The benefits and negative impacts of citizen science applications to water as experienced by participants and communities

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Abstract
Citizen science is proliferating in the water sciences with increasing public involvement in monitoring water resources, climate variables, water quality, and in mapping and modeling exercises. In addition to the well-reported scientific benefits of such projects, in particular solving data scarcity issues, it is common to extol the benefits for participants, for example, increased knowledge and empowerment. We reviewed 549 publications concerning citizen science applications in the water sciences to examine personal benefits and motivations, and wider community benefits. The potential benefits of involvement were often simply listed without explanation or investigation. Studies that investigated whether or not participants and communities actually benefitted from involvement, or experienced negative impacts, were uncommon, especially in the Global South. Assuming certain benefits will be experienced can be fallacious as in some cases the intended benefits were either not achieved or in fact had negative impacts. Identified benefits are described and we reveal that more consideration should be given to how these benefits interrelate and how they build community capitals to foster their realization in citizen science water projects. Additionally, we describe identified negative impacts showing they were seldom considered though they may not be uncommon and should be borne in mind when implementing citizen science. Given the time and effort commitment made by citizen scientists for the benefit of research, there is a need for further study of participants and communities involved in citizen science applications to water, particularly in low-income regions, to ensure both researchers and communities are benefitting.

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1 | INTRODUCTION

Citizen science continues to gain in popularity in both scientific and general media discourse (Conrad & Hilchey, 2011; Dickinson, Zuckerberg, & Bonter, 2010; Paul et al., 2018). Citizen science is defined as scientific activities in which the general public participate to some degree in data collection, analysis, and dissemination. The origins of citizen science are the origins of modern science, that is, prior to professionalization when scientific endeavors were conducted by amateurs; notably by such illustrious individuals as Benjamin Franklin and Charles Darwin in the 18th and 19th centuries, respectively (Miller-Rushing, Primack, & Bonney, 2012; Silvertown, 2009). Whereas in the past, scientific study was only possible for a privileged few, this is no longer the case as globally reaching projects such as eBird (2019) and Galaxy Zoo (2019) have brought the opportunity to participate in scientific research to the masses. These mass participation projects have been predominantly in the fields of ecology (e.g., wildlife surveys) and astronomy (e.g., searching for new planets); these two disciplines were the first to identify the potential for significantly increasing the quantity and frequency of observational data by utilizing enthusiastic amateurs (Dickinson et al., 2010).

The blossoming of citizen science in environmental studies is due to this realization by researchers that involving the public can both increase the range of their data collection (spatially, temporally, and in quantity) and achieve the public outreach often required by funders. Other contributing factors are: technological advances for both informing the public about projects and then for gathering data (i.e., greater internet and smartphone availability); growth in the population of well-educated individuals; growing concerns of communities regarding the health of their local environment and; reduction in working hours with an increase in leisure activities (Carlson & Cohen, 2018; Haklay, 2013; Silvertown, 2009). As noted by Haklay (2013), these drivers point to an inherent bias in the socioeconomic make-up of citizen science with participants most likely to live in an advanced economy and be middle class, thus having the education, technical skills, access to resources and infrastructure, and the free time or the particular leisure pursuits that facilitate participation. This results in a geographic bias as the majority of projects are located in North America and Europe. Consequently, most of the research conducted on participants and communities involved in citizen science originates from North America and Europe (Conrad & Hilchey, 2011; Jordan, Ballard, & Phillips, 2012).

The application of citizen science in the water sciences is relatively recent and is growing (Njue et al., 2019; Zheng et al., 2018); an exception is weather monitoring where there are records from amateur meteorologists dating back centuries (Eden, 2009). The growing number of publications advocating and reporting citizen science applications to water commonly state, in addition to the scientific benefits to researchers, the numerous benefits that could be experienced by communities through participation (e.g., Buytaert et al., 2014; McKinley et al., 2015; Thornhill, Loiselle, Clymans, & van Noordwijk, 2019). These benefits include education, raised awareness, empowerment, and satisfaction of motivations such as “being in nature,” “contributing to science,” and “meeting likeminded people” (Haywood, 2014; Hobbs & White, 2012; Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011). However, the transferability of findings on participants from the other fields where this research originates is uncertain because there are often fundamental differences between how, where, and why citizen science is applied: that is, occasional wildlife observations versus daily monitoring of hydrometeorological variables at fixed times; volunteering to participate during leisure time to further an existing interest versus being nominated by a community leader to participate in a program that could bring livelihood benefits. Therefore, do we know if these benefits are being experienced by participants and communities involved in citizen science water projects, especially those in low-income areas? Furthermore, do we know if participants and communities are being negatively impacted through their involvement?

Reviews of citizen science applications in the water sciences so far focused on the state of the art and future opportunities for scientific benefits rather than the impact on participants (e.g., Assumpção, Popescu, Jonoski, & Solomatine, 2018; Njue et al., 2019; Paul et al., 2018). More broadly within the environmental sciences, a small number of reviews have aimed to synthesize impacts of involvement for participants (e.g., Conrad & Hilchey, 2011; Shirk et al., 2012; Stepenuck & Green, 2015). However, these reviews included very few water sciences case studies, of which most concerned water quality in North America and Europe. There is therefore a need for this synthesis that reports the benefits and negative impacts of citizen science involvement from all fields of the water sciences utilizing case studies from around the world. We are at a point where we know that citizen science applications are proliferating in the water sciences, but we can only speculate on what impact they are having on participants. This review aims to raise awareness of outcomes experienced by participants involved in citizen science applications to water, which should enable better project design and management, maximizing benefits and avoiding negative impacts.


## 2 | BACKGROUND

### 2.1 | Water sciences

We considered the water sciences to include hydrology, meteorology, water quality, water management, and water-related disasters (e.g., droughts, floods, rainfall-induced landslides). Mapping projects and assessment of soils were also considered when conducted to aid understanding of the aforementioned fields. The focus was on freshwater—rivers, lakes, groundwater, tap water—marine and coastal studies were not incorporated. While this may be considered a broad taxonomy, what unifies the reviewed studies from these disciplines is the application of citizen science for the collection and analysis of water-related variables. A key aim of this review is to share relevant findings across disciplinary approaches.

### 2.2 | Citizen science typologies

The degree of citizen versus professional scientist control ranges from 100:0 (top of Figure 1) in the case of collegial projects designed and implemented by non-professionals to almost 0:100 for passive sensing which essentially excludes any effort on the part of the citizen. Collegial citizen science projects, where non-professionals collect, analyze, then use or disseminate the data, mostly go unpublished in scientific literature (Bonney et al., 2009). Approximately equal control refers to co-created projects established jointly between scientists and communities. Decreasing though still present citizen versus professional control refers to collaborative projects, in which citizens perform data or sample analysis and may help with study design, data interpretation, and results dissemination. It is collaborative and co-created projects that are increasingly promoted as the pathway to achieving the many potential benefits of citizen science (Buytaert et al., 2014; Cundill & Fabricius, 2009; Haklay, 2013). Lower on the scale of citizen control are contributory projects, which are designed by scientists while members of the public primarily contribute data. Passive or opportunistic sensing involves taking advantage of the *Internet of Things* and *Big data* analytics by utilizing embedded sensors in smartphones and other electronic equipment. Data can be contributed voluntarily by citizen scientists or harvested/mined from social media (Zheng et al., 2018).

### 2.3 | Citizen science in the water sciences

Citizen science applications to water range in scale—both geographically and in numbers of volunteers—from local scale studies involving a single volunteer, for example, presence/absence of flow in an ephemeral river (Walker, Smigaj, & Jovanovic, 2019), to global scale studies involving tens of thousands of volunteers, for example, backyard weather stations contributing to global databases of meteorological variables (WOW, 2019).

The level of sophistication ranges from the simple and cheap to the highly technical, and whereas manual equipment combined with a high monitoring frequency may necessitate a significant time and effort commitment, automatic equipment may involve little work by the citizen scientist. Though that considers only

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**FIGURE 1** The relative degree of control of citizens and professional scientists for different typologies of citizen science. Categorization of a project is subjective; examples such as community-based monitoring and participatory modeling could move up or down the scale. After Shirk et al. (2012)
involvement in data collection whereas the public can be involved in prior and subsequent steps in collaborative projects.

Most citizen science applications to water involve some form of monitoring. However, infrequent participatory activities such as mapping, modeling, and collection of narratives are valuable sources of data (Gaddis, Vladich, & Voinov, 2007; Ramsey, 2009), particularly for incorporation of local and indigenous knowledge for disaster risk reduction at community-scale (Evers, Jonoski, Almoradie, & Lange, 2016; Hicks et al., 2019).

All citizen science typologies are applied within the water sciences, ranging from collegial, which generally comprise waterbody health projects (mostly in North America) set up by concerned local residents (Bonney et al., 2009) through co-created, collaborative to contributory projects involving decreasing levels of citizen control in what is monitored, where and how, who conducts the analysis, and who uses the data. Current applications of opportunistic sensing in the water sciences include estimating rainfall intensity using dashboard camera footage (Nashashibi, de Charrette, & Lia, 2010) or acoustic sensors on umbrellas (Hut, de Jong, & van de Giesen, 2014). Another relevant passive form of citizen science is social media harvesting to obtain hydrometeorological data. Twitter in particular proves to be a valuable data source, especially with regard to disasters because tweets can be analyzed and georeferenced for real-time hazard mapping and for planning emergency response (Cervone et al., 2016; Smith, Liang, James, & Lin, 2017).

