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Citizens' Campaigns for Environmental Water Monitoring: Lessons From Field Experiments

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ABSTRACT Advanced sensing technologies, combined with wireless sensor networks, have already demonstrated their value in monitoring urban water systems, where management is rather centralized within water utility organizations. Environmental water resources, characterized by more diverse stakeholders and overlapping management responsibilities of different agencies, present more challenging contexts for implementing novel sensing technologies. Crowdsourcing by citizens has been proposed as an alternative approach for adaptive data collection that can augment the amount of data collected, as well as bring together the diverse stakeholders and citizens in more participatory water resources management processes. This article first introduces the challenges of designing citizens' campaigns for collecting data on environmental waters. A set of developed mobile phone and web applications is then introduced, integrated within a specific platform, as it was used in the execution of citizens' campaigns for data needed in flood analysis and management. Experiences and lessons learned are presented from the field execution of citizens' campaigns in two pilot areas located in Europe - the Danube Delta in Romania, and the Kifissos catchment in Greece. Two of the campaigns are on river data collection – water levels and water velocities, and two on collecting land use/land cover data. Surveys carried out with campaign participants indicate their appreciation of the initiative, but challenges remain regarding user-friendliness of the applications. Logistic issues such as timing, duration, and pathways for data collection impacted the motivation of participants. Overall, a unique and large dataset was obtained in terms of quantitative water measurements, despite data losses due to low raw data quality. Further work lies in evaluating the usability of this dataset for local authorities.

INDEX TERMS Citizen science, citizen observatories, campaigns, water resources, gamification, data collection, management.

I. INTRODUCTION

Historically, water monitoring for the management of environmental waters has been considered a challenge in terms of providing sufficient spatiotemporal information for hydrological and hydrodynamic understanding. This is especially true for developing countries [1], specifically in terms of water level and discharge data [2]. Advancements in the Internet of Things (IoT) technologies, including smart sensors and wireless networks, are recently enabling much more efficient

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in-situ sensing, especially in urban water systems within the overall concept of smart cities development [3]. On the other hand, environmental monitoring in general, including water resources, has greatly benefitted from remote sensing [4]. Another source of information is 'citizen science' or 'citizen observatories', in which citizens contribute with data, with their ability to interpret information or through distributed computing [5], [6].

With the emergence of all these new sources of data, there is a lack of guidelines on their application to different local and regional contexts. For example, in water quantity estimation in urban water distribution networks, new devices and network technologies are presented as part of the overall water supply system with clearly identified data needs for their area [7], [8]. In general, all urban water systems have these characteristics, due to the rather centralized management of the system by water utility organizations. However, when monitoring environmental water resources, the connection to the local decision-making context is more difficult, due to the diverse number of involved stakeholders and overlapping management responsibilities of involved institutions. Also, environmental water resources are much more affected by the challenges that are still present in using IoT technologies for monitoring. These include the inherent cost for each sensor device, which increases exponentially in relation to the technological features provided (sensor type, resolution, energy bank, transfer speed, transmission power, etc), as well as the associated costs of deployment and long-term maintenance. Therefore, it is still difficult to take advantage of such sensor networks and their autonomous operation in collecting quantitative measurements, in communicating to each other (local routing/relaying) or directly to a central hub and, eventually, enriching a global measurements map for a specific spatiotemporal domain [9]. With these aspects in mind, scaling up the current wireless sensor networks in the realm of big data applications is still problematic, if not unfeasible altogether for many domains, including monitoring environmental water resources [10], [11].

Similar challenges also appear in citizen science and citizen observatories, for which contributions from volunteers are either opportunistic (i.e. citizen contribute at random locations and random times) or are restricted to small-scale experiments (i.e. at very specific and limited locations and moments in time) [12]. On the other hand, there are community-based monitoring efforts with clear data collection objectives, although these tend to concentrate on collecting water quality data [13], for which collection protocols and citizen science research are more consolidated. Thus, for monitoring water quantity in the environment, the link of new data sources and data collection needs is poorly described in the scientific literature.

In view of this background, the overall objective of this research is to tackle a common challenge to citizen science, IoT and new sensor technologies: the lack of connection with a local context. In other words, how to adapt citizen science and new sensing technologies to collect data that is useful to local authorities? More specifically, the objective is to evaluate the feasibility of implementing such author-centric approach in citizens' campaigns. By author-centric it is meant adapted to data needs identified by the managing water authorities and diverse stakeholders. Further, we also present technologies adapted to dealing with identified needs, although the main focus is on discussing the practical aspects of field experiments. We gauge its success in terms of citizen experience and efficiency of data collection through the data cycle.

The approach both requires and supports a stronger partnership amount the authorities, stakeholders and citizens, leading to clear identification of data needs, with shared understanding and purpose by all involved parties. Actual data collection takes place with targeted campaigns, in which supporting web and mobile phone applications allow authorities to set parameters of the campaign (type of data to be collected, duration, points of interest), while the citizens carry out the campaigns using an entertaining game-like mobile phone app. The approach has been developed within the framework of a European research project from the H2020 programme, entitled Smart Toolbox for Engaging Citizens into a People-Centric Observation Web (Scent). Several field campaigns have already taken place within this project, from where experiences and lessons learned are here presented.

This article is structured as follows: Section II discusses the conceptual framework within which the citizens' campaigns are organized; Section III describes the proposed approach within that framework, together with the developed tools used for overcoming the current challenges; Section IV presents the results and discussion on the effectiveness of the proposed adaptive methods, including the lessons learned from the campaigns organized so far within the Scent project; Section V closes the article with conclusions and recommendations.

II. CONCEPTUAL FRAMEWORK FOR ENVIRONMENTAL WATER RESOURCES DATA COLLECTION WITH CITIZENS' CAMPAIGNS

Citizens participation in data collection for science can be traced back to the 17^{th} century, followed by the uprising of citizen science and citizen observatories projects in diverse fields [14], [15]. As a result, frameworks have been created to classify and understand them. In the following sections, we situate this study within existing frameworks and propose one for analyzing citizen campaigns. The latter is aimed to better communicate the challenges involved in the data collection cycle of this study. Although suggestive, it is not intended as a generic framework for citizen science projects involving campaigns, as for that sociological research is needed, which is outside the scope of this study.

