observatories can be used to support citizen communities and check whether communication can be developed among all stakeholders. The findings from our systematic review reveal three main trends.

First, out of the 58 papers analyzed, 39 focused on examining the flexibility and accuracy of the equipment and tools used by citizens, such as a study on the creation of a visual environment for people without a programming background to build a mobile data-collection application (Kim 2012). These studies were primarily concerned with the features of the tools used, such as cost, ease of use, accuracy, and data quality (Castell et al. 2015; Maisonneuve et al. 2009; Zaldei et al. 2017).

Second, 12 studies focused on capturing the user experience beyond the use of the equipment. They were concerned both with user motivation and with how the approach changes participants' perceptions of the environment. The SecondNose air quality monitoring system, for example, examined volunteer enthusiasm in using the sensor and how it impacted their perception of air-quality issues (Leonardi et al. 2014). Citizens then play an active role in these studies by observing their environment, which is one component discussed in citizen science from the participants' perspective (Liu and Kobernus 2016).

Finally, only eight studies focused on an actual or theoretical framework for communication between citizens and other stakeholders. For example, the Citi-Sense-MOB in Norway provides citizens and authorities with information on transport, carbon-dioxide (CO₂) emissions, and air quality (Castell et al. 2015). These studies focus on developing a system to support stakeholder engagement.

Discussion

The main purpose of this study was to map the current landscape of research on citizen observatories.

The rubrics identified in the methodology section were derived from three areas identified as critical because of the concentrated research carried out on them: civic participation, quality of data, and societal implications. This section covers the perspectives obtained when these rubrics are used as lenses to view the selected corpus of papers.

Civic participation

Civic participation is considered a major factor in the success of citizen-science initiatives for environmental monitoring, and concepts such as citizen empowerment and participatory democracy are used to justify citizen-observatory studies (European Commission 2014a). However, this review shows that most citizen-observatories tend to focus on testing the citizen-science approach as an affordable method of acquiring a large volume of environmental data (e.g., Barrows et al. 2016). The comprehensiveness of data is the most common objective in implementing citizen observatories. Some studies try to examine the usability of citizen-based data when combined with data gathered using traditional methods such as satellite images in order to gain a comprehensive perspective (e.g., Jarvis et al. 2015). It emerges from the literature that testing the potential of citizen observatories to enhance the collective knowledge of citizens as a civic crowdsourcing tool (Surowiecki 2005) is another important motivation underpinning such initiatives.

Another key finding is that such studies are mostly conducted in developed countries. While sustainability is high on the agenda in these nations (European Commission 2014b), there are exceptions to the rule, as is currently showcased in US policy, where, paradoxically, most of the citizen science examples are based. The way we make sense of this is by acknowledging, on the one hand, that resources and opportunities (as seen historically) which create a fertile ground for citizen science engagement tend to be distributed more in the global north. Hence citizen science emerges as a priority in their agenda and, at the same time, fluctuations in the sociopolitical climate deeply impact the expression of those privileges, where shifts in political discourse can sharply change the weighted sustainability carries in practice. Less developed nations with fewer resources at their disposal or a shorter history of decentralized democratic governance might be able to achieve more than nations in the global north by committing to sustainability goals in the long term.

It is possible that the participants in studies from the global north have fundamental differences compared with those in studies from the global south.

Evidence suggests that only a small percentage of citizens in low- and moderate-income countries are aware of aspects such as sustainable development (Omisore et al. 2017; International Young Naturefriends 2018; Mustunsir 2015; Aldaba et al. 2000). Moreover, the general perception of sustainability issues tends to be that they should be dealt with by the government or relevant authorities (DevCom 2017). It would be interesting to explore the impact of citizen observatories on both environmental monitoring and civic engagement in such a setting. Likewise, it might be equally important to examine the feasibility of using citizen observatories as a tool to fill any void in existing systems in global south countries. This begs the question of how the concept can be better designed to accommodate the needs and contextual requirements of those living in the global south, and whether there are currently any hindrances that can be corrected to allow for more equitable participation.