2.4 Community capitals

When considering the benefits of involvement in citizen science it is useful to consider how the benefits contribute to community capitals. Community capitals represent the overlapping assets of a community required for social wellbeing as well as healthy ecosystems and economy (Emery & Flora, 2006). The relevant capitals in the context of citizen science are human, social, political, natural, cultural, and in some cases financial (or resource). Human capital represents “the skills and abilities of people to develop and enhance their resources and to access outside resources and bodies of knowledge in order to increase their understanding, identify promising practices, and to access data for community-building” (Emery & Flora, 2006). Social capital refers to the networks, shared values, understandings, and trust in society that enable individuals and groups to act together to pursue shared objectives (Cundill & Fabricius, 2009). Political capital is the ability to influence regulations and reflects access to power. Natural capital refers to the environment, natural resources, and natural beauty. Cultural capital includes traditions, beliefs, and values that reflect how a community understands the world and acts within it. Financial capital corresponds to the financial resources available in a community.

3 METHODOLOGY

3.1 Objective

The benefits of citizen science to the scientific community are numerous with the most commonly reported being to infill regions of data scarcity and expand monitoring or investigations beyond what research or authority budgets usually allow (Assumpção et al., 2018; Danielsen et al., 2009; Paul et al., 2018). This review concerns benefits, and negative impacts, to the non-scientific community. Therefore, the objective was to systematically review published literature concerning citizen science applications in the water sciences to evaluate the benefits and negative impacts experienced by participants and communities. Specifically, the review sought to analyze how these experienced impacts are discussed in the literature, as opposed to analyzing whether or not the projects had an impact. The review had the following queries:

1. Is there mention of benefits and negative impacts for participants or communities involved in the citizen science?
2. How were the mentioned benefits and negative impacts determined?
3. What are the benefits and negative impacts reported to have been experienced by participants and communities and how do they interrelate?
4. Are there differences in whether benefits and negative impacts are mentioned and how they are determined between typologies of citizen science, geographic regions, and water science fields?
3.2 Literature search

We sought to identify and review a substantial and comprehensive range of literature concerning citizen science applications to water. A literature search was conducted in early 2020 using Web of Science and search terms intended to pick up the various synonyms for citizen science and the various water-related applications (Table 1). The large number of initial “hits” (almost 14,000) was refined using the Web of Science selection and exclusion by categories feature. The still large total was further refined by excluding papers containing certain keywords aimed at filtering out fields such as marine sciences and terrestrial biodiversity studies. Many inapplicable studies passed through these filtering steps and only during the review could the applicability of a paper be determined. The total reviewed and incorporated papers from the Web of Science search was 433.

Manuscripts were included in the review if they contained elements of citizen science in the context of the water sciences. Where the data were collected for hydrological and disaster risk reduction studies, we included land use land cover and hazard mapping and measurements of soil parameters. We excluded studies focusing on fish, bird, and mammal biodiversity but included studies using macroinvertebrate monitoring for water quality assessment. Water projects labeled as “participatory” were only included where the stakeholder engagement involved contribution by stakeholders of water-related variables.

Additional manuscripts were added to the total through forward and backward snowball sampling of cited and citing literature, making particular use of the review papers that the Web of Science search revealed. Finally, manuscripts that were known to the authors from previous or concurrent research projects were included. In summary, a further 116 papers were reviewed giving an overall total of 549. The complete list of reviewed publications is provided in the Supporting information.

The total of 549 published studies is considered representative; however, we cannot claim that this literature review is exhaustive of all citizen science water projects for several reasons:

- There are likely to be many citizen science water projects, especially collegial and co-created typologies, operated by and for the benefit of communities that are unrepresented in the literature.
- There are likely to be numerous citizen science water projects established by NGOs that may be described in reports or on websites but are unrepresented in the literature.
- Many published water science studies make use of data collected by non-professionals, but this is not always explicitly stated within the manuscript.
- The many synonyms for citizen science and the various water-related applications mean some relevant peer-reviewed literature may have been overlooked.

### TABLE 1 Systematic literature review methodology – a summary of the literature search and exclusion criteria

| Search criteria | Papers |
|-----------------|--------|
| (Citizen science OR crowdsourcing OR observatory OR volunteer OR participatory OR (community based AND monitoring)) AND (water OR hydrology OR river OR stream OR watershed OR catchment OR hydrogeology OR groundwater OR meteorology OR rainfall OR flood OR flooding OR drought) | 13,946 |
| Required Web of Science categorizations*: water resources OR environmental sciences OR geosciences multidisciplinary OR environmental studies OR multidisciplinary studies | 3,277 |
| Excluded Web of Science categorizations*: engineering ocean OR public administration OR energy fuels OR computer science information systems OR plant sciences OR engineering chemical OR green sustainable science technology OR astronomy astrophysics OR business OR engineering electrical electronic OR business finance OR computer science interdisciplinary applications OR nuclear science technology OR chemistry inorganic nuclear OR radiology nuclear medicine medical imaging OR public environmental occupational health OR engineering petroleum OR architecture OR fisheries OR biophysics OR food science technology OR economics OR infectious diseases OR hospitality leisure sport tourism OR information science library science OR law OR materials science characterization testing OR mining mineral processing OR mineralogy OR telecommunications OR toxicology OR virology | 2,741 |
| NOT (marine OR coast OR coastal OR sea OR ocean OR estuary OR estuarine OR plant OR air OR birds) | 2,151 |
| Reviewed papers from Web of Science search deemed applicable for incorporation | 433 |
| Additional applicable incorporated papers | 116 |
| Total reviewed papers | 549 |

*Web of Science assigns papers to multiple categories.
Benefits and negative impacts were identified applying a grounded theory methodology to the literature review. Despite the above points, the body of literature reviewed was sufficient to reach saturation in terms of specific identified benefits and negative impacts.

3.3 | Categorization of publications

The country where each study site was located was recorded, along with the year of publication, citizen science typology, and water science field in order to present the geographic, chronological, and field distribution of citizen science applications to water (Sections 4.1 and 4.6). For comparison, publications were divided according to broad geographic/socioeconomic regions: Global North and Global South. This division was made because the literature showed that there often was a difference between how citizen science projects were established in wealthy and in lower-income regions, as well as differences in project aims and citizen scientist demographics. However, heterogeneities within regions as well as across and within “communities” mean care must be taken when applying such generalizations since citizen science projects are present in low-income areas of the Global North (e.g., Gérin-Lajoie et al., 2018; Masterson et al., 2019) and within affluent communities of the Global South (e.g., Graham & Taylor, 2018; Pérez-Belmont et al., 2019). Studies which had a global focus (typically review papers) or no geographic focus (typically advocating for greater use of citizen scientists in data collection) were categorized as “Global” and “General,” respectively.

Categories of how benefits and negative impacts were mentioned and determined were identified early in the systematic literature review into which the water science publications were subsequently classified:

1. No mention: there was no mention of participant or community benefits or negative impacts.
2. Potential: possible benefits and negative impacts of citizen science were stated, usually in the introduction or conclusions, citing seminal citizen science papers. Additionally, some papers offered case-specific potential benefits that were hoped would occur.
3. Actual: benefits and negative impacts were stated that had been:
   a. Inferred: outcomes were reported but not investigated.
   b. Observed: observations of outcomes were provided.
   c. Investigated: research of outcomes was conducted.
   d. Attributed: published case studies were referenced with inferred, observed or investigated benefits and/or negative impacts.

4 | RESULTS

4.1 | Geography, chronology, and water science fields

The geographical distribution of projects identified in the literature review (Figure 2) was similar to earlier reviews of citizen science applications to water (e.g., Buytaert et al., 2014; Njue et al., 2019; Theobald et al., 2015): North America dominates with 30% of studies, followed by Europe with 22%. Notably, the number of studies from Asia (15%), sub-Saharan Africa (11%), and Latin America and the Caribbean (10%) was greater than previously reported suggesting growth in citizen science water projects in the Global South. Figure 3 confirms that the Global South is no longer significantly behind the Global North in uptake of citizen science in the water sciences. Australasia and the Middle East and North Africa were represented in only 5% and 2% of studies, respectively.

According to Follett and Strezov (2015), citizen science publications flourished from under 10 per year before 2005 up to 250 per year by 2014. Within the water sciences there was a similarly rapid growth of published citizen science studies, from under 12 per year before 2011 up to 102 in 2019 (Figure 4). Since 2016 when the numbers truly proliferated, the proportion of studies from the Global South has consistently been around 30–40%.

In the Global North, water quality assessments dominated published citizen science water projects (Figure 5). There was a more even distribution of fields in the Global South and, when combined, hydrometeorological and water management projects comprised 50% of all studies. This may illustrate how Global North projects are often focused on education and raising awareness; water quality assessments perhaps lend themselves better to broad outreach and for
involving participants with motivations such as existing environmental concerns or desiring to spend more time in nature (Hamel et al., 2018; Rutten, Minkman, & van der Sanden, 2017). On the other hand, Global South projects focus more on improving livelihoods where a better quantitative understanding of water resources is required (Buytaert et al., 2014).

4.2 Overview—benefits and negative impacts

Twenty-four percent of all the papers reviewed had no mention of participant or community benefits while 70% had no mention of negative impacts (Figure 6). No mention of benefits or negative impacts may indicate a lack of awareness of the outcomes that could have occurred through citizen science; a situation this paper aims to address. Thirty-two percent of the reviewed papers presented only potential benefits of involvement in citizen science. Of the reviewed papers providing actual benefits experienced by participants and communities: 12% inferred benefits, 13% observed benefits, 16% investigated benefits, and 5% attributed benefits.