A. EXISTING CITIZEN SCIENCE FRAMEWORKS

One important distinction among citizen science and citizen observatories initiatives is the degree of participation, which ranges from citizens as data collectors to collaborators in designing the research [5]. In this study, citizens contribute by collecting data and interpreting it, which is associated with the two lower levels of engagement (crowdsourcing and distributed intelligence). Another framework for citizen science, mainly in the context of environmental monitoring, is the kind of information collected (geographic or not) and if it was contributed in a voluntary, deliberate manner, or implicitly [16]. Although in the Scent project citizens can collect data both voluntarily and involuntarily, this research is focused on presential citizens' campaigns, to collect land cover, water depth and velocity information. Therefore, it can be classified as both implicitly and explicitly geographic and as explicitly volunteered.

Similarly, citizen science and citizen observatories have evolved as a concept, englobing an increasing amount of contexts and purposes. For example, in a study conducted by Carlson and Cohen [13], participants from community-based monitoring organizations in Canada were interviewed on the purpose of their program. Answers were grouped into five categories, with the most popular one being to deal with their concerns about ecosystems. The remaining categories were related to: incentivizing education and engagement; acting against the lack of data; provide content for managerial decision related to the local ecosystems; and taking part in research and in building a baseline database to discuss trends. Scent has the purpose of setting up a toolbox to facilitate citizens to generate content for managerial decisions. In the same study, the difficulty in establishing the link between data collection and their usage for the local management process was emphasized.

One of the main challenges of citizen science initiatives is data quality [17]. Recent research shows that in some fields, citizen data quality can surpass that of experts, while in others, it is not good enough [18]. However, it is a consensus that there is a need for more detailed reporting and standardization of methodologies for collecting and evaluating citizen data [17], [18]. As would be expected, the degree to which these needs are addressed varies. In consolidated, long-running citizen science projects (e.g. eBirds) and/or when it involves performing simple tasks (e.g. counting birds), protocols for data collection were already reported and standardized; discussions proceed on how to improve them to ensure that data quality is sufficiently high. In contrast, in fields in which citizen science applications are recent (e.g. quantitative water resources) and tasks are complex (e.g. measuring water velocity), the focus lies on proving the feasibility of collecting data through citizens; which is still done through heterogeneous methods reported at varying levels of details [12]. The present study is a proof-of-concept that implements a chain of novel, untested technologies. As a consequence, data quality is addressed through raw data quality control, when possible, and by assessing and reporting raw data quality. Even if not addressed in this research, it is worth mentioning that data quality can also be affected by contextual elements, such as engagement strategies, the citizens' education and training.

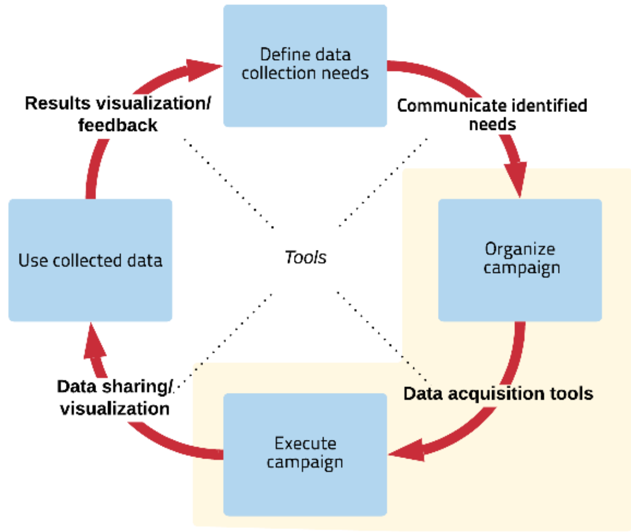

FIGURE 1. Data collection cycle for citizens' campaigns in water management. This study focus on the lower left corner, highlighted in yellow.

Thus, it is also important to acknowledge and factor in the influence of these in data quality, and vice-versa.

B. CITIZENS' CAMPAIGNS FRAMEWORK

Several technological advances for aiding citizen science projects were made previously, composing a dense body of literature spread through many fields. For example, in the eBird project, over the years, a flexible platform was developed for collecting data in three ways (website, forms and apps), verifying it and distributing for multiple user communities [19]. Another example is the author-centric approach proposed by Kim, Mankoof and Paulos [20].

As mentioned in the previous section, for environmental water resources, most current platforms are not driven by data use. Therefore, the link with the local context can be studied by conceptualizing the data collection within a cycle (Fig. 1):

- Stakeholders' data collection needs are identified
- Information regarding the required data is communicated to the citizens' groups that are to be involved in the campaigns
- The campaign is organized: citizens are encouraged to volunteer and participate in the data collection in required locations and periods that fulfil identified needs (e.g. water levels, velocities, discharges, etc)
- Dedicated data acquisition tools are developed and tested
- Data are collected during campaigns execution
- Data are shared with authorities and other stakeholders
- Data are used for identified purposes (e.g. monitoring, modelling, assessment, management actions, etc)
- Results from the usage of data are provided together with feedback to the participating citizens/volunteers

The cycle components represented in blue boxes are considered here as complex processes that involve multiple actors and processes, while those represented with red arrows are considered support tools for moving within the cycle from one component to another. The cycle presented is a conceptual framework for discussion, rather than the architecture of the data collection framework, which is briefly discussed in section III.

Using this conceptual presentation, we can now briefly describe the purpose and of each component together with the current challenges for their implementation. We highlight that although we discuss the full cycle, the focus of the research is on the organization and execution of the citizens' campaigns (the right and bottom-right corner of Fig. 1). These are components that have tangible, directly observable results. Definition of data collection needs (first element) is not innovative in this study. Moreover, evaluating the use of collected data for decision making (fourth element) is a separate research in itself, which can only be done after all data has been processed, analysed and integrated into modelling (when it is due), using another set of evaluation tools. The current research focuses on experiences from field experiments and therefore, results are shown for the second and third element, as mediated by technological tools.

Data needs identification is a participatory process in which stakeholders are gathered in dedicated workshops, often supported by web information platforms. Structured approaches are commonly used, by which the problems of interest to different stakeholders are mapped and scientific objectives or management goals are identified. These are then disaggregated and hierarchically organized in tree-like structures so that the low-level nodes are in fact associated with data needs. The main challenge is to engage in this process representatives of local volunteer groups (e.g. Non-Governmental Organizations - NGOs) that can, in fact, mobilize the citizens in the follow-up campaigns and link the data needs with immediate concerns within a particular location (see, for example, [21]). Further challenges are those of diverse knowledge needs of different stakeholders, conflicting interests, and the necessity for prioritizing data needs, given the limited availability of resources. These challenges regularly occur in water resources, given their shared nature. A more focused data needs identification associated with a particular water problem (e.g. flood management, specific water quality problem, or similar) would lead to easier prioritization and well-targeted campaigns. In turn, this approach contributes to the broader goals of citizens' engagement in co-creation of solutions to water problems.

