Citizen Science in River Monitoring: A Systematic Literature Review of the Whys and Hows

1 Introduction

The use of citizen science is well-established in the field of river monitoring (Buytaert et al. 2014), encompassing a wide range of institutions, governmental departments, and community resource groups on a global scale (Conrad and Hilchey 2011; Njue et al. 2021). River monitoring encompasses a variety of methods, including chemical and biological techniques (Pacini et al. 2019; Lamberth and Hughes 2019), which may be tailored to different monitoring objectives. However, existing literature primarily focuses on verifying the accuracy and reliance of citizen science projects (Krabbenhoft and Kashian 2020; von Gönner et al. 2023), as well as socioeconomic factors that affect the effectiveness of citizen science projects (Aura et al. 2021; Mgoba and Kabote 2020). Furthermore, existing literature reviews tend to focus on peer reviewed literature, which may exclude a large proportion of active citizen science projects (Ramírez et al. 2023).

Therefore, this study aims to conduct a systematic review of global literature on river monitoring, including academic journals and institutional manuals (grey literature), to identify the principal objectives and monitoring methodologies employed in diverse citizen science projects. The overarching goal is to establish a coherent framework linking objectives with methods for citizen scientists within the realm of river monitoring, outlining cost-effective and operationally feasible methods suitable for citizen scientists. Ultimately, the framework aims to provide foundational guidance for new citizen science initiatives, enabling participants to select appropriate monitoring methods aligned with their conservation objectives effectively.