FIGURE 2 Locations and number (n) of published citizen science water projects

FIGURE 3 Proportions of published citizen science water projects from different regions. The numbers of studies sum to greater than the number of papers reviewed because multiple case studies from different regions in a single paper were counted independently.
The identified potential benefits are described in Section 4.3 while the actual benefits are described in Section 4.4 subdivided into inferred, observed, and investigated subsections. There is no subsection covering the manuscripts classified as having attributed benefits because those reported case studies are considered in the other actual benefits subsections. There are far fewer examples of negative impacts to draw from, therefore, potential and actual negative impacts are presented together in Section 4.5.

4.3 | Potential benefits of involvement in citizen science

The 32% of papers that presented only potential benefits of involvement in citizen science typically listed a few general benefits in the introduction or in the conclusions referencing key citizen science papers such as Bonney et al. (2009), Buytaert et al. (2014), and Conrad and Hilchey (2011). The listed potential benefits rarely received further discussion and there were no subsequent observations or investigations informing whether the benefits actually occurred.

Therefore, in addition to the systematic review of citizen science applications to water, it was necessary to simultaneously review key citizen science and participatory literature from a variety of fields to explore these commonly mentioned general potential benefits of citizen science. The review revealed that these potential benefits were more complex than may first appear and warrant further explanation. The benefits are often overlapping or not mutually exclusive and can be considered a sequence rather than discrete outcomes.

This section lists potential benefits that are commonly mentioned in citizen science applications to water. Descriptions rationalizing these benefits derive from multiple fields of literature though include examples from the water sciences where possible. The benefits are listed in the sequence that they typically occur:

**Public engagement**: This is self-evident in most citizen science projects and is generally advocated to be a necessity for raising awareness of environmental issues, democratizing science, and (re)building trust between science and society (Groffman et al., 2010).

**Raising awareness**: Participation in a citizen science project is likely to raise awareness of the issue being studied when engagement leads to learning (Brossard, Lewenstein, & Bonney, 2005). Raised awareness is known to correlate...
(via subsequent steps) with environmental stewardship (Jordan et al., 2011) and communities' preparedness for natural hazards (Papagiannaki, Diakakis, Kotroni, Lagouvardos, & Andreadakis, 2019). However, individuals who volunteer for a project are likely to be already aware of the issue, hence their interest. This is especially true if the individual belonged to a group that was targeted for participation precisely because it has an interest, such as a local conservation group in a river health monitoring project (Pocock, Chapman, Sheppard, & Roy, 2014; Trumbull, Bonney, Bascom, & Cabral, 2000).

Democraticization of science: Similar to and requiring public engagement and raising awareness, democratization of science stresses the opportunity for participation in the generation of scientific knowledge (Pollock & Whitelaw, 2005). Freitag and Pfeffer (2013) define it as “the breaking down of walls between scientific experts and the general public... to incorporate segments of the public existing outside ivory towers and government halls.”

Development of mutual trust, confidence, and respect between scientists, authorities, and the public: This is perhaps more important than ever if we are living in a “post-truth world” (Lubchenco, 2017). Many authors call for greater public engagement by scientists to develop trust, emphasizing a need for truly collaborative citizen science projects (Groffman et al., 2010; Wynne, 2006).

Knowledge gain: Through training, experiential learning, and feedback, citizen scientists may expand their knowledge of the issue central to the project (Bonney et al., 2009). In many papers this benefit was termed “education” or “increased understanding.” However, as with raising awareness, because interested groups are often targeted for participation, citizen scientists are commonly already knowledgeable about the issue (Trumbull et al., 2000).

Increased scientific literacy: Beyond gaining specific knowledge, scientific literacy is the appreciation of the aims and limitations of science and the use of scientific thinking for personal decision-making (Laugksch, 2000). Knowledge gain and increased scientific literacy represent an increase in human capital.

Social learning: Collaborative and generative learning in context that is particularly applicable for adaptive management (Jordan et al., 2016). Social learning builds human capital through knowledge gain and increased scientific literacy while also relying on and building social capital.

Incorporation of local, traditional, or indigenous knowledge: The value of such knowledge is increasingly appreciated for ecosystems and natural resource management (Wiseman & Bardsley, 2016) and risk reduction (Van Asselt & Renn, 2011), and there are calls for its greater utilization for monitoring networks before it is lost (Alessa et al., 2016). This is an example of utilizing and preserving a community’s cultural capital for the benefit of their natural capital. However, whereas the intellectual property of monitoring data is usually owned by program organizers, local knowledge is usually owned by the community, and its publication should be approved by knowledge holders (Gérin-Lajoie et al., 2018).

Increased social capital: Social capital can be divided into three categories: bonding—these are “horizontal” ties between people within the same social group; bridging—“vertical” ties between people in different social groups and that cross social divides, and linking—similar to bridging social capital though involves interactions across formal and institutionalized power and authority gradients (Claridge, 2013). It has been stated that social capital is both a requirement for the success of a citizen science project (Mullen & Allison, 1999) and a key outcome (Jordan et al., 2012; Shirk et al., 2012). Citizen science builds social capital through activities that engage volunteers, create agency connections,
strengthen existing institutions, develop leadership capacity, solve problems, and identify community and resource values that would otherwise be overlooked (Bliss et al., 2001; Whitelaw, Vaughan, Craig, & Atkinson, 2003). Many of the other benefits in this section are aspects of social capital or vice versa: existing or development of bonding social capital means that raised awareness and knowledge gain may spread beyond the citizen scientist to their social group, and; empowerment requires bridging social capital to unite communities and linking social capital to put communities and policymakers together.

Empowerment: In this context it means learning that enables citizens to gain scope for civic participation in policy-relevant debates and decision-making processes (Turrini, Dörler, Richter, Heigl, & Bonn, 2018). Empowerment, therefore, requires many of the other described benefits: increased human capital to make better informed decisions and increased linking social capital that would provide a voice for communities with policymakers. Empowerment may represent increased political capital, which reflects access to people and organizations in positions of power.

Behavior change: Resulting from increased knowledge and awareness, this change could be more responsible environmental behavior, or stewardship, especially toward sustainable use of natural resources (Jordan et al., 2011; Ryan, Kaplan, & Grese, 2001). Alternatively, behavior change may mean increased political participation, or empowerment (Overdevest & Mayer, 2007), or increased social capital through encouraging participation with additional groups (Jones et al., 2006).

Improved environment: An increase in natural capital can result from behavior change with consequent better environmental stewardship (Jordan et al., 2011), and empowerment through collection of pertinent data leading to, for example: (a) identification and prosecution of polluters (Kinchy, Jalbert, & Lyons, 2014), and (b) tougher environmental policies, laws, and regulations (Voinov & Bousquet, 2010).

Decreased risk or improved health: This requires many of the previous benefits to first be achieved, such as raised awareness, knowledge gain, increased scientific literacy, and behavior change. Decreased risk is a common goal of Global South citizen science, particularly community-based early warning systems (EWS) for disasters (Marchezini et al., 2018). However, decreased risk as a potential benefit was also stated in Global North studies, such as social media harvesting projects that utilize real-time data to identify emergency services access routes (Smith et al., 2017) and evacuation or aid supply routes (Cervone et al., 2016). Being passive citizen science, these latter examples would not require realization of the previous potential benefits.

Improved livelihoods: This is a common goal of citizen science in low-income regions (Rutten et al., 2017) and similarly requires many of the previously stated benefits, or more simply, an increase in community capitals. Some authors gave case-specific potential livelihood benefits for communities at their study sites, which would hopefully occur as the citizen science projects progressed. For example: improved irrigation management and crop selection through community-led monitoring and interpretation of hydrometeorological variables in Nepal (Regmi et al., 2019) and Ghana (Nyadzi et al., 2018).

Motivational benefits: Satisfying a motivation for participation can be considered a personal benefit. Motivations are frequently categorized as egotism (increasing one's own welfare), collectivism (increasing welfare of one's group), altruism (increasing welfare of others), and principlism (upholding one's moral principles) (Batson, Ahmad, & Tsang, 2002; Rotman et al., 2012). Motivational benefits include: financial and non-monetary incentives, career progression, social recognition, enjoyment, pleasure in being close to nature, a sense of “giving something back,” and being able to contribute to science (Estellés-Arolas & González-Ladrón-De-Guevara, 2012; Hobbs & White, 2012). Some of these can be considered representative of the benefits listed previously, for example the motivations of meeting likeminded people and working with scientists (Assumpção et al., 2019; Storey, Wright-Stow, Kin, Davies-Colley, & Stott, 2016) represent increased social capital. Other motivations for participating in citizen science are more difficult to place in the capitals framework, such as enjoyment, pleasure in being close to nature, and a sense of giving something back, though these may contribute to human capital by improving mental and physical health. Discussions in the literature generally proclaim the importance of intrinsic motivation, people doing something because they enjoy it, find some kind of value in it or it is the socially acceptable thing to do, over extrinsic motivation (e.g., Buytaert et al., 2014; Chan, Anderson, Chapman, Jespersen, & Olmsted, 2017). Extrinsic motivation—external incentives such as monetary payments—can lead to “crowding out” of intrinsic motivations (Frey, 1997). Evidence indicates the displacement of intrinsic motivation is very difficult to reverse should the external incentives be removed (Gneezy & Rustichini, 2000). However, this may be less applicable when the external incentive is a small compensatory amount, clearly less than the time and effort would otherwise demand, because in such a case the participant must retain intrinsic motivations to justify their participation (Kosoy, Martinez-Tuna, Muradian, & Martinez-Alier, 2007). An extrinsic motivation successfully utilized to drive
participation in virtual (online) citizen science is when points are offered for completing a task or through gamification (e.g., Zooniverse, 2019).