Tools for communicating the identified data needs to a broad group of citizens and volunteers are currently lacking. Translating the data needs from the identified scientific objectives or management goals to content and form that is both easily understood and motivating for the citizens is challenging. Such tools and application need to also develop and maintain the trust and partnership between the water management authorities and the broader stakeholder groups and citizens. In some cases, this is achieved through the use of specific tools that allow the set-up of data collection surveys/campaigns, enabling users to create new campaigns, modify existing ones, and view campaign data on a map-based interface that displays the locations where observations were made, along with observation data [20], [22], [23]. Other approaches involve the use of mobile applications towards the acquisition of environmental related information and communication of the latter in dedicated repositories [24], [25]. However, such cases do not support the customization and configuration of the data acquisition tools, and thus do not support the proper connection to the interested stakeholders' requirements and needs. The actual organization of citizens campaigns would greatly benefit from innovative tools that could enable water management authorities to design and setup citizens campaigns for a particular water-related problem. The campaigns themselves, however, require more organizational efforts in terms of logistic support. With citizen observatories being still in development, these tasks are commonly carried out within particular research projects.

Not only there is the challenge of operationalizing campaigns within local institutions, but campaign organization itself is also a complex, context-dependent process for which decision directly influence the results. It can be encapsulated in three general steps:

- Volunteer recruitment
- Dates and duration definition
- Points of Interest and routes definition.

The execution of these steps is also affected by the number of campaigns, their periodicity and the types of data being collected.

The acquisition of data for water management encompasses multiple domains: the weather, the flows and the geography. In this way, there are various types of data that can be collected, requiring different data acquisition tools. We will discuss here such tools for acquiring Land Cover/Land Use (LU/LC) information, and for water quantity measurements (water level and water velocity), as these were main target variables in our citizens' campaigns.

LU/LC information is needed for many application areas, beyond the water domain, such as transportation, spatial planning etc. Community mapping and web and mobile apps through which citizen can provide such information are already in place (see, for example [26]). The apps commonly require citizens to annotate LU/LC features from a pre-defined taxonomy, either using externally generated images (by remote sensing, or by other contributors) or images taken by their own mobile phone camera. The main challenge here is the integration of the citizens' data with other sources, such as remote sensing, including drone generated data.

For water quantity measurements, some recent reviews discuss the topic in more detail [12], [27]. In terms of water level, one of the most basic forms of data collection is manual annotation of water levels from installed gauges [28]. These records are usually given directly to the authorities/researchers or uploaded to a database. With the advancement of mobile technology and the Internet of Things, initiatives in which citizens send text messages with such water levels started to appear [29]–[31], as well as sending their readings through dedicated apps or websites [32], [33]. The process of obtaining data from gauges is limited to these actions, without any automation. While there are many methods dedicated to the text extraction from images, known as Optical Character Recognition (OCR), to the best of our knowledge there are no efforts to implement these techniques to water level extraction. On the other hand, apps and websites have been used for collecting images of floods [34]. From these images, however, the water level estimation is generally more difficult [12].

For water velocity measurements, due to their complexity, there are limited available studies that use applications with which citizens would contribute such data. Volunteers have been instructed to make direct velocity measurements in citizen science projects [35] as well as to upload videos to a dedicated website [36]. In the latter, one video was uploaded and this video was used to extract velocities using the LSPIV (Large-Scale Particle Image Velocimetry) technique. Likewise, measurements of discharge are traditionally complex. In a specific review about that, Davids et al. [37] discuss that there is a lack of studies in which volunteers use existing smartphone-based video processing methods. The authors then proceed to evaluate the applicability of simple streamflow measurement methods for citizens. After selecting and testing three of them (float, salt dilution and Bernoulli run-up), they conclude that salt dilution worked better for their case study in Nepal, while the float method was the simpler one to perform. Similarly to water level, the challenge is to introduce some procedure by which water velocity estimates would be automatically provided from videos provided by citizens.

Citizen-generated data show a particular diversity in terms of their type and characteristics. This, in combination with the continuously increasing volume of citizen science data, necessitates the need for efficient and standardized management, sharing and visualization of such data. Most of the relevant applications capitalize on a variety of open source platforms and tools focusing on the visualization of the information collected from the citizen scientists in a dynamic way. To this end, Open Geospatial Consortium (OGC) standards such as the Web Map Service (WMS), Web Feature Service (WFS) and/or Sensor Observation Service (SOS) are utilized in applications, aiming to organize and present the citizen contributions and facilitate the interpretation of the environmental parameters under investigation. As discussed previously, one challenge here is data quality, more specifically, its effect on the decision to share particular datasets generated by citizens. Even after data quality checks and improvements these datasets often have significant uncertainties that need to be communicated in the sharing and visualization process. Further challenges are in developing standards that are both efficient for machine-to-machine processes and sufficiently expressive for sharing and visualization by human users.

Using data collected by citizens, depicted in the left-most component of Fig. 1, can be done for different purposes, such as augmenting monitoring information, improved modelling or even management of water resources. However, due to the uncertainties associated with these data, especially water level and velocity/discharge measurements, current studies on citizen science and citizen observatories focused on these data types do not report analyses of data usage. The current situation is such that crowdsourced or volunteered data are collected for scientific purposes, first as a proof of concept that such data can be obtained [36], and, secondly, with the purpose of studying how informative these data can be, due to their uncertainties [34]. The complexity of obtaining such data with citizens may be too high for the desired accuracy. For example, water models generally require data in certain standards (e.g. time series for upstream boundary condition) and therefore there is a need to conciliate the temporal and spatial availability of data with that of models, adjacent to the challenge of merging with other data sources such as remote sensing [12]. This can be contrasted with the comparatively easier acquisition of flood extent data that have been collected by volunteers, communities and stakeholders for flood risk management, attending specific data needs [38].