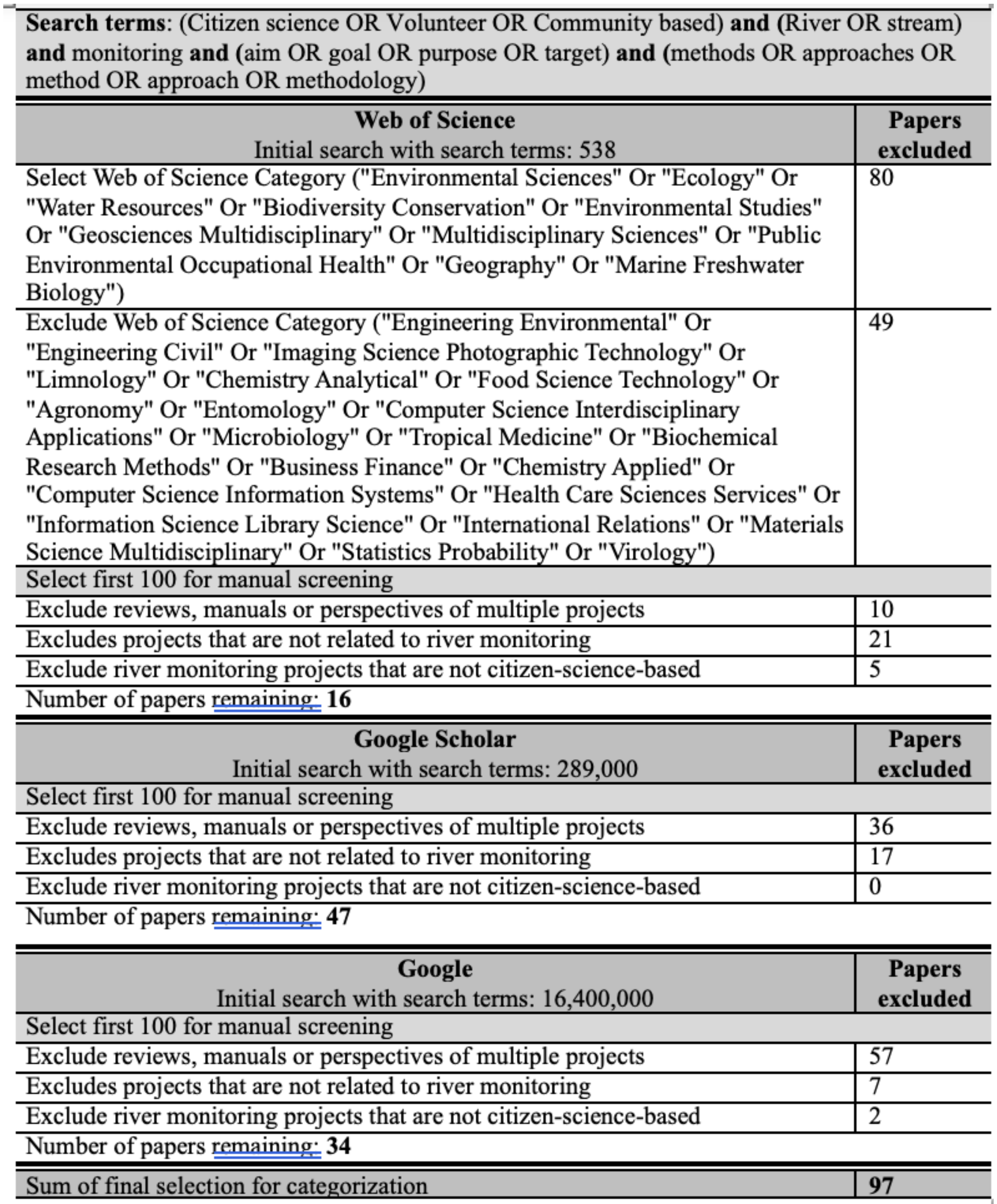
2 Methodology

2.1 Literature Search

To perform a systematic search of the literature, we used the PSALSAR method for environmental science research described by Mengist *et. al.* (2020). We searched: Web of Science, Google Scholar, and Google. The search results from Web of Science and Google Scholar primarily consisted of academic journals, while results from Google provided a substantial number of institutional materials. Given the unique nature of citizen science as a source of data from non-academic fields, including grey literature from non-academic sources is essential to capture a broader spectrum of firsthand information on citizen science projects.

However, Google searches can also lack specificity, and our search returned an unmanageable number of hits (> 16 million). For this reason, we decided to analyse a representative sample of the full dataset by extracting data from only the first 100 search returns. We applied this to all three search databases to ensure parity.

Ultimately, a total of 97 entries from the three databases were selected for subsequent classification and analysis.



Search terms: (Citizen science OR Volunteer OR Community based) **and** (River OR stream) **and** monitoring **and** (aim OR goal OR purpose OR target) **and** (methods OR approaches OR method OR approach OR methodology)	
Web of Science Initial search with search terms: 538	**Papers excluded**
Select Web of Science Category ("Environmental Sciences" Or "Ecology" Or "Water Resources" Or "Biodiversity Conservation" Or "Environmental Studies" Or "Geosciences Multidisciplinary" Or "Multidisciplinary Sciences" Or "Public Environmental Occupational Health" Or "Geography" Or "Marine Freshwater Biology")	80
Exclude Web of Science Category ("Engineering Environmental" Or "Engineering Civil" Or "Imaging Science Photographic Technology" Or "Limnology" Or "Chemistry Analytical" Or "Food Science Technology" Or "Agronomy" Or "Entomology" Or "Computer Science Interdisciplinary Applications" Or "Microbiology" Or "Tropical Medicine" Or "Biochemical Research Methods" Or "Business Finance" Or "Chemistry Applied" Or "Computer Science Information Systems" Or "Health Care Sciences Services" Or "Information Science Library Science" Or "International Relations" Or "Materials Science Multidisciplinary" Or "Statistics Probability" Or "Virology")	49
Select first 100 for manual screening	
Exclude reviews, manuals or perspectives of multiple projects	10
Excludes projects that are not related to river monitoring	21
Exclude river monitoring projects that are not citizen-science-based	5
Number of papers remaining: **16**	
Google Scholar Initial search with search terms: 289,000	**Papers excluded**
Select first 100 for manual screening	
Exclude reviews, manuals or perspectives of multiple projects	36
Excludes projects that are not related to river monitoring	17
Exclude river monitoring projects that are not citizen-science-based	0
Number of papers remaining: **47**	
Google Initial search with search terms: 16,400,000	**Papers excluded**
Select first 100 for manual screening	
Exclude reviews, manuals or perspectives of multiple projects	57
Excludes projects that are not related to river monitoring	7
Exclude river monitoring projects that are not citizen-science-based	2
Number of papers remaining: **34**	
Sum of final selection for categorization	**97**

Table 1 Literature search and exclusion criteria and procedure

2.2 Data analysis

Initially, the principal objectives identified in each piece of literature are classified into basic types and further subdivided for detailed analysis. Through a comprehensive review of all 97 selected studies, the objectives of citizen science river monitoring projects are extracted and listed, and the objectives are categorized and color-coded for clarity. The types and quantities of each category are then quantified.