### 4.4 Actual benefits of involvement in citizen science

The following subsections list actual benefits for participants and communities that were derived from water sciences literature. The case studies are subdivided according to whether benefits were inferred, observed, or investigated.

#### 4.4.1 Inferred benefits

Twelve percent of the reviewed papers had inferred benefits of involvement in citizen science. The following examples are provided including how such inferences were made.

Public engagement fostering a greater appreciation of flood hydrology and modeling was inferred from high media and public interest by Le Coz et al. (2016) for a project in New Zealand using volunteers’ photos for hydrodynamic model validation to build flood hazard maps.

Educational benefits contributing to human capital, such as knowledge gain, increased scientific literacy, and social learning, were commonly inferred when a project involved large numbers of participants and/or training. Cifelli et al. (2005) reported that involvement in the Community Collaborative Rain, Hail, and Snow Network, with over 20,000 participants across North America, facilitated acquisition of basic skills in scientific data collection and research methodology during initial training plus through receiving emails and newsletters on data use. Education following training was similarly inferred by Fehri, Khalifi, and Vanclrooster (2020) for a rainfall monitoring project in Tunisia, particularly regarding IT education of older participants. A 7-year water quality monitoring program in Oregon, USA, was reported by Edwards, Shaloum, and Bedell (2018) to have educated, through authentic scientific inquiry, over 1,800 students encouraging environmental stewardship and interest in science-technology-engineering-maths (STEM) fields. Abbott et al. (2018) stated that 18 years of weekly water quality monitoring for the Ecoflux program in France had personal impacts on awareness and mentality of thousands of students and volunteers who had participated. Nicholson, Ryan, and Hodgkins (2002) stated that the educational outcomes were “evident” because the Waterwatch program had facilitated over 9,000 students to monitor more than 2,000 sites in Australia. Collegial and co-created projects addressing citizens’ environmental concerns often inferred data provision that can lead to improved understanding as a benefit. Dawson, Hutchins, Bachiller-Jareno, and Loiselle (2019) presented such a project monitoring groundwater quality beneath community gardens in London, UK, initiated in response to concerns about the effect of contaminants on organic produce, which showed that concerns about external sources of pollution were unfounded.

Papers reporting disaster risk reduction projects often inferred decreased risk through raised awareness of vulnerabilities and impacts when an EWS had been established or when vulnerability maps were collaboratively created. Examples include (all from Nepal) river stage monitoring for a community-based flood EWS (Gautam & Phaiju, 2013; Gladfelter, 2018), rainfall monitoring for a landslide EWS (Malakar, 2014), and participatory vulnerability mapping (Maharjan, Maharjan, Tiwari, & Sen, 2017).

#### 4.4.2 Observed benefits

Thirteen percent of the reviewed papers had observed benefits of involvement in citizen science. The evidence was observed by the authors or reported anecdotally by participants.

Democratization of science was reported in the United Kingdom where restructured participatory modeling brought together scientists and the public in a way that enabled coproduction of knowledge through “environmental competency groups” or “community modeling.” Beyond only contributing local knowledge, the public controlled the flood risk modeling with professional scientists acting as facilitators (Landsstrom et al., 2011; Lane et al., 2011). Community meetings revealed enhancement of the capacity of the local public to participate in flood risk and other environmental management decision-making (Landsstrom, Becker, Odoni, & Whatmore, 2019).

Many studies observed combinations of benefits, such as raised awareness, increased scientific literacy and social capital, and consequent behavior change. During a water quality monitoring project in Mexico, Pérez-Belmont
et al. (2019) noted citizen scientists’ opinions on involvement, including: “thanks to the knowledge I now have, I can influence my family and friends to become aware of the implications of every individual decision we make in terms of water scarcity and water quality...” Other participants mentioned a greater appreciation of the need to have reliable information on freshwater systems and realization that most people were ignorant of environment and water issues. Some volunteers continued to participate in other monitoring programs and others began supporting agroecological farming in the area by buying fair trade products. Another example of increased human capital leading to behavior change was observed by Kongo, Kosgei, Jewitt, and Lorentz (2010); villagers involved in a catchment monitoring network in South Africa began using concrete blocks in pit latrines and reinforced house foundations after recording groundwater level near to the surface and linking that to latrine contamination and house collapse.

According to a researcher’s journal, Inuit youth who attended camps as part of the IMALIRUJJIT environmental monitoring project in Nunavik, Canada, “were initially unwilling to participate in science activities and at the end they were constantly pestering me to help with my own sampling.” Researchers also observed that the project’s river-based activities allowed traditional knowledge to be passed intergenerationally and between indigenous communities demonstrating increased human, social, and cultural capital. Upon return to their communities, Inuit elders went on local radio to inform people of the relevance of environmental protection of their river and researchers were invited to give presentations to further raise awareness (Gérin-Lajoie et al., 2018). Participation in water research in a rural Andean watershed in Colombia, in particular through co-led workshops, was observed to have enabled sharing of experience and best practices between community members concerning riparian vegetation management, water re-use, filtration systems to achieve potable water, and septic system maintenance (Garcia & Brown, 2009). Thus, the building of human and social capital contributed toward behavior change to the benefit of natural capital.

Examples of empowerment presented within water resource monitoring case studies from South Africa by Graham and Taylor (2018) included communities pressurizing authorities to repair leaking water pipes and sewer lines. They stated that the most significant outcome of the programs was the increased levels of trust, mutual recognition, and working together on common problems which emerged between citizen science teams and municipal authorities indicating increased human, social, and political capital. Deutsch, Busby, Orprecio, Bago-Labis, and Cequifía (2005) described a river flow, water quality, and sediment discharge monitoring project in the Philippines, based on local people's concerns elicited during interviews: waterborne pathogens and pesticides causing illness to livestock, and soil erosion with subsequent sedimentation of streams and irrigation canals. Evidence of increased social and political capital and consequent empowerment included the core group of observers forming an NGO which later presented data to the local government. Consequently, citizen science water monitoring was incorporated into the municipality’s Natural Resource Management Plan and the NGO are consulted during environmental and development policymaking. Various examples exist in India (Jadeja et al., 2018) and Ethiopia (Walker, Haile, et al., 2019) of citizen scientists trained in monitoring groundwater levels and rainfall who became recognized in their communities as water experts and were empowered to advise on irrigation, contamination, and well maintenance building human and social capital. Baalbaki et al. (2019) presented an empowering groundwater quality monitoring project in Lebanon with villagers trained to utilize a mobile laboratory. A local water committee was formed that continued monitoring beyond the project’s lifespan and implemented remedial measures such as replacing contaminated infrastructure and utilizing disinfection treatment. Trajber et al. (2019) described a project in Brazil where youth conducted activities such as watershed risk mapping and rainfall monitoring. Youth ran workshops to educate farmers on environmental issues and argued for community members not to vote for certain political candidates due to their environmental stance, which led to invitation to present their work at a public hearing.

Multiple manuscripts described the infamous situation of Flint, USA, where concerned citizens teamed up with researchers to collect water quality data leading to behavior change (people stopped using lead-contaminated tap water), policy change (the city reverted to its former water source), and ultimately improved health (Gaber, 2019; Krings, Kornberg, & Lane, 2019; Pieper et al., 2018). There are numerous examples of how identification of pollution incidents through citizen science water quality monitoring led to prosecution of polluters, such as through the Anglers’ Riverfly Monitoring Initiative in the United Kingdom (DiFiore & Fitch, 2016) and the Izaak Walton League of America (IWLA) (Middleton, 2001), both founded by anglers to combat water pollution and other environmental abuses. Since its foundation in 1922, IWLA has played a pivotal role in the passage of almost every major U.S. federal environmental law.

The many case studies of successful community-based EWS are examples of decreased risk resulting from raised awareness, increased hazard knowledge, and improved communication, that is, increased human and social capital, leading to behavior change. Evidence of decreased risk was observed by Oven et al. (2017) in community-based disaster
risk reduction projects in Nepal. The authors gave successful examples of flood EWS when pre-identified river danger levels were reached and communication downstream notified local police, who used sirens and megaphones to initiate evacuation procedures leading to no loss of life or livestock. Improved health was observed by Tosi Robinson et al. (2018) in rural mountainous Nepal where field laboratories were established with trained citizen scientists to monitor microbial water quality and sanitary status of springfed piped water schemes. Assessment indicated an improvement in water quality with the share of taps meeting international guidelines increasing from 7 to 50% and decreased levels of illness.

Livelihood improvement is difficult to measure (Reed, 2008), therefore was most commonly reported with observational evidence. Bannatyne, Rowntree, van der Waal, and Nyamela (2017) observed that paid participants in a river sediment monitoring network in South Africa had benefitted from the additional financial capital by enabling extension of a catering business, house improvements, and enrolment on a computer literacy course. WaterAid (2015) observed how improved small-scale irrigation water management in Burkina Faso through community-based rainfall and groundwater level monitoring that increased human and social capital had reduced conflict and improved livelihoods. The data aided decision-making on what and when to plant, whether to focus on livestock, or resort to alternative livelihoods and halt certain water-using activities (e.g., brickmaking) during drought years to maintain the water for domestic use. Flores-Díaz, Quevedo Chacón, Páez Bistrain, Ramírez, and Larrazábal (2018) noted 5 of the 25 citizen scientists involved in a water quality monitoring project in Mexico went on to begin internships to gain certification to become citizen scientist trainers. Rather than improving livelihood, Thomas, Richardson, Durbridge, Fitzpatrick, and Seaman (2016) reported how citizen science prevented deleterious impact on livelihood. Drought in the Murray-Darling Basin, Australia, lowered lake levels creating sulphuric acid sulphate soils raising fears for livelihoods, public health, and loss of recreational amenity. Prompt identification and reporting by citizen scientists initiated emergency remediation using aircraft to broadcast neutralizing calcium carbonate.