Finally, regardless of the purpose for which the data have been collected and used, it is very important that the actual results are visualized and feedback is provided back to the community that participated in data collection. Such feedback needs to be connected back to the issues raised during the data needs identification, especially to those that are of local concern of the involved citizens. This approach strengthens the ownership of the whole process by all involved partners, which in turn ensures its long term sustainability.

III. ADAPTIVE DATA COLLECTION FOR WATER RESOURCES MANAGEMENT

Based on the challenges identified in section II, there is a clear need to develop technologies that integrate the data cycle presented in the conceptual framework, enabling the transfer of identified data collection needs through the subsequent steps in the process. Moreover, these tools need to be adaptive; be able to handle new data needs.

As mentioned previously, this research is part of the Scent project, which aims at making the citizens the eyes of the decision makers. The project implements a range of technologies to achieve this goal, encapsulated within the so-called Scent Toolbox. It includes three tools that are featured in the cycle (Fig. 2): the campaign manager, a platform for communicating identified data needs (section III-A); the Scent Explore, an application for collecting data (section III-B); and two tools to extract measurements from images (section III-C).

In terms of architecture, the Scent toolbox includes a crowdsourcing platform, acting as a central data broker. It links the Scent frontend applications used by citizens to provide images, annotations, sensory data, event reports and videos, to all the other toolbox components.

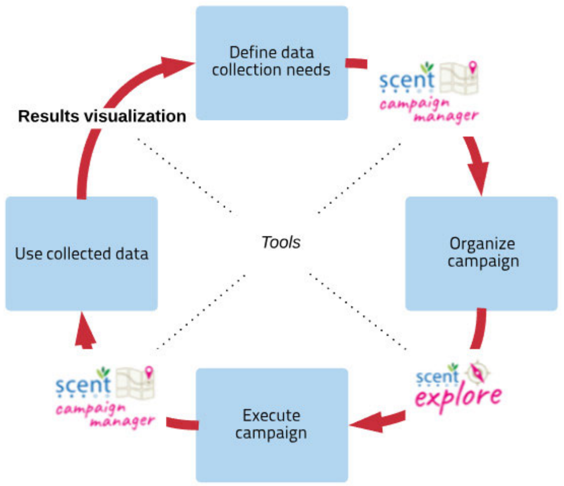

FIGURE 2. Data collection cycle for citizens' campaigns in water management with adaptive tools.

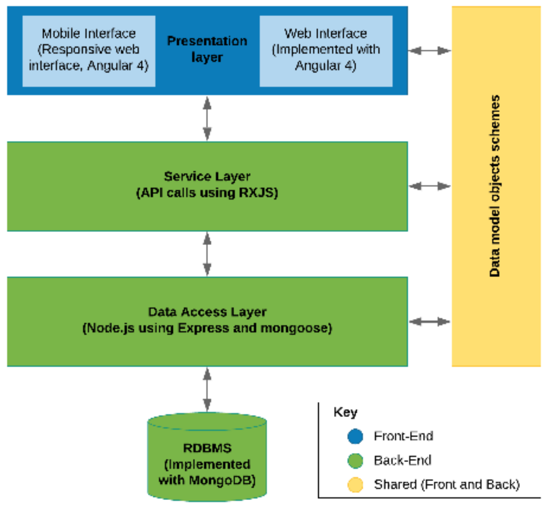

FIGURE 3. Scent campaign manager architecture.

It also ensures the quality of the citizens' image annotations through a data quality control module (section III-B). Some control routines were also implemented to assess the quality of image/videos for water-related data extraction (section III-C). Due to the novelty of the extraction tools, the quality of the final extracted measurement is not controlled automatically. After treated in varied toolbox components, the data are converted to international data sharing standards and stored, together with drone data, satellite imagery and other information acquired within the project.

The full toolbox architecture includes more elements and is very complex. As the focus of this study is on the feasibility of field experiments, the full toolbox architecture and benchmarks with similar solutions are not presented.

A. CAMPAIGN MANAGER

Scent Campaign Manager constitutes a web-based application that enables policymakers and local, regional or national authorities to monitor and streamline the collection of environmental information. More specifically, users are able to design citizen-science campaigns and define points of interest in locations where data on land cover/land use (LC/LU), soil conditions and river parameters are needed, mobilizing the use of the relevant components of Scent toolbox. The tool is also responsible for managing the policymakers' user accounts, their personal settings as well as for notifying them of any relevant reported events. In addition, it supports the visualization of the citizen-generated data (i.e. crowdsourced images, sensor measurements, etc) as well as maps of the areas of interest with information regarding LC/LU and flood hazards maps.

The Campaign Manager architecture (Fig. 3) has been designed according to the classical multi-tier (layer) system with a communication paradigm based on open source service-oriented architecture, where each component (service), interacts with the other through a set of messages written in a standard format. The architecture and relevant services are composed of the following layers:

- Presentation layer: Consisting of a mobile and web interface, constitutes the main gateway for interacting with the application's main services.
- Service layer: Includes services responsible for the communication between parts of the Presentation Layer as well as for the communication between Campaign Manager and external API endpoints provided by other Scent toolbox components.
- Data access layer: Consisting of Campaign Manager internal API endpoints.
- Database: Composed of a database and collections implemented using MongoDB.

B. SCENT EXPLORE

Scent Explore[1] is a gaming app for crowdsourcing. It was specifically designed to gather multiple types of environmental data and to be connected to the Scent Campaign Manager. Therefore, there are not very similar applications available for smartphones, mainly considering the augmented reality strategy applied.

Citizens can select a campaign and display the Points of Interest on a map (Fig. 4a). When approaching a PoI within a range of 75 meters, the application activates the camera. For pictures, augmented reality is also activated and the citizen can see an animal, to be captured by taking a picture of it (Fig. 4b). Based on the amount and type of animals captured, the citizen increases its score. By capturing an animal a picture is taken, for which the citizen chooses a tag: either land cover-related tags or the tag 'Water level indicator' for images of water gauges (Fig. 4c).