Next, the number of studies under each major objective category is recorded, and a graph is created to show the proportion of different objectives. Moreover, the publication dates and regional distribution of the studies are recorded. The primary objectives of projects within each continent are also analysed to illustrate the geographical distribution of study numbers and objectives globally, as well as a histogram to demonstrate the year of publication.

Subsequently, the primary monitoring methods utilized across different projects are identified based on their respective monitoring objectives. For projects with multiple monitoring objectives, each objective is documented separately along with the associated research methods employed. These methods are then categorized, and the number of studies using each method within each category is counted and tabulated.

Finally, a framework (fig 4) linking each objective with its corresponding main methods has been developed in the discussion section.

3 Results

3.1 Categorization of objectives

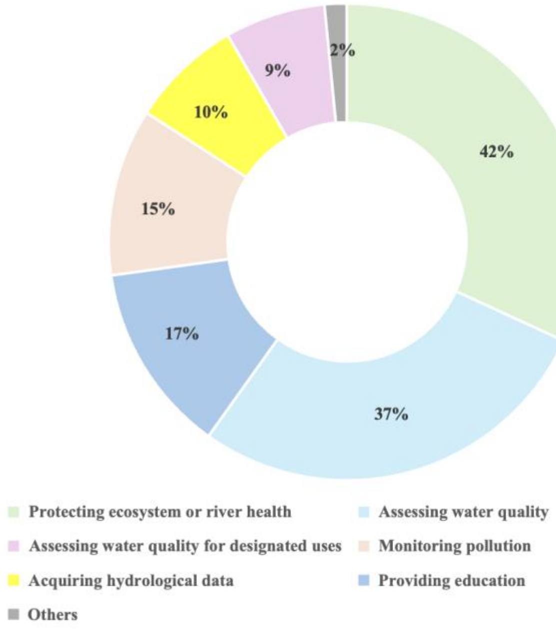


Fig 1 Categorization and proportions of objectives

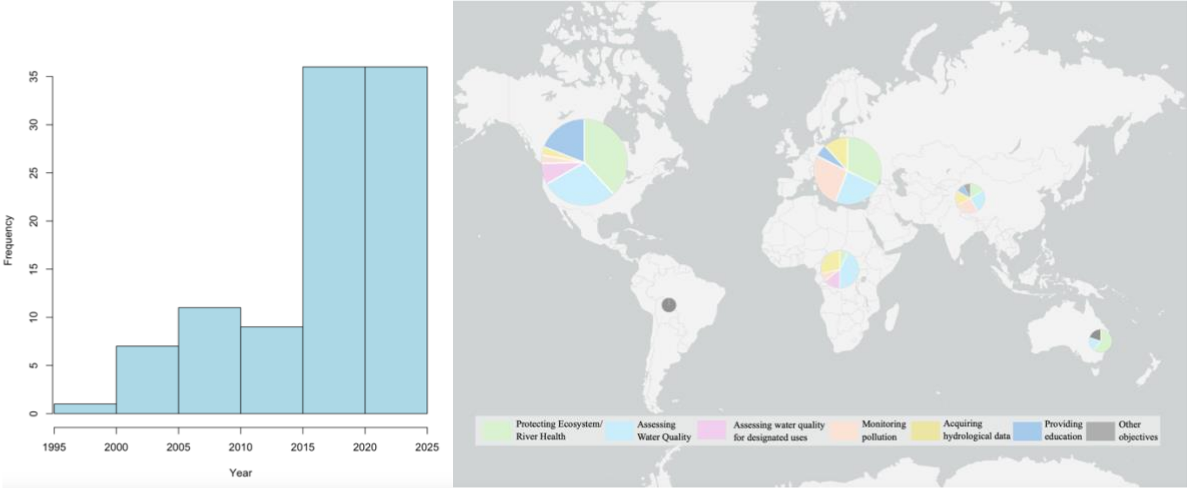