### 4.4.3 Investigated benefits

Sixteen percent of the reviewed papers investigated benefits of involvement in citizen science. Investigations variously comprised questionnaire surveys with Likert scale questions to quantitatively assess benefits or coding of responses during semi-structured interviews or focus group discussions for qualitative analysis. The examples below give further information on the generally multiple benefits that were actually realized and describe how they were investigated.

Masterson et al. (2019) described three projects co-created by university students, high-school students, and community residents to address flooding challenges in socially vulnerable neighborhoods of Houston, USA. Post-project surveys showed an increase in trust due to the co-production process and the appreciation of local knowledge; residents had indicated they were initially hesitant to collaborate due to past experiences with researchers who collected data and did not return. Thornton and Leahy (2012) discovered through pre- and post-program interviews of community members and students involved in groundwater quality monitoring in New England, USA, that citizen science increased interpersonal trust and familiarity that generated trust in data quality. Studies investigating knowledge gain and increased scientific literacy included Walkinshaw, Hecht, Patel, and Podrabsky (2019) who implemented a water use investigation at high-schools across the United States. Follow-up surveys indicated development of research and teamwork skills and garnered suggestions for improving and furthering the project. Krček, Palán, Palzourková, and Stuchlík (2019) reported on a water and precipitation quality monitoring project running for over 20 years in a mountain catchment affected by acidification and logging in the Czech Republic. After each annual two-week field program, specific tests were set evaluating participants’ acquisition of new knowledge and skills. Ballard, Dixon, and Harris (2017) listed multiple ways that youth educationally benefitted from involvement in two environmental monitoring programs in California, USA. In-depth observation and qualitative analysis of pre- and post-program interviews showed that participants, among other things: learned the norms of science communication (writing, oral and poster presentations, answering questions, and obtaining feedback); transferred public speaking practice to other settings; adapted and personalized methods to ensure data quality; identified their own areas of expertise; developed leadership skills; and learned the complexity of social–ecological systems.

In Norway, Damman, Helness, Grindvoll, and Sun (2019) interviewed citizen scientists and learnt that participation increased their knowledge about water quality and ecosystem services. Participants appreciated that the project was an opportunity to get to know the river, relive old memories, and socialize with others. This benefit of increased social capital in addition to increased human capital was similarly reported by Grudens-Schuck and Sirajuddin (2019) who
analyzed over 600 responses to online surveys sent to citizen scientists involved in the Iowater program monitoring water quality in Iowa, USA. Volunteers reported greater understanding and interest in water quality and policy, increased networking with members of other water quality groups, family, friends, and colleagues, as well as additional participation in watershed groups and clean-up days. Overdevest, Orr, and Stepenuck (2004) evaluated stream-health monitoring programs in Wisconsin, USA. They questioned experienced (greater than one season of involvement) and, for control, inexperienced (recent members who were yet to conduct monitoring) participants. The comparison found that participation did not significantly increase factual learning; rather, new volunteers and experienced volunteers were equally knowledgeable about stream-related topics. However, participation had significantly increased political participation, personal networks, and feelings of community connectedness among volunteers. Similarly, Selman, Carter, Lawrence, and Morgan (2010) found for an arts-based citizen science project at a river in the United Kingdom that older participants, despite enjoying the project, learned little that was new; nevertheless they were a crucial source of information for younger participants.

Jones et al. (2006) specifically researched social capital using questionnaires to investigate participants’ experience with Ontario’s Benthos Biomonitoring Network, Canada. Responses revealed evidence of increased social capital that the authors interpreted would lead to an increase in environmental problem-solving ability. Brasier, Jalbert, Kinchy, Brantley, and Unroe (2017) interviewed participants during workshops held by The Shale Network, a group of stakeholders collating, publishing, and conducting research on water quality data collected in northeastern U.S. experiencing shale gas extraction from hydraulic fracturing. Participants frequently indicated they valued the opportunity to network with others in the wider water quality monitoring community and to connect with university and agency research. Endfield and Morris (2012) interviewed participants of a collegial weather monitoring organization in the United Kingdom (Climatologists Observers Link [COL]) revealing that the main motivation was the increase in social capital. Participants praised how COL brought all types of people together, how they became involved in educational events with the public and schoolchildren, and how they contributed to local newspapers and websites gaining community recognition.

Bremer, Haque, Aziz, and Kvamme (2019) assessed the impact of citizen science on communities and on climate adaptation in Bangladesh. Community workshops were an opportunity for social learning, eliciting local and traditional knowledge, and co-selection of indicator variables to be monitored such as weather, river stage, and tree budding timing (Bremer et al., 2017). Interviews following a year of monitoring revealed high increases in citizen scientists’ human capital relative to understanding of local rainfall; learning that they applied in adaptive practices and local leadership. Additionally, there were high increases in social capital and moderate increases in political capital with some evidence of the citizen science being used to support public adaptation decision-making. In New Zealand, Storey et al. (2016) conducted focus group interviews with nine community groups involved in water quality monitoring. Increased social capital was evidenced by interactions with the local council who participants felt had a genuine interest in their results, and mutual support within the group, expressed as friendship and sense of shared purpose. Feedback suggested participation increased understanding of the scientific process, knowledge of and attentiveness to freshwater issues, and ecological awareness of local waters. Volunteers were strongly motivated by interaction with scientists and identified “learning” as one of the main benefits as well as a desire to “make a difference.”

Investigated examples of empowerment generally resulting from increased human and political capital include Wilson, Mutter, Inkster, and Satterfield (2018) who presented a water quality monitoring program led by indigenous communities in the Yukon Basin, Canada, and United States. During interviews, volunteers reported they trusted their own data more than data from the government and mining companies, who they could then hold to account. Ramirez-Andreotta, Brusseau, Artiola, Maier, and Gandolfi (2015) detailed the Gardenroots project in Arizona, USA, where sampling of irrigation water revealed that the public water supply exceeded the arsenic drinking water standard. Participants identified and notified households connected to the public water system and reported their test results leading to Notices of Violation. The project built trust prompting further community-academic partnership research projects. The SMART program in Maine, USA, deliberately engaged female and racial minority high-school students in water quality monitoring focusing on creating active and relevant educational experiences that built confidence, and developed knowledge and skills for solving problems in local communities (Musavi, Friess, James, & Isherwood, 2018). Pre- and post-program surveys showed participation increased interest in pursuing a STEM career with more than 41% enrolled in STEM university degrees.

Decreased risk was investigated by Hassan and Shah-Jr (2008) for a community-based EWS in Bangladesh that used upstream staff gauges and a system of flags to alert for floods. Household interviews quantified impacts of more rapidly disseminated early warnings: 92% of households used the warnings to save livestock, 73% relocated food storage, and
70% shifted themselves to safer locations. Chen and Wu (2014) reported that in Taiwan the progressive establishment since 2000 of community-based EWS built human and social capital concerning hazards and evacuation procedures that reduced average debris flow casualties from 7.00 per event to 1.95.

Behavior change resulting from knowledge gain and increased scientific literacy was reported by Egerer, Lin, and Philpott (2018) who conducted pre- and post-study surveys of urban gardeners monitoring rainfall and water use in California, USA. Results indicated a better understanding of plant water needs, soil management, and water conservation that led to behavior change with environmental and financial benefits (e.g., increased natural and financial capital). Kniveton et al. (2015) developed weather and climate forecasts through participatory downscaling and the integration of local and scientific knowledge in drought-prone Kenya and flood-prone Senegal. Increased human capital was evidenced by participating farmers who reported basing cropping decisions on the forecasts, which increased yields, and actions to save their lives and livelihood assets in the case of floods. Church, Payne, Peel, and Prokopy (2019) emailed questionnaires to participants monitoring water quality for the Wabash Sampling Blitz, USA. Responses indicated personal motivational benefits (e.g., helping the environment, being in nature) and behavior change (e.g., installed a rain barrel, bought eco-friendly cleaning products) demonstrating that citizen science can engage the public to make environmentally friendly decisions. In Australia, water use diaries sensitized householders to their water use in terms of volumes and activities (Harriden, 2013). Interviews revealed enduring behavior change for 76% of households such as changed bathing and water using appliance practices, and wastewater reuse.

Many studies specifically investigated motivational benefits and the satisfaction of many of these benefits contributed to increased human and social capital. A survey of volunteers from eight water quality monitoring organizations in the United States by Alender (2016) revealed the top motivation was being able to contribute to scientific research and conservation; numerous other examples state this motivation as a key benefit (e.g., DiFiore & Fitch, 2016; Shupe, 2017). Questionnaires by Jakositz et al. (2020) in a tap water quality monitoring program in New Hampshire, USA, revealed most motivations were intrinsic and egotistic, with an interest in the topic and health concerns being most prevalent. Surveys of five water quality monitoring projects in the Netherlands by Brouwer and Hessels (2019) showed that while older participants were primarily motivated by an interest in the topic, younger participants were more strongly motivated by the fun element. Notably, the surveys revealed that participants with the lowest level of education perceived citizen science more often than others as a learning opportunity. Jollymore, Haines, Satterfield, and Johnson (2017) established citizen science campaigns to assess watershed impacts on water quality in Vancouver, Canada. The resulting data and participation were analyzed to understand the impacts of participants’ motivations and contextual knowledge on data outcomes. A key benefit for the interested groups who were targeted was the autonomy of sampling timing and location according to their own concerns. In Greece and Romania, around 400 participants recruited from local interest groups measured water depth and velocity, and land cover using games on smartphones (Assumpção et al., 2019). At the end of the program, participants completed a questionnaire revealing that 83–95% regarded it as an interesting to excellent experience. The most enjoyable aspects were the experience of being out on boats among pleasant scenery and spending time with nice people. Questionnaires and focus group discussions following a tap water sampling program in the Netherlands, by Brouwer, van der Wielen, Schriks, Claassen, and Frijns (2018) concluded a majority of citizen scientists felt their participation was both fun (88%) and educational (94%). Many participants desired more involvement, either in additional testing or in research design; thought to be due to the lengthy registration process that self-selected the most committed volunteers. Incidentally, Palermo, Laut, Nov, Cappa, and Porfiri (2017) for a water quality monitoring project in Washington, USA, found that participation in citizen science was a motivation for physical exercise.