To improve the user experience, Scent Explore can generate PoIs itself, so the citizen has no long breaks between

[1]https://play.google.com/store/apps/details?id=com.xteamsoftware.scentexplore&hl=en

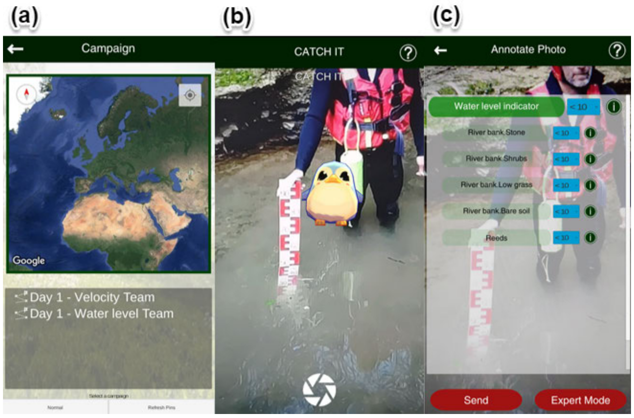

FIGURE 4. Scent Explore functionalities.

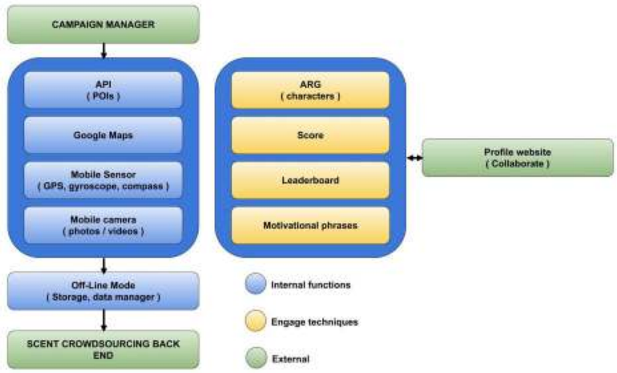

FIGURE 5. Scent Explore architecture.

2 PoIs and can have fun with the game. To accurately define the position of the PoI with respect to the citizen, in addition to using the position by GPS, the application uses the gyroscope (if available) for the direction, thus integrating the values with the compass data.

Both pictures and video are supported by the app functionalities. Pictures are used for land cover and water level estimation whereas videos are the raw material for velocity detection. All pictures receive tags from volunteers, either related to land cover or water level.

The app connects to the Scent Crowdsourcing Backend, which sends images to the Scent Intelligence Engine (SIE), where tags are attributed to the received images, with a confidence score. From SIE, images are moved back to the backend towards the Data Quality Engine, in which the citizen tags and the attributed tags are compared, as a validation process. If the SIE has a confidence score higher than a certain threshold, the SIE tag is validated; if not, human confirmation is required, weighing more as the tool loses confidence. Human confirmation comes from tags provided by volunteers in the field and can also be achieved through Scent Collaborate, a web-based platform in which citizens annotate images online. Tags provided by field volunteers are valued double the tags from online annotation. If a tag provided by a field volunteer is not found by SIE, it should pass through Scent Collaborate and will be considered valid if about 70% of evaluators agree with the presence of the tag. This procedure does not go on forever though: if the threshold is not reached after a maximum number of annotations, the tag is considered invalid.

Validated images of water gauges are sent to the Water Level Extraction Tool (WLET). For videos, Explore automatically connects to the Water Velocity Extraction Tool (WVET).

The app also provides support for the acquisition of improved data to the WLET and WVET tools. The app stabilizes images by directly accessing the CCD camera of the phone (i.e. sensors that record still and moving images), instead of using pictures interpolation. Image stabilization is improved by taking 3 photos at close range and choosing the photo with less variation of the mobile accelerometer. The resulting photos have sharper colours and better definition, despite being small in size (about 2M pixels). The video stabilization is obtained with the accelerometer, to compensate for the movement of the phone, which is relevant if citizens are aboard a boat. It detects the roll and up-down movements at each frame. Since the first tests, stabilization of videos are improved by 15%-20% using this technique.

Beyond improving the content through stabilization, the app improves positional data quality by attempting to get GPS data with an implementation of Position (3D) Dilution of Precision (PDOP). This means that whilst the GPS best-expected accuracy is in the order of 3-5 meters or 10-20 meters in isolated environments, with PDOP the position accuracy can be less than 2 meters or 3-5 meters, respectively. To allow the use of the app in conditions where there is not a good internet connection, Scent Explore can work online and offline. These features are all part of the Scent Explore architecture (Fig. 5).

C. ESTIMATION METHODS

As discussed in Section II, it is challenging to balance the accuracy of the measurement method, the easiness in data collection and the level of involvement expected by the citizen.

In order to balance these aspects, it was defined that the methods to estimate LC/LU, water levels and velocities would be based on pictures and videos, once these could be easily obtained by citizens and handled by Scent Explore app. All tools are based on pattern recognition algorithms.

Specifically for the water level and velocity tools, as discussed in Section II-B, the methods described in the current literature are not automated thus, in this study, new methods with automatic data extraction are proposed. For these tools, object detection was chosen, and it is implemented in Python, using the OpenCV 3.0 library.[2]

1) MAP SEGMENTATION TOOL

The map segmentation tool is a technology developed to obtain land cover maps from tagged images taken by citizens. The images are tagged according to a tailored taxonomy

[2]https://www.opencv.org/releases.html

FIGURE 6. Portable water gauges in different colours.

developed attending to identified data needs. The images that passed through quality control are then used in a deep learning classification method. Considering the complexity of the tool and the current focus on water-related technologies, this study does not discuss in details the inner workings of the tool.

2) WATER LEVEL EXTRACTION TOOL (WLET)

The Water Level Extraction Tool detects the water depth based on the picture of a gauge, graded according to international standards. The gauge can be fixed or painted to the river bank or it can be a portable one.

A histogram of oriented gradients (HOG) classifier is trained to recognize digits. HOG is a feature descriptor used in computer vision and image processing for the purpose of object detection. The technique counts occurrences of gradient orientation in localized portions of an image [39]. This method is similar to that of edge orientation histograms, scale-invariant feature transform descriptors, and shape contexts, but differs in that it is computed on a dense grid of uniformly spaced cells and uses overlapping local contrast normalization for improved accuracy. A visual explanation of the algorithm can be found in the ''Learn OpenCV'' platform.[3]

The procedure for extraction is described below:

- The trained classifier is used to detect digits in the image captured by the volunteers.
- The identified digits are processed to remove overlapping identifications.
- Based on the very distinct and uniform pattern of the hydrological gauges, the digits are formed into pairs.
- The pair that is located at the lower part of the image is chosen as the identified measurement.