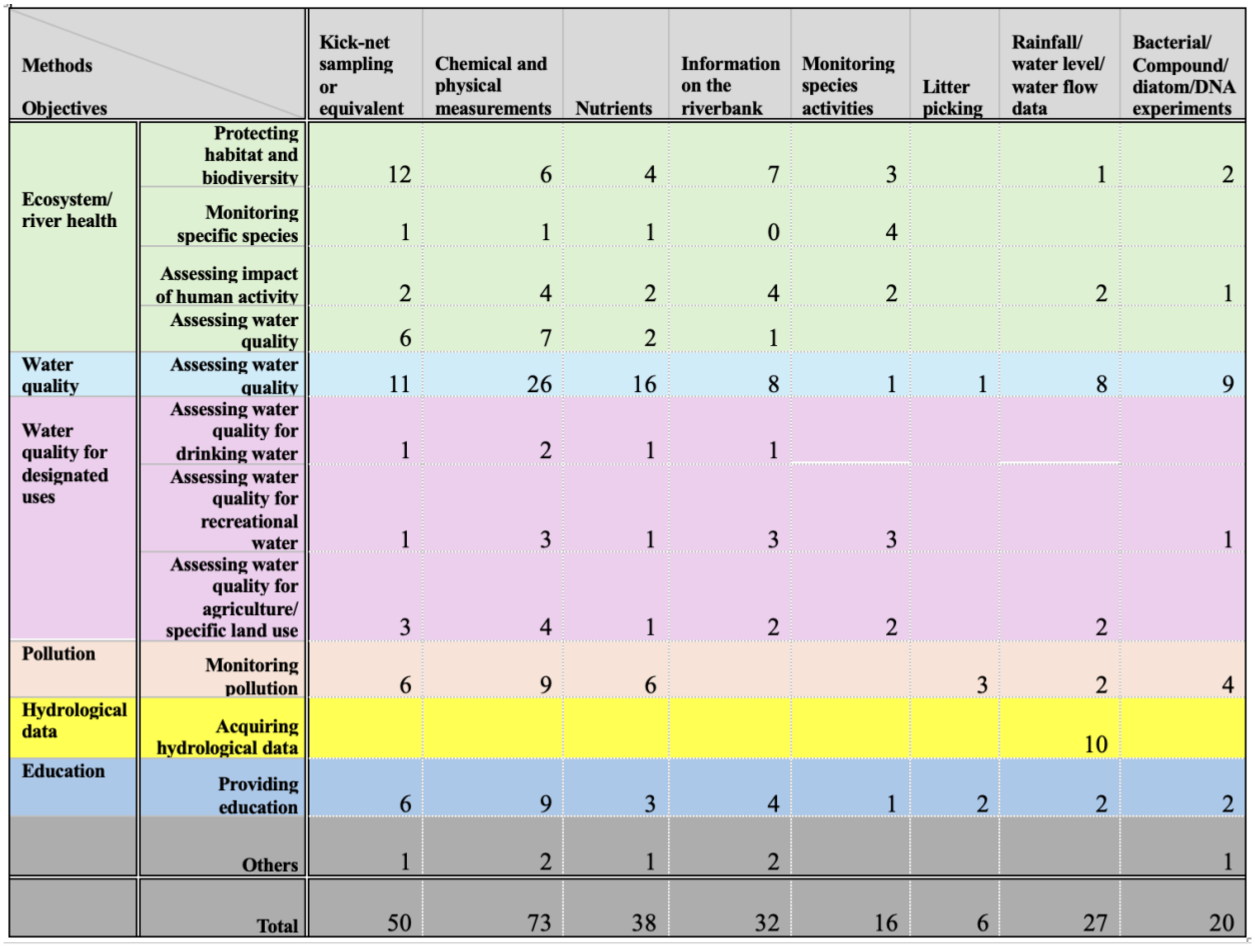
Fig 2 Histogram of publication year and map of origin continent of selected literature

The 80 selected literature were analysed to extract the primary objectives of each river monitoring project, and these objectives were subsequently categorized. Figures 1 and 2 illustrate the categorization of these objectives, the proportion of the studies with each objective (studies with certain objective/total number of studies), and the publication time and location of the literature. Fig 1 reflects their respective frequency compared to other objectives.

From Fig 2, the continent with the highest number of selected studies is North America (47), followed by Europe (26), Africa (12), Asia (8), Oceania (5) and South America (1), predominantly reflecting the Global North, although the Global South is also represented. The countries with the highest number of selected studies are the United States (37), the United Kingdom (14), and Canada (9).

Over 90% of the selected literature was published after 2015, thereby providing this study with a foundation to illustrate contemporary patterns in citizen science and river monitoring.