### 4.5 Negative impacts of involvement in citizen science

It was most common—in 70% of the reviewed water science papers—for there to be no mention of negative impacts. Studies that investigated benefits commonly did not report negative impacts. One would think the citizen scientists had the opportunity to provide negative feedback during the interviews or questionnaires, even if such information was not specifically requested. Therefore, it was uncertain whether negative impacts were deemed irrelevant for the paper, were not elicited, or whether the projects were a purely positive experience. Due to the limited number of publications mentioning negative impacts, this section groups the identified potential (12% of reviewed papers), inferred (1%), observed (6%), investigated (8%), and attributed (3%) negative impacts. To the best of our knowledge, the possible negative impacts of involvement in citizen science have not previously been listed and described in the literature. Therefore, the
negative impacts are provided in this section as per the list of potential benefits in Section 4.3. In addition to providing examples from the reviewed water sciences literature, this section draws on citizen science publications from other fields that reported negative impacts that are applicable to the water sciences. To enhance readability of this section, the negative impacts are grouped into three general categories: livelihood impacts, disempowerment, and demotivational impacts.

4.5.1  |  Livelihood impacts

Over-burdening the public: While public engagement is generally claimed to be a benefit, it could be a negative impact, particularly in low-income areas. Citizen science participation, especially in the form of regular monitoring, may add an additional burden to people whose daily lives are a struggle (Chan et al., 2017; Resnik, Elliott, & Miller, 2015). There is the ethical question of whether the participants are simply providing cheap or unpaid labor (Goodwin, 1998; Lave, 2012). A poignant example was provided by Poolman and Van de Giesen (2006) of a farmer leaving a training workshop in Ghana giving the reason: “We have already done this before. We have already spent time on such a workshop and haven’t seen any changes. Yet now you ask me to spend my time again? Instead of wasting my time, I am going to work on my land.”

Health and safety issues: Several studies warned of the potential risk to citizen scientists when monitoring river stage during floods, noting that safety considerations should be incorporated into training (Bannatyne et al., 2017; Starkey et al., 2017; Walker, Haile, et al., 2019). Au et al. (2000) noted for a water quality monitoring project in Canada working with schoolchildren, that not only health and safety training, but also adult supervision was required. Le Coz et al. (2016) analyzed videos of floods contributed by the public in Argentina, France, and New Zealand for discharge estimation and flood mapping. They were refused permission to distribute flyers and put up posters by local authorities in southeast France, who expressed concerns that the call could encourage the public to put themselves into unsafe positions during floods to record videos. These fears are not unfounded as Gladfelter (2018) reported actual injury and death from drowning of river gauge observers from community-based flood EWS in Nepal.

Decreased self-reliance: Where project duration is determined by funding, when that funding stops, support for the project generally stops, which could cause a decline in human and social capital. As noted by Malakar (2014) of a rainfall monitoring for landslide forecasting project in Nepal, withdrawal of scientific support at the end of funding could hinder communities’ empowerment and self-reliance to make their own decisions. Pauses in funding, due to NGOs awaiting confirmation of project extensions, that interrupted monitoring of groundwater level and use led to abandonment of sustainable groundwater management practices in India (Reddy, Reddy, & Rout, 2014). Allen (2006) reported on disaster preparedness in the Philippines, noting that where local knowledge, institutions, and understandings are neglected, it undermines community self-reliance and damages existing community institutions.

Increased sensitization to hazard: A potential negative impact of raising awareness is where a community becomes overly preoccupied with a hazard. Kattelmann (2003) reported that stakeholder engagement during works to reduce the likelihood of a glacial lake outburst flood in Nepal led to downstream residents believing that a catastrophe was imminent.

4.5.2  |  Disempowerment

Exclusion: Disempowerment can occur when existing power structures are reinforced through exclusion of certain groups from the participatory process (Reed, 2008). Social and political capital could increase for the included already privileged classes while other groups remain disempowered (Buytaert et al., 2014). Participatory processes can be biased if the representation and influence of competing groups are unbalanced, leading to undue emphasis on issues pertinent only to certain groups (Gomani et al., 2010). Surveys of Global North citizen scientists generally reveal a predominance of white, middle-class, well-educated, wealthy, middle-aged males (Haklay, 2013; Reges et al., 2016). Concerning water quality projects in the Netherlands, Brouwer and Hessels (2019) recommended sending personal invitations to a random sample of the population to help attain a diverse sample of participants, as opposed to the scattergun approach of advertising on mass media. However, they also noted that maintaining active participation was problematic with younger citizen scientists having the highest dropout rate. A lack of diversity among participants is recognized in many studies as potentially continuing marginalization of certain groups in society where citizen science should be an
opportunity for bringing people together (Chase & Levine, 2018). Despite the success of hydrometeorological monitoring for flow restoration of salmon rivers in California, USA, Woelfle-Erskine (2017) lamented the lack of engagement with indigenous tribes, farmworkers and other marginalized residents that could have deepened environmental justice commitments. Marchezini et al. (2018) provided examples of non-inclusive participatory EWS such as non-consideration of age-related capacity, exclusion of migrants and refugees, and announcements in streets or mosques where women were not allowed. Women are commonly an underrepresented group in the participatory process (Bremer et al., 2017). Examples given by Gaventa and Barrett (2010) from Brazil and India showed that women often have only tokenistic representation, that is, coerced inclusion to meet procedural requirements (to “tick a box”), that resulted more in humiliation than empowerment. Paradoxically, a project in India with the aim of empowering women through training to monitor groundwater level and quality had the inadvertent impact of leading to some women being ostracized by their communities who were suspicious of their activities (Frommen, Groeschke, Ambrus, & Schneider, 2018). Tokenism leading to exclusion of all local stakeholders was discussed by Voinov and Bousquet (2010), who noted how disempowerment can occur when stakeholder engagement, participation or collaboration are incorporated into a proposal for the purpose of obtaining funding and subsequent engagement and consideration are nominal. Exclusion due to privileging of particular knowledge systems was reported by Himley (2014) concerning water quality monitoring by communities affected by mining in Peru. Investigations revealed that privileging expert frameworks for water quality assessment prevented communities from holding mining firms accountable for observed impacts on water resources.

Technology: Numerous studies reported that exclusion can unintentionally occur by the use of technology in citizen science if certain groups (e.g., the aged, the non-technologically savvy, the poor) cannot use it, do not use it, or cannot afford it, such as if smartphones, certain social media, or access to the internet are a requirement (Baudoin, Henly-Shepard, Fernando, Sitati, & Zommers, 2016; Roy et al., 2012; Sula, 2016). As noted by Wild, Dempsey, and Broadhead (2019), there is a risk that “the only voices to be heard will be those that can afford the skills, time, technology and capacity to make their voices heard.” Jalbert and Kinchy (2016) found when comparing automatic sensors to volunteers for water quality monitoring in the United States, that “the increased use of automated devices tends to reinforce hierarchies of expertise and constrains the agendas of non-professionals who participate in monitoring projects.”

Decentralizing monitoring and passing burden from authorities to public: While community-based monitoring is promoted as a solution to declining formal hydroclimate monitoring networks (Njue et al., 2019; Walker, Forsythe, Parkin, & Gowing, 2016), this can lead to authorities relinquishing responsibility for purposes of cost-saving and passing the burden to the public (Chan et al., 2017). Governments can use successful citizen science examples to celebrate democratization of science thus legitimizing their own cost-savings (Kimura, 2016). Sharpe, Savan, and Amott (2000) discussed citizen science monitoring in Ontario, Canada, which was established when the government abandoned much of its monitoring network. Critics feared that the groups providing substitute labor were legitimizing the dismantling of environmental monitoring and enforcement programs and could be used as an excuse for further government reductions in other departments.

Decentralizing risk and passing burden from authorities to public: Beyond passing on the onus for monitoring is when a government also relinquishes responsibility for caring for its citizens to the citizens themselves. Discussing community-based flood EWS in Nepal, Gladfelter (2018) suggested that well-meaning interventions to increase communities’ resilience, can, in the name of empowerment, unintentionally naturalize vulnerability, individualize responsibility for self-security, and provide an excuse for government neglect of marginalized citizens.

Conflict creation: Conflicts can result from certain groups disbelieving citizen science data if it is against their interests. Baalbaki et al. (2019) reported that the municipality and owner of a well in Lebanon would not accept citizen science data showing contaminated groundwater so that they would not have to carry out remedial measures. Jamieson, Elson, Carruthers, and Ordens (2020) gave examples of conflicts from a groundwater level monitoring project in Australia established by the Queensland Government to monitor impacts of coal seam gas extraction. Some landholders with monitoring boreholes distrusted government organizers, others refused to share data, and some educational workshops were disrupted by protesters. Zemadim, McCartney, Langan, and Sharma (2014) described tensions in a community in Ethiopia created by provision of financial incentives only to the people involved in hydrometeorology.