By following this procedure, data is measured with an accuracy of 10 cm. While initially the ''E'' grading (distinct pattern of the hydrological rods) was to be taken into consideration to improve the accuracy of the estimation to 2 cm, the different models of rods used during the pilot activities did not enable its use (Fig. 6).

[3] https://www.learnopencv.com/histogram-of-oriented-gradients/

The extraction procedure is triggered for each image captured by Scent Explore that contained the 'water level indicator' tag and was validated. However, this validation is only checking if the image is indeed the image of a water gauge. Within WLET, a quality control routine is used to detect problems and invalidate images. These include that no numbers are recognized, image is of too low quality to confidently extract measurement and the image is corrupted/not available. In this study, we visually extract the water depth value from the pictures, to check the efficiency of the control mechanism.

3) WATER VELOCITY EXTRACTION TOOL (WVET)

For the extraction of velocity, a specific object is the target of detection in the frames of the video. The object selected was a tennis ball. The algorithm combines two distinct characteristics of the object, the round shape and the yellow colour. The procedure for extraction of velocity is listed beneath:

- The tool examines the videos captured by volunteers frame by frame. In each frame, the pre-defined floating object, a tennis ball, is located.
- The start and end of the video are determined, the start being the first frame that contains the object while the end is the first frame after this one that does not contain the object.
- The valid part of the video is processed again. For each pair of successive frames:
- The optical flow between two successive frames is calculated. Optical flow is the pattern of apparent motion of image objects between two consecutive frames caused by the movement of object or camera. It is a 2D vector field where each vector is a displacement vector showing the movement of points from the first frame to the second.
- The average displacement of the area identified as the object is calculated.
- The average displacement of the rest frame is calculated.
- The two values are subtracted. In this manner, the result is devoided of any noise that might have been caused by the movement of the camera.

Differently from images, videos are not validated by the Data Quality Engine. There is a quality control routine that invalidates videos in which: the pre-defined object is not found; video is not long enough (i.e. the object is present in fewer frames than the video frame rate, meaning less than one second of useful material); and video is corrupted/not available. Every valid video is associated with a confidence level. It is calculated based on the resolution of the video, the duration of the valid part of the video, the presence or not of stable elements from the surrounding environment as well as the stability of the video.

IV. APPLICATIONS AND RESULTS

The adaptive data collection approach with citizens' campaigns is being assessed in two real-world pilot cases. The case studies were selected to offer contrasting testing conditions. Each of these two deployments will provide valuable operational feedback from field experts, as well as end-user feedback regarding the actual experience with the Scent Toolbox. Preliminary steps towards preparing for the field experiments included:

- Identification of end-user and stakeholder needs and requirements relevant to citizen observatories, aided by the experience and expertise of local partners as regional authorities, as well as their strategic goals as a policy-maker.
- Insights on the design features of the campaign manager, aiming to enhance its relevance to the local context.

The workshops for the stakeholders followed the techniques described in Section II-A and revealed that in the Danube Delta there are high concerns in terms of water quantity and that the Mila canal is of major local importance. It was also stressed the importance of having a good hydrodynamic model. In Kifissos, in the other hand, it was discussed that it is a smaller scale and very dynamic area, either in terms of changes in land cover and land use but also in terms of the passage of floods. Thus, there is interest in monitoring in such a way that these differences are captured. A list of all identified data needs is presented in Appendix A.

In the following section the case studies are presented (Section IV-1), as well as results on how the campaigns were organized (Section IV-2), what the experience of volunteers was (Section IV-3) and what the results in terms of data were (Section IV-4).

A. CASE STUDIES

One pilot is located in the Central-West part of the Danube Delta whereas the Danube Delta itself is situated in the North-West part of the Black Sea basin, in Romania [40]. The Danube Delta covers approximately 4152 km^2 and the pilot area covers around 276 km^2. The second pilot is located within the Attica region, in Greece, which is surrounded by the mountains and within which the biggest catchment is Kifissos, with an approximate area of 379 km2 (71%) belong to Kifissos catchment [41].

The pilots differ completely in landscape and hydrological regime. The Sontea-Fortuna pilot is a wetland area, with approximately 92 lakes, and has an elongated shape, sitting between two branches of the Danube River. Given the dominant influence of the river, the majority of the constructed canals are large in dimension and aim to permanently and intensively replenish the waters of the large lacustrine complex. On the other hand, Kifissos catchment is mostly urbanised (68%) and has an approximate population of 4 million residents. The main watercourse of Kifissos River has a length of 38 km, flowing through Athens and discharging into the Mediterranean Sea. The upper part of the river has a natural watercourse, the central part is channelized, and most of the lower part is diverted underground prior to its final discharge. Due to the complex interaction of urban drainage and flow in the flatter downstream area, an upstream sub-basin was selected as a pilot, with an approximate area of 135 km^2.

The pilots also contrast in their interaction with floods. The Danube Delta contains large portions of protected area in which the floods are essential to balance the nutrients and consequently the ecosystem. Kifissos catchment is a flash flood-vulnerable area, as a consequence of the steep slope upstream, intense rainfall events and a rather low drainage capacity downstream. From the last 130 years (1880-2010), it is estimated an occurrence of 52 flood events with 182 casualties [42].

B. CAMPAIGN ORGANIZATION AND EXECUTION

As mentioned previously, the organization of campaigns is generally a task within research projects. In the case of Scent, local institutions that are project partners were the campaign organizers. Danube Delta National Institute (DDNI) and the Romanian Ornithological Society (SOR) led the efforts in the Danube Delta, while the Region of Attica (RoA)[4] was the main organizer in the Kifissos catchment, together with the Hellenic Rescue Team of Attica (HRTA).

In any citizen science initiative, engaging citizens is a complex task. Hence, for both case studies, desk research, online surveys and focus groups were organized to understand citizens' attitudes and behaviours. Based on this, for mobilizing volunteers in the Danube Delta, members from the Romanian Ornithological Society (SOR) were targeted and their involvement was fostered through direct communications and emailing. In Kifissos, RoA addressed to its broad network of stakeholders (municipalities from the regional authority of Attica, NGOs, individual citizens, citizen-led communities, walking groups, and scouts). In order to motivate and mobilize such diverse target groups, RoA disseminated the Scent brand communication material through mailing lists, via the Region's website and social media. Printed leaflets were handed out and press releases have taken place.