3.2 Categorization of methods



Objectives		Kick-net sampling or equivalent	Chemical and physical measurements	Nutrients	Information on the riverbank	Monitoring species activities	Litter picking	Rainfall/ water level/ water flow data	Bacterial/ Compound/ diatom/DNA experiments
Ecosystem/ river health	**Protecting habitat and biodiversity**	12	6	4	7	3		1	2
	Monitoring specific species	1	1	1	0	4			
	Assessing impact of human activity	2	4	2	4	2		2	1
	Assessing water quality	6	7	2	1				
Water quality	**Assessing water quality**	11	26	16	8	1	1	8	9
Water quality for designated uses	**Assessing water quality for drinking water**	1	2	1	1				
	Assessing water quality for recreational water	1	3	1	3	3			1
	Assessing water quality for agriculture/ specific land use	3	4	1	2	2		2	
Pollution	**Monitoring pollution**	6	9	6			3	2	4
Hydrological data	**Acquiring hydrological data**							10	
Education	**Providing education**	6	9	3	4	1	2	2	2
	Others	1	2	1	2				1
	Total	50	73	38	32	16	6	27	20

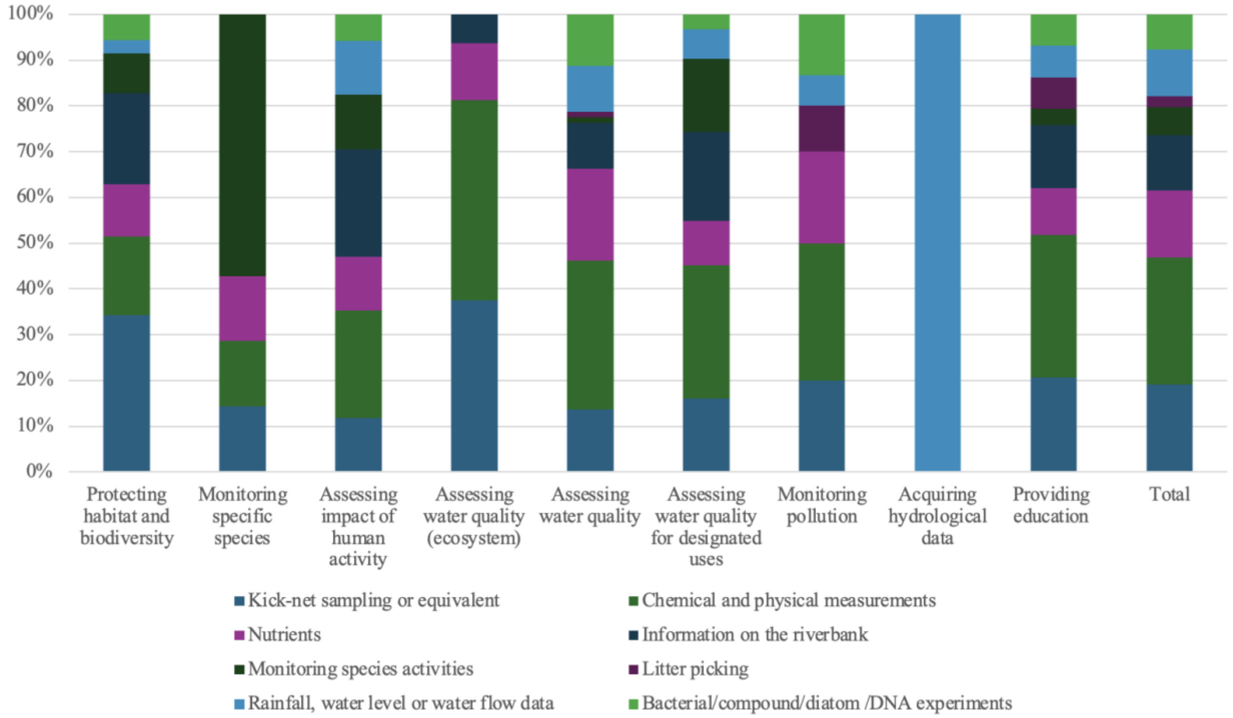


Fig3 Literature count and graph of methods used according to objectives

***Chemical test** includes water temperature, pH, electrical conductivity, dissolved oxygen, turbidity, etc.

***Information of riverbank** includes riverbank slope, riverbank vegetation, peripheral land use and human activities, etc.