Data privacy: Citizen science projects increasingly involve the use of smartphones, which introduces the potential issue of data privacy if personal information can be gleaned from the collected data (Mooney et al., 2017; Zheng et al., 2018). Despite anonymization, Kotovirta, Toivanen, Järvinen, Lindholm, and Kallio (2014) suggested it may be possible to identify participants who monitored algal blooms in lakes in Finland and consequently to identify their
locations and habits. Discussing active and passive sensing of weather information, Niforatos, Vourvopoulos, and Langheinrich (2017) noted that movement patterns could reveal not only the user’s identity but a range of sensitive information (e.g., health, political views, sexual preferences).

### 4.5.3 Demotivational impacts

**Time consuming or boring, and difficulty of tasks:** These issues are often mentioned from the point of view of being potentially demotivational for participants, therefore, they may reduce their participation or stop altogether (Canfield, Brown, Bachmann, & Hoyer, 2002; Farnham et al., 2017). Preventing a project from becoming boring is particularly important to maintain interest of underrepresented youth (Gérin-Lajoie et al., 2018). It was noted in many studies that lengthy and overly detailed instructions on how to conduct the citizen science is off-putting for participants (e.g., regarding water quality sampling in Canada by Forrest, Holman, Murphy, & Vermaire, 2019). Burgos, Páez, Carmona, and Rivas (2013) questioned participants on the difficulty of 17 aspects of a citizen science water quality monitoring program in Mexico with data administration tasks proving to be more difficult than data collection or interpretation. Excessive complexity was commonly noted by organizers of participatory modeling projects to be demotivational to participants and limited the transfer of such models from research to practice (Barthel, Seidl, Nickel, & Buttner, 2016; Johnson, 2009).

**Importance of data matching goals of citizens:** When citizens have genuine environmental concerns, their motivation will be to collect data to address these concerns. However, Nerbonne and Nelson (2004) found from a survey of volunteer macroinvertebrate monitoring groups across the United States that the majority of groups relied on support from state and regional programs that were interested in raising awareness, rather than bringing about structural or legislative change (the aim of participants). Furthermore, Jollymore et al. (2017) wrote that the model of “data as payment,” that is, where scientific analysis of data collected by the public contributes to engagement and understanding, is unethical if the data are not meaningful or useful. Ramsey (2009) trialed participatory modeling for collaborative water management in Idaho, USA. However, as different stakeholders had very different descriptions of the problem and very different goals, public meetings ended without any sense of a shared strategy. Such mismatch of goals between citizen scientists and project organizers is particularly applicable to academia where writing papers and winning further grants may be prioritized; goals unlikely to be shared by the public (Groom, Weatherdon, & Geijzendorffer, 2017; Resnik & Kennedy, 2010).

**Disappointment when no impact:** Munnik et al. (2011) presented several South African case studies where interviews of participants revealed the most common disappointment was a lack of impact; in most cases because there was no improvement to water quality. Sometimes this was due to differing aims of those involved or a lack of information flow meaning impacts were unknown. Brasier et al. (2017) noted from interviews of participants during workshops held by The Shale Network that some water quality monitoring groups became frustrated because there was no obvious use for their data. One participant stated, “why collect data when it’s not going anywhere?” Similarly, in a water quality monitoring data in fracking areas of northeastern USA, Kinchy (2017) noted the difficulty of convincing volunteers that their work had meaning when they were collecting “baseline” data, which was essential to future efforts to hold polluters accountable. Regarding Alabama Water Watch in the United States, Deutsch and Ruiz-Córdova (2015) wrote of disillusionment and volunteer fatigue: “The process of stopping pollution, restoring degraded environments, and improving water policy is often long and arduous. Some volunteers stopped monitoring after they either won or lost their short-term environmental goals. Others discontinued after years of monitoring because they became disillusioned with the difficulty of fighting government bureaucracy and corporate resistance.” Several case studies noted that citizen scientists involved in long-running monitoring lose motivation when there is no change in the measurements and may not understand why they need to continue (Damman et al., 2019; Frommen et al., 2018).

**Erosion of confidence, trust and social capital:** Volunteers on a groundwater level monitoring program in Alberta, Canada reported in email questionnaires feeling unimportant when they did not receive feedback on data use and interpretation (Little, Hayashi, & Liang, 2016). Furthermore, Comte et al. (2016), who conducted participatory action research for coastal groundwater management in Tanzania, Kenya, and Comoros, reported that a lack of feedback erodes confidence and trust. In a community-based flood EWS in Malawi, Śakić Trogričić, Wright, Adeloye, Duncan, and Mwale (2018) reported erosion of confidence and trust when local stakeholders are only consulted at the onset of projects. The deterioration of social capital also resulted from professionals overlooking local and traditional knowledge and from projects duplicating actions. Conversely, Endfield and Morris (2012) provided examples of amateur
meteorologists in the United Kingdom being pestered by the media for sensational stories, by the police for evidence, or by companies for forecasts, all of which was beyond what the citizen scientists were comfortable in providing.

**Problems caused by financial incentives:** Lave (2012) discussed the ethics of utilizing citizen scientists as a source of unpaid labor and Cieslik et al. (2019), regarding mobilization of people of low socioeconomic status, stated that financial compensation, or other non-monetary incentives, are right and necessary. Yang, Ng, and Cai (2019) warned that neglecting participant heterogeneity when designing or implementing an incentive allocation program risks undercutting the ultimate outcome due to differences in attitudes, beliefs, and experiences that can cause people to respond quite differently to the same incentives. There can be adverse impacts of financial incentives on participant motivation (Frey, 1997) and data quality (Walker et al., 2016). Wanjala, Mwinami, Harper, Morrison, and Pacini (2018) described several bottom up monitoring projects in Kenya, where authorities promised financial incentives to incorporate flow gauging but payments were irregular or non-existent impacting both motivation and data quality.

### 4.6 Differences across typologies, geographic regions, and fields

“Contributory” was the dominant typology in citizen science applications to water comprising 48% of studies. The inclusion of participatory modeling and mapping projects was an important factor in driving the significant proportion (35%) of “collaborative” typology. As degree of control of citizens increased, there was more likely to have been consideration of actual benefits and negative impacts of participation (Figure 7), which could be a result of more time that organizers and participants were likely to have spent together. Most publications with “various” typologies were review papers, hence the higher proportions of potential and attributed benefits and negative impacts.

Reporting benefits through observations was much more prevalent in Global South studies (23% of cases) compared to the Global North (9%, Figure 8). Whereas there are far fewer studies from the Global South where benefits were investigated: we found 27 examples, compared to 60 from the Global North. It was more common for Global North studies to have no mention of negative impacts (74 vs. 62%) while Global South studies were more likely to state potential or observed negative impacts.

Analyzing the category of benefits by water science field revealed that water management had the highest proportion of studies that investigated benefits (Figure 9). This is primarily due to the abundant participatory modeling projects included in this review that commonly incorporate a feedback stage where participants are consulted on their experience. In absolute numbers, water quality studies from the Global North dominated those which investigated benefits (34 of 87 studies); 79% of those studies were from North America. Hydrometeorological studies, dominantly community-based monitoring, had the lowest consideration of benefits. Conversely, aside from water management, hydrometeorological studies had the greatest consideration of negative impacts, particularly in the Global South where a high proportion provided observational evidence.

### 5 DISCUSSION

#### 5.1 Transferability of potential benefits

Much of the literature that was commonly cited within lists of potential benefits was from non-water fields of the environmental sciences. Even though only 16% of water science studies investigated benefits experienced by participants and communities, and 13% provided observed examples, the findings confirmed that the commonly listed potential benefits can and do occur in citizen science applications to water. However, the majority of the commonly cited literature had a Global North focus where citizen science is generally a leisure activity (Everett & Geoghegan, 2016). Many of the listed potential benefits may be less appropriate for citizen scientists in low-income areas, both in the Global North and South, unless they lead to improved health or livelihood, or decreased risk. For example, raising awareness is a commonly stated aim and potential benefit of Global North citizen science projects in order to encourage behavior change, such as environmental stewardship (Edwards et al., 2018; Middleton, 2001). Yet raising awareness may be less appropriate for some communities who are well-aware of an environmental hazard they live under but are powerless to change behavior. Furthermore, increased social capital is a commonly identified benefit of citizen science projects in higher-income areas; participants regularly state that community involvement, meeting likeminded people, and expanding their social group are key motivations (Alender, 2016; Rotman...
et al., 2012). The small communities in rural low-income areas where citizen science projects are often established commonly already have an abundance of this type of social capital while being poor in human and financial capital (Isham, Kelly, & Ramaswamy, 2002). Nevertheless, this review found that many of these personal motivations and benefits such as raised awareness and knowledge gain that are the aims of projects in higher-income areas must still be achieved first in low-income areas in order to build community capitals if grander aims such as empowerment and improved livelihood are to be subsequently realized.