In general, based on the expected number of volunteers, campaigns were planned for an overall duration of 4-6 days (weekdays and weekends), including training. As the Sontea-Fortuna area is remote, with difficult access, all volunteers were present during the whole campaign. Initial/conceptual training was performed on the first day for all volunteers and it covered the Scent project, the Scent toolbox and the aim of the campaign. The volunteers then received daily training on the Scent Explore app. In Kifissos catchment, during each day of the campaign, an average of 1.5 hours was allocated for all types of training.

The daily campaign duration varied due to the volunteering profile and case study characteristics. In Sontea-Fortuna, volunteers were more open to being in the field for longer hours and therefore, the daily duration was 4.5-6 hours. On the

[4]RoA introduces and implements policies, including the development and application of strategic plans and the particularization of the guidelines of environmental policies at a regional level.

other hand, in Kifissos catchment volunteers were engaged in 2-3 hours of data collection, to support those citizens that were willing to become involved but could not invest in a time demanding activity. These values include transportation through the area.

In Scent, Points of Interest (POIs) were identified by the project's domain experts, taking into account the identified data needs. The final set of PoIs was defined iteratively with the routes, as citizens participate for a delimitated period. Once final decisions are reached, domain experts, developers and local partners setup the campaign in the Scent Campaign Manager.

In the Sontea-Fortuna area, routes are carried out by boats and a specific methodology was designed by Venturini et al. (in press) for prioritizing routes. In Kifissos, routes are covered by feet. Due to the unpredictability of PoIs conditions, routes were surveyed by the field experts (Hellenic Rescue Team Attica - HRTA) with a special focus on accessibility, safety and guidance. Moreover, during the campaign, volunteers were escorted by safety teams at all times.

This overall architecture for campaign organization is being executed for several campaigns planned through a one-year time horizon. Campaigns are organized twice: in the dry and wet period of each pilot. To simplify data collection by citizens, campaigns were organized thematically – per data type to be collected:

- Land Cover/Land Use
- River data collection (water levels and velocities)
- Sensor data collection (soil moisture and air temperature)
- Obstacles (obstacles to the flow within the river)

So far, the LC/LU campaign for the dry period was carried out in Aug/2018 (summer) and the river data collection one occurred in Sep/2018 (autumn). In Kifissos, the LC/LU campaign for the dry period was executed in Sep/2018. For the wet period, the river and sensor data collection were carried out in Nov/2018. We present the results for these campaigns, except the sensor data results as they are outside the scope of this study.

Overall around 400 participations were recorded during all campaigns (Table 1), with some volunteers participating more than once. In Sontea-Fortuna, numbers were lower as the local community is small and was not particularly targeted; birdwatchers came from many cities in Romania. For the LC/LU campaign in Sontea-Fortuna, the main incentive for participation was its inclusion in a birdwatching summer camp. It is assumed that the decline in number of volunteers in the river collection campaigns is due to the cold weather; volunteers were less willing to participate. In Kifissos catchment, more significant participation was obtained, due to its urban context and broader mobilization.

In the Scent Campaign Manager, a campaign was setup for each day together with the corresponding points of interest to be visited (Fig. 7).

PoIs definition was very contrasting between the types of thematic campaigns. For LC/LU, multiple PoIs were set up along the routes to ensure a high number of pictures. For river data collection, few PoIs were set up in specific locations. Due to potential impossibilities to visit PoIs in Sontea-Fortuna (e.g. dense underwater vegetation, too low water levels), extra PoIs were also set up. In Sontea-Fortuna, from all setup PoIs (including extras), 67-83% were covered, except for the last day, for which only half were visited due to a large detour (Table 2). In Kifissos catchment, the choice of restricting data collection to 2-3 hours, together with traffic conditions, culminated in less PoIs to visit. The river data collection campaign was successful for the first two days but, due to unexpected rainfall, on day 3 the route from day 2 was revisited (no rain in that area) and on day 4 the campaign was cancelled.

In both case studies, 1-3 routes were planned for each campaign day. For the Sontea-Fortuna case, most of the paths were covered more than 80 percent (Fig. 8). Some were not fully completed or were altered due to lack of accessibility, as anticipated. In Kifissos, due to a more controlled and

TABLE 1. Number of volunteers per campaign.

Campaign type	Sontea-Fortuna	Kifissos catchment
Land Cover/Land Use	62	183
River Data Collection	27	129

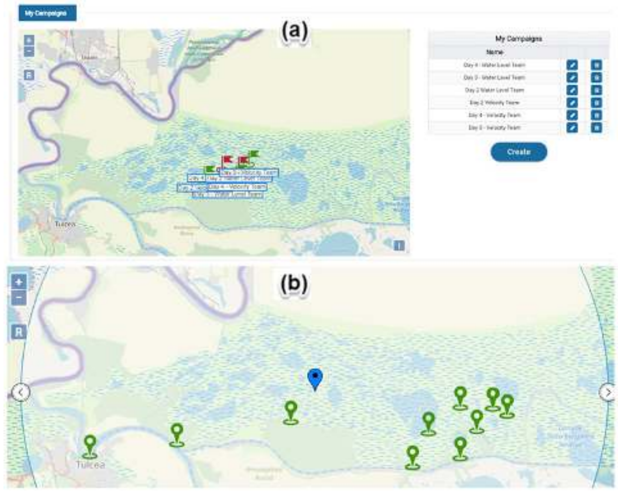

FIGURE 7. Scent Campaign Manager. (a) Setup of river data collection campaign; (b) Setup points of interest.

TABLE 2. Planned and realized number of Points of Interest visited in the river data collection campaign.

Day	Sontea-Fortuna		Kifissos catchment	
	Planned	Realized	Planned	Realized
1	15	10	11	9
2	12	10	7	6
3	22	18	5	5[a]
4	13	7	3	0
Total	62	45	26	20

[a]Not the planned PoIs

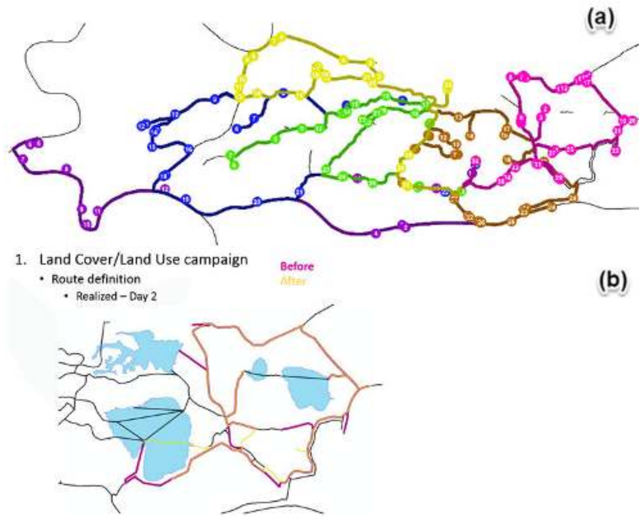

FIGURE 8. Pathway selection. (a) All routes planned for Sontea-Fortuna LC/LU campaign; (b) Example of planned and realized routes for the second campaign day.