Through systematic analysis of the literature and documentation of the methods used for each objective, Figure 3 presents the number of studies employing each method and the proportion of methods used under each objective. Given the high number of studies aimed at protecting ecosystems or river health, this category has been subdivided into four specific sub-objectives for more detailed analysis.

From Figure 3, it is evident that most studies employ multiple methods. Generally, kick-net sampling (or equivalent) and chemical and physical measurements are the most commonly used methods, and they are applied across multiple objectives. Conversely, projects under the objective of acquiring hydrological data exclusively use methods related to acquiring rainfall, water level, or water flow data. Objectives related to monitoring specific species, providing education, and assessing impact of human activities also tend to utilize more specialized methods. For instance, monitoring species activities are primarily used under the objective of monitoring specific species, and assessing impact of human activities primarily uses methods related to information on the riverbank and chemical/physical measurements.

Furthermore, within the broad category of protecting ecosystems or river health, the sub-objective of assessing water quality tends to use fewer but more dominant methods, such as kick-net sampling and chemical and physical measurements. This contrasts with the general objective of assessing water quality, which employs a broader range of methods.

4 Discussion

4.1 Common objectives

Protecting ecosystem or river health

Protecting habitats and biodiversity: this objective represents a general objective of protecting the overall ecosystem quality, enhancing biodiversity and conserving habitat. Projects under this objective intends to maintain and restore river ecology and natural habitats. For example, Wilson et al. (2018) records citizen science projects led by indigenous people in the Yukon River Basin, aiming to improve the river to sustain the living creatures supported by the river ecosystem.

Monitoring specific species: this objective either intends to protect a particular species or group of species, or to observe the activity of specific species to safeguard the broader ecosystem or public health. For example, Dickson et al. (2023) measures multiple parameters in the river in order to assist the recovery of an endangered species M. georgesi..

Assessing impact of human activities: this objective evaluates how human activities such as pollution, agriculture, and industrial production affect river ecosystems and environmental quality. Projects under this category monitor changes in the ecosystem caused by anthropogenic factors and aim to mitigate negative impacts, as exampled in Miguel-Chinchilla et al. (2019) measuring turbidity to assess the relationship between urbanization and water quality.

Assessing water quality: this general objective focuses on monitoring water quality as part of protecting ecosystem and river health. Projects under this category measure various parameters such as chemical, physical, and biological indicators to ensure that the water quality supports a healthy ecosystem. For example, Micorps (n.d.) organises volunteers to monitor the ecological quality of the river by documenting the stream profile, peripheral habitats, riverbank erosion status and water turbidity.

Assessing water quality

This objective encompasses projects that do not focus on a specific target but aim to monitor the general water quality in a river area. Multiple methods are commonly used with this objective, but chemical and physical measurements are the most essential methods used. Hydro-chemical parameters is usually collected for long term monitoring of river, in order to gain more information and pattern of the river water quality (Njue et al. 2021). The impact of human activities (e.g. agriculture and land use) to water quality is also assessed (Tssatsaros et al. 2021).

Assessing water quality for designated uses

This objective focuses on evaluating river water quality to determine its suitability for various human uses, including drinking water, recreational activities (e.g., swimming, fishing, aesthetics), irrigation, and land use. This objective is closely tied to the daily lives of volunteers, as evidenced by citizen science projects that measure water quality and pollution levels to assess whether the water is safe for consumption or recreational use (Grantz and Haggard 2022; Middleton 2001).

Monitoring pollution

This objective encompasses citizen science projects that aim to prevent, monitor, and address pollution issues. These projects focus on various forms of water pollution in rivers, such as nutrient contamination, fecal bacteria pollution, microplastic pollution, and contamination from agrochemical and industrial compounds (Wessex Rivers Trust & Earthwatch; CESAM 2016). Additionally, they address pollution in specific wastewater sources and plastic pollution on riverbanks. For example, Graham et al. (2023) introduce citizen science projects in South Africa that specifically address wastewater issues using clarity tubes.

Acquiring hydrological data

This objective focuses on gathering hydrological data to understand river dynamics and water flow. Citizen science projects under this objective often involve monitoring parameters such as water levels and rainfall data, equipping volunteers with tools and techniques, like water level sensor and rain gauges, to systematically collect and record data (Ferede et al. 2020). These projects typically utilize mobile applications to facilitate data collection and storage, ensuring a comprehensive and accessible database (Fehri et al. 2020).