### 5.2 Appropriateness of inferred benefits

The studies categorized as inferred benefits appear to have made justifiable inferences. Regarding knowledge gain, increased scientific literacy, and decreased risk, there was abundant observed and investigated evidence from other studies suggesting these benefits are often realized. However, because of the listed exceptions where investigation revealed, for example, that knowledge gain did not occur (Overdevest et al., 2004; Selman et al., 2010) or when intended empowerment had the opposite effect (Gaventa & Barrett, 2010; Gladfelter, 2018), or when later follow-up assessment revealed that new knowledge and skills did not lead to the desired actions (Ducrot, van Paassen, Barban, Dare, & Gramaglia, 2015), it may sometimes be inaccurate to infer benefits.
Commonalities in studies presenting observed and investigated benefits

Investigation of motivational benefits generally utilized simple questionnaires with Likert-scale or multiple-choice questions and could be conducted at any time during a citizen science program. Consequently, such investigation was often performed remotely with telephone, email, or online surveys by researchers not necessarily involved in the program. Investigation of motivations was generally for the benefit of program organizers to improve targeting and retention of citizen scientists. Significantly, we found no example of an investigation of motivations of Global South citizen scientists. This is a critical research gap because many studies—all from the Global North—decry the lack of diversity among citizen science participants with the majority being white, middle-class, well-educated, wealthy, middle-aged males (Haklay, 2013; Reges et al., 2016). What motivates this demographic to engage and maintain involvement in citizen science water projects is unlikely to be transferable to participants of other demographics.

**FIGURE 9** Comparison between Global North and Global South studies of how benefits (upper) and negative impacts (lower) were mentioned in different fields of the water sciences

5.3 Commonalities in studies presenting observed and investigated benefits
Beyond motivational benefits, often there was specific investigation for a particular benefit; such as how participation in citizen science impacted trust, knowledge gain, scientific literacy, or social capital. Participants and communities could not simply be asked if they had experienced these benefits, rather survey questions were designed that would reveal such outcomes. An exception is where questionnaires did simply ask if participation had led to any behavior change and positive responses were often reported as evidence of success. It is clearly more straightforward to measure gains when there was baseline testing, yet only 13 studies conducted pre-program assessments.

Investigation of long-running projects often uncovered, through responses during semi-structured interviews, a sequence of benefits leading to wider community benefits. However, it was the studies categorized as providing observed benefits that most commonly reported such community benefits as empowerment or improved livelihood (in 74% of studies that observed benefits vs. 30% that investigated benefits). These benefits are often the aims of citizen science in low-income areas explaining why observational evidence was more common for studies in the Global South (23%) compared to the Global North (9%). Most of the Global North observed benefits examples involved community empowerment and increased political capital where water quality data collection led to lawsuits against polluters. Compared to personal benefits, these wider community benefits are difficult to measure (Reed, 2008), explaining why they are typically reported as observations.

### 5.4 Uncommon reporting of negative impacts

Many of the identified examples of negative impacts may be occurring more widely. It is intended that the provided case studies will raise awareness among citizen science organizers of possible negative impacts enabling design of citizen science programs that avoid their occurrence. It is also hoped questionnaires and interviews will be designed to evaluate if participants experience negative impacts rather than only evaluating specific benefits. Considering many studies did research participant outcomes, no mention of negative impacts may represent the known bias against publishing negative or null results (Franco, Malhotra, & Simonovits, 2014). While there is an inherent risk in sharing negative or null results due to possible loss of support for the program, reporting such outcomes affords others the opportunity to learn from them and avoid pitfalls (Stepenuck & Green, 2015).

Consideration of negative impacts is critically important for organizers of citizen science in low-income areas. If a Global North citizen scientist begins to experience any of the negative impacts presented in this review, they can generally simply reduce or stop participation. However, that may not be so easy for a citizen scientist in certain areas of the Global South who was nominated by their community because they were known to have the required attributes, such as literacy, numeracy, responsibility, living in proximity to a monitoring location (e.g., Jacobs et al., 2019; Kongo et al., 2010; Regmi et al., 2019; Zemadim et al., 2014). As stated by Resnik et al. (2015), it is the ethical responsibility of organizers to not put citizens into unsafe situations or circumstances or unduly burden citizens with work that they feel they may be unable to perform on time, given their other commitments and interests.

### 5.5 Ensuring participant and community benefits through project design

The majority of the reviewed water sciences publications described citizen science projects with aims of achieving research outcomes (e.g., scientific findings). Consequently, participant and socioecological systems’ outcomes were rarely investigated. However, given the time and effort commitment made by citizen scientists for the benefit of researchers, should we not be evaluating whether participants are also benefiting? Because it is ethical and would likely be to the betterment of the project. Or at least ensuring that participants are not negatively impacted? Resnik et al. (2015) discussed the possibility of “mutually beneficial exploitation” in citizen science that can occur when both parties consent to and benefit from a relationship but the benefits are distributed inequitably. They stated that to avoid exploitation, scientists should offer participants and communities a fair share of benefits, such as those identified in this review.

Figure 10 illustrates the stages of benefit achievement and how they interrelate. The diagram shows the benefits that should be aimed for and designed into a citizen science project in order to build certain community capitals to achieve wider community benefits. Figure 10 suggests how citizens with particular personal motivations could be targeted and those motivations nurtured to realize benefits which would build community capitals. The literature review indicated that empowerment and behavior change result from the realization of multiple benefits; generally increased human capital (e.g., raised awareness, knowledge gain, increased scientific literacy) in addition to increased social capital (and
political capital in many cases). Empowerment and behavior change in turn contribute to building community capitals further, leading to improved environment, improved health, decreased risk, and ultimately improved livelihoods. This is a guide rather than a “one size fits all” diagram because, depending on the context (i.e., citizen science typology, socioeconomics, culture, water-related issue being addressed), certain capitals may already be more or less abundant while certain benefits and stages may be unnecessary. For example, in a high-income area or for a virtual citizen science project where participants are intrinsically motivated for egotistic benefits, striving for additional wider community benefits may be an unnecessary use of resources. However, furthering this example, the collected data may contribute to environmentally-friendly policymaking (i.e., increased political capital) though the intermediary stages may be unapparent. Similarly, raised awareness may lead directly to behavior change, such as adherence to environmental regulations thus increasing natural capital (Conrad & Hilchey, 2011). It is hoped that Figure 10 can serve as a guide for the design of future citizen science applications to water for the benefit of participants and communities.

5.6 Future research recommendations

There were some Global South studies that investigated benefits or provided observed evidence to suggest that the predominant Global North research is transferable. However, more research of participants in citizen science water projects in the Global South and low-income areas is required so that we can be sure that both the scientific and non-scientific community are benefitting. Furthermore, due to the dominance of water quality projects in the United States, there is a research deficit of citizen science projects from all other water science fields in all regions.

This call for greater research of participants and communities involved in citizen science has been sounded from other fields of environmental sciences. Specific recommendations include: selecting appropriate indicators to ensure...

**FIGURE 10** The motivations for involvement in citizen science leading to benefits that build community capitals leading to improved livelihoods. “Increased social capital” is included as a benefit within the social capital arrow because it encapsulates multiple social benefits and is commonly an explicit aim and result of citizen science in the literature alongside for example, knowledge gain and increased scientific literacy. The boxed motivations are difficult to categorize but may be considered that they improve general wellbeing and thus contribute to human capital.
that desired outcomes are achieved (Jordan et al., 2012), social analysis before and long-after citizen science establishment to critically analyze the legacy of projects beyond their funding period (Gharesifard, Wehn, & van der Zaag, 2019), and assessing the timeline of benefit achievement to better inform participants and conducting independent research of projects to enable reporting of null and negative impacts (Stepenuck & Green, 2015). Furthermore, many review papers advocate for citizen science water projects to be more collaborative and co-created to ensure they are beneficial to participants (e.g., Baudoin et al., 2016; Carlson & Cohen, 2018; a hypothesis that could be tested with greater research into citizen science benefits and negative impacts.

It is possible that there exist reports, blogs, or articles produced by NGOs or local level organizations concerning collegial and co-created citizen science water programs, that is, those largely autonomous projects that had little to no input from professional scientists. It was beyond the scope of this study to explore these projects though, being citizen driven, such projects may be a complementary resource of assessment of benefits and negative impacts for participants and communities.

6 | CONCLUSIONS

Citizen science continues to gain in popularity within water sciences around the globe, with more significant growth than previously suggested in the Global South. While scientific benefits of citizen science to researchers are well reported, impacts on participating communities are often overlooked. The benefits of involvement were commonly not mentioned or were simply listed without explanation or investigation and can therefore be considered only potential benefits. The small proportion of studies that investigated or observed benefits demonstrated that the potential benefits often referenced from other scientific fields can and do occur during citizen science applications to water. Nevertheless, simply assuming certain benefits will be experienced can be fallacious as in some cases the intended positive outcomes were either not achieved or had negative impacts. Furthermore, many of the commonly stated potential benefits may be less appropriate for citizen scientists in low-income areas unless they lead to improved health or livelihood, or decreased risk.

Reporting of negative impacts of citizen science on communities was uncommon, even in studies that conducted participant surveys. When considered, disempowerment, conflict creation, burdening the public and even loss of life, among others, were reported as direct results of citizen science. Care must be taken that project goals match those of the community, that citizen science does not overly burden participants, nor perpetuate or spark new forms of inequality. Greater investigation and reporting of negative impacts are needed to ensure that citizen science organizers are aware of potential issues and can eliminate them at the design stage or during a project.

This review revealed a scarcity of investigative studies from the Global South, particularly regarding citizen scientists’ motivations that, when considering low-income areas, are likely very different from most Global North participants. Along with motivations, benefits such as increased knowledge, scientific literacy, and social capital are generally more straightforward to investigate. Their realization is necessary to build community capitals to achieve wider community benefits like empowerment, decreased risk, and improved environment, health, and livelihoods.

As citizen science continues to proliferate in the water sciences, greater consideration of both benefits and negative impacts for participants is required. Given the time and effort commitment made by citizen scientists for the benefit of research, the scientific community should more widely evaluate whether participants are also benefiting and ensure they are not negatively impacted.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

David W. Walker: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; visualization; writing-original draft; writing-review and editing. Magdalena Smigaj:
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