The longevity of citizen participation is a key variable for the sustainability of citizen observatories. Most of the studies reported higher volunteer participation in the initial stage, which progressively declined over time. The sustainability of citizen-science projects with continuous citizen participation is not covered extensively in the literature.

Data

What emerged clearly from the literature is that as citizens are engaged in the data gathering process, the quality of data plays a very important part in making citizen-science approaches widely acceptable (Cerratto-Pargman, Joshi, and When 2019).

Mobile technological sensors are the main data-gathering tool. It appears that there are both advantages and limitations to this approach and research takes place to make such products or applications consistent and user-friendly (Kim and Paulos 2012). As the studies tend to skew toward one part of the world, it is interesting to see the feasibility of implementing such technologies in other locations when used by people with a different socioeconomic background. The selective focus on technology design and quality of data takes on a different impact within the developing world context due to confounding variables such as access, inequality, and differing priorities.

The literature reveals that one of the motivations to adopt a citizen-science approach is the lower costs involved in gathering data (e.g., Vinci et al. 2017) compared with expensive equipment used to measure or monitor precise numerical data (Cunha et al. 2017).

Qualitative methods are used in most of the studies analyzed. We can conclude that this is the most appropriate method because of a number of practical reasons. One aspect is that data gathered from observations of natural settings including images, videos, and sounds, have many advantages for qualitative methods (Denscombe 2014). The richness and detail of the data are preserved through qualitative methods. Another advantage is its ability to tolerate ambiguity and contradictions. It is obvious that due to the sense of uncertainty prevailing in nature, pre-structured answers or explanations are not suitable to explain the scenarios. While some predefined answers are possible, the tolerance of qualitative approaches allows them to handle the reality of the participants' subjective observations of their environment.

Societal implications

Citizen participation has largely been confined to data gathering by individuals as citizens of the community. While it may lead to achieving the goals of crowdsourcing such as gathering large volumes of data at an affordable cost, there appears to be a lack of initiative to examine the social implications of these studies (Bonney et al. 2014). It is certainly worthwhile to extend the endeavor to analyze if the processed data have any impact on stakeholders. It is worth mentioning that this stakeholder cohort goes beyond citizens to others such as local government authorities and technical and other public officers. There are no studies examining the impact or co-existence of these groups in a citizen-observatory project. Similarly, it would be worthwhile for future studies to make a framework for establishing effective communication and assessing the social impact on the community. Most studies do not place emphasis on creating a framework for data to be used by other stakeholders such as officials and governments. One illustration of an attempt to arrive at a framework is the CITI-SENSE framework, which covers nine European cities and provides the best practices to adopt to ensure the success of citizen observatories (Kobernus et al. 2013). This framework considers raising awareness, initiating dialogue, and data exchange as the three pillars that support a citizen observatory. Accordingly, getting useful messages across to the public in the right way is considered crucial, with successful dialogues regarded as critical for ensuring a deeper interest from stakeholders and their long-term engagement. The citizen-science approach needs to be a much more effective mechanism in the global South than just being another data-collection tool (Perkins 2013).

Conclusion

In summary, citizen science-based environmental monitoring is gaining momentum as an emerging research area in the academic domain today. Studies tend to skew toward two major issues of water and air, while, practically, most of the projects are executed in developed countries. Our study concluded that further research is needed on the social impact of citizen science-based environmental monitoring. The studies are mainly case studies and use qualitative methods, which are suitable for assessing observation data on the environment. It would be worthwhile to extend the research both in horizontal and vertical directions to see the scalability and reliability of citizen observatories. This would pave the way for projects with higher social impact and sustainability and formulate the design and implementation of citizen observatories in the initial stage.

A significant drawback around evaluating each project and its impact on stakeholders other than citizens is the degree of trust experts or authorities can place on citizen data and the citizen-science approach. Many aspects need to be developed further to create a reliable and beneficial method for all parties involved.

This article has highlighted some critical gaps in current citizen-science studies and paves the way for future studies within the domain of citizen science and civic participation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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