Providing education

This objective aims to educate and raise awareness among communities about river health and conservation, as well as methods to monitor and protect water quality. Citizen science projects under this objective typically utilize methods that are more accessible to volunteers, such as litter picking, chemical and physical measurements, and gathering information on the riverbank (Ho et al., 2020; CESAM, 2016). Education programs and activities are also designed for students and community members to learn about the water cycle and river ecosystems (Olson et al., 2023).

4.2 Common methods

Chemical and physical measurements is the most commonly used method among the 100 selected studies. This method typically includes testing parameters such as water temperature, pH, electrical conductivity, dissolved oxygen, and turbidity, and can be conducted using on-field test kits, making it accessible for citizen scientists. For example, turbidity can be measured using Secchi tubes, as demonstrated by Miguel-Chinchilla et al. (2019), while parameters such as pH and conductivity can be tested using specific test kits and strips. These chemical parameters provide citizen scientists with direct indicators and underlying determinants of water quality.

Kick-net sampling or equivalent predominantly involves collecting benthic macroinvertebrates by disturbing the riverbed through kicking and using a hand net to take a sweep sample. The collected specimens are then identified either on the field or in a laboratory (Marchant and Yule, 2019). Since different species have varying levels of pollution tolerance and inhabit water bodies with distinct chemical, physical and biological conditions, their presence in a particular river area can serve as indicators of the corresponding environmental quality of the river (Tampo et al. 2021). For example, the Save Our Stream project documented in Gowan et al. (2007) uses four metrics based on macroinvertebrates obtained in field samples, to calculate a score indicative of stream health. This method is relatively cost-effective for volunteers and requires less professionality.

Information on the riverbank is used for general methods including documentation and description of various characteristics in and around the river basin, which could be used to create a river profile, facilitating qualitative analysis of the ecological quality. The index used in studies includes characterization of habitats (Scotti et al. 2022), type of surrounding land use (Edmonson 2004), height, abundance, structure and species of riverbank vegetation (Modular River Survey Team 2016). It can also be critical for identifying sources of pollution and monitoring urban interference.

Monitoring species activities refers to the observation and recording of species, including their behaviours, quantity, and movements within their habitats. Examples include counting bats to indicate riverine forest quality (López-Bosch et al. 2023), monitoring malaria mosquitoes to assess health risks (Murindahabi et al. 2020), and detecting fish landings to ensure sustainable small-scale fisheries (Silvano and Hallwass 2020).

Nutrients can be monitored onsite with test kits by citizen scientists, similar to other chemical measurements. However, nutrient measurement is less commonly performed than parameters like conductivity and dissolved oxygen, possibly due to higher costs. Nutrients primarily affect water quality by causing eutrophication, a form of water pollution characterized by harmful algal blooms that deplete oxygen levels, reduce biodiversity, and degrade water quality (Chen et al. 2018). In selected projects documented in this study, the commonly measured nutrient parameters include nitrogen, nitrate, phosphorus, phosphate, and chloride (Babiso et al. 2023; Herman-Mercer et al. 2018).

Rainfall, water level or water flow data refers to the acquisition of hydrological data and the dynamics of river water flow. These parameters are collected to gain hydrological insights, typically involving the use of rain gauges and water level sensors, which demands citizen scientists of equipment installation. For example, river water gauges are used to assess the impact of rainfall on water quality, pollution levels, and habitat conditions (Fehri et al. 2020). Additionally, water flow data is valuable for analysing flow patterns, monitor groundwater recharge, and supports effective river management (Ferede et al. 2020; Wesser et al. 2018).

Bacterial/compound/diatom /DNA experiments represent biochemical experiments conducted to examine the microbiological characteristics of river samples, which detects the presence and concentration of chemical and biological contaminations. It should be noted that this method is not the primary approach for all objectives, but it is utilised in studies addressing the majority of the objectives. The most commonly employed methods include E. coli and total coliform tests. Most of these experiments require professional laboratory facilities, making them less accessible to citizen scientists. However, the establishment of community laboratories has facilitated the possibility for citizen science projects to conduct more sophisticated experiments (Water Rangers 2024).

4.3 Linking objectives and methods—the framework

The flowchart in Fig 4 links the common objectives to the primary methods used for each objective. Primary methods of a specific objective are defined as those utilised by more than 40% of the projects under that objective. Each objective draws an arrow to its main methods, illustrating that most objectives employ multiple methods and that most methods are applied across multiple objectives. Generally, the objectives of protecting ecosystem or river health, monitoring pollution, and assessing water quality for designated uses utilise the most methods.

Among all methods, chemical and physical measurements, followed by kick-net sampling or equivalent, are the most widely applied. Objectives directly or indirectly aiming to assess water quality—whether through general water quality measurement, designated use assessment, or pollution monitoring—tend to use a greater variety of methods. Conversely, specific objectives such as protecting ecosystem or river health, acquiring hydrological data, and providing education use fewer methods.

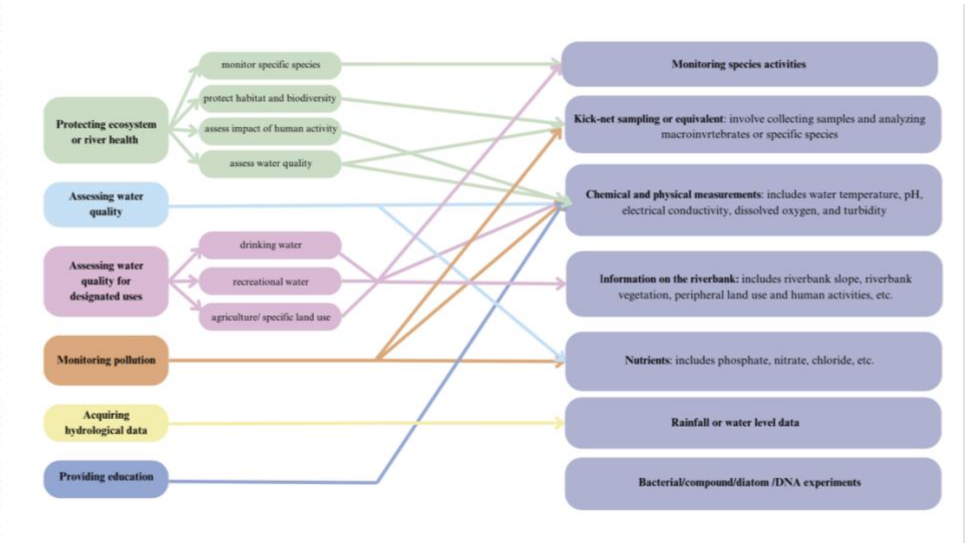


Fig 4 A framework linking the objectives to the main methods used

In general, kick-net sampling, chemical and physical measurements and gathering information on the riverbank may be suitable for more citizen science projects as they are widely used and requires less training and cost less. Specific methods like monitoring species activities require a particular understanding of the species, and acquiring rainfall, water level, or water flow data requires the setting of river gauges or sensors, thus they may be limited to specific objectives. The use of bacterial/compound/diatom/DNA experiments requires high cost and professional expertise, it is not a method primarily used in all objectives.

It should be noted that 24% of the documented projects require the use of a laboratory, which may pose obstacles for citizen scientists due to increased requirements for funding, access to resources, and professional assistance. Sensors, smartphone applications and Geographic Information Systems (GIS) are also commonly used to assess multiple parameters in the water. In this study, all objectives except providing education include projects that use smartphone applications, sensors, or GIS to monitor water quality or water levels. The use of these technologies enhances data accuracy and reliability and facilitates the acquisition and documentation of real-time data. However, the associated costs, maintenance requirements, and data management challenges pose significant barriers for citizen scientists (Lane et al. 2015).

5 Conclusions

This systematic literature review offers a comprehensive academic assessment of the common objectives and methods employed by citizen scientists in the field of river monitoring. Through a statistical analysis of the global distribution of citizen science projects, we examined their primary objectives and methods used. Our study presents a framework that intuitively links these objectives and methods, providing guidance for new citizen science initiatives in project positioning, objective definition, and efficient method identification. The common objectives and methods are elucidated with characteristics and examples, offering an index for project organizers.

Moreover, 16% of the recorded projects are studies comparing citizen science with professional measurements from laboratories, governmental departments, or monitoring stations. These studies may select different methods than purely independent citizen science projects.

Future research should investigate the development and variation in objectives and methods used in more contemporary river monitoring citizen science projects, for example, with a focus on geographical distribution. Additionally, since the establishment of citizen science projects requires practical training, which cannot be easily conveyed through written frameworks, should focus on delivering practical support. This includes providing technical guidance and hands-on skills training to better equip citizen scientists.

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