TABLE 3. Planned and realized number of questionnaires per campaign.

Campaign type #Questionnaires	Sontea-Fortuna		Kifissos catchment	
	Planned	Realized	Planned	Realized
Land Cover/Land Use	62	6	183	100
River Data Collection	27	17	129	89

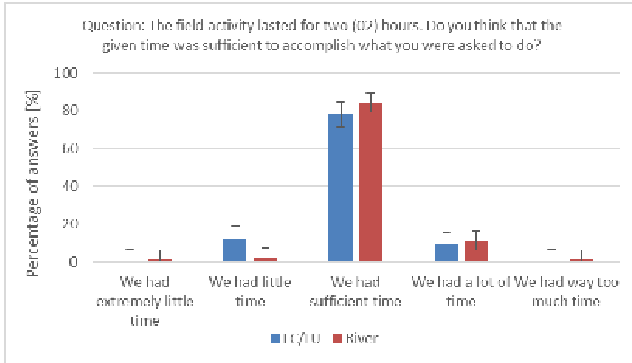

FIGURE 9. Answers to the campaign duration in Kifissos case study.

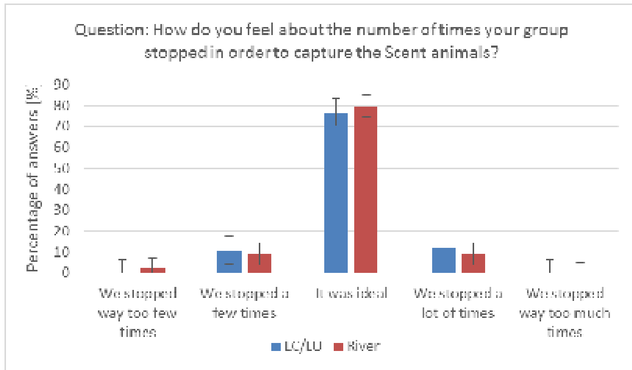

FIGURE 10. Answers to the number of stops in Kifissos case study.

previously surveyed environment, all attempted routes were covered.

C. CAMPAIGN AND APPLICATION EXPERIENCE

The fieldwork carried out by volunteers was evaluated by questionnaires distributed to all the participants at the end of the campaign. The questionnaires aimed at gauging how volunteers experienced the campaign and the app. The feedback provided is used to tailor the campaigns and the app to increase engagement.

The questionnaires were anonymous but enquired some demographics. They included both open and multiple-choice questions, nine of which were targeted to the evaluation of the field activity. Initially, four questions were designed to evaluate the training experience, but it was realized that more concrete feedback on the app experience was necessary and therefore, the first were substituted by the latter from the river campaign onwards. Unfortunately, due to logistic problems, only 6 questionnaires were answered in the LC/LU campaign of Sontea-Fortuna, which are not statistically significant and thus are evaluated subjectively. A little over half of the questionnaires were returned answered (Table 3). With 95% confidence, the margin of error ranged from 5.81 to 14.74%.

In Kifissos pilot, responses for both LC/LU and river campaigns were very similar. The response to the time spent on the activities was positive. Around 80% of the volunteers thought they had enough time to collect images and videos (Fig. 9) and around 63% considered that the two hours allocated for it were enough. In the Danube Delta (where 5 hours were spent in the boat), 65% of the surveyed volunteers considered it a little too much and almost 90% would prefer to stay up to 4 hours.

The overall feeling during the field activity was also positive. 83-95% of the participants regarded it as an interesting to excellent experience; in the LC/LU campaign and 91-95% in the river campaign. Up to 10% overall found it boring, tiring or disliked the weather. In Sontea-Fortuna the situation was different, in the river data collection campaign these motivations were the main reason why the timing was not perfect.

Questions about the gaming experience were also made, in which 90% of the volunteers judged from normal to extremely easy to play the game by capturing the Augmented Intelligence animal. Three-quarters of volunteers agreed on the pace with each the group was moving to perform data collection (Fig. 10), although considering the number of animals that appeared 60% were satisfied, about 15% thought it was too much and 20% thought it was too few. Again, looking at the responses in the open questions pertinent to the field activity offers useful insight. A few participants expressed their confusion regarding the location of the Scent animals, mentioning that at times the animals appeared on insignificant locations –such as in the sky; or were in a non-interesting location that they would prefer to photograph.

In what concerns the evaluation of the training session, almost 90% was satisfied with the guidelines provided and the remaining were partially satisfied.

Issues that emerged after analyzing the open questions focused on the use of the Scent Explore app and were pertinent to energy consumption, access to Wi-Fi and compatibility with older versions of smartphones' operating systems. Regarding the design of the Scent Explore app, many participants requested for more categories in order to be able to classify the captured images more accurately and asked for easier functionality and usability of the taxonomy process. Finally, a few participants wished for better accessibility, bigger letters and clearer images in the app.

Other aspects were that they wanted to see more birds, that the tasks were repetitive and boring and that there were issues with the instructions and the app. Considering the capturing of animals, opinions were divided; about half of the volunteers considered it hard to capture animals with the boat moving, and the other half considered it easy. Around 60% of the people thought the number of animals appearing was good, whilst the other 40% considered they were too many. There is also some dispersion of opinions on boat stops; half considered it was ok, about 30% thought it was too much and about 20% thought there could be more. The ones that said it was too much had more PoI in their route.

Overall, the answers to the open questions were very shallow and many participants didn't answer all boxes. We assume the reasoning is that due to the cold wind generated by the wind speed, the participants didn't want to stay with their hands out for too long. Three volunteers did not answer the open questions and for some questions there were only 60% of responses. What volunteers liked the most about their boat experience was the scenery: the view, birdwatching, the Danube Delta habitats. Many volunteers from one boat answered it was to spend time with nice people. The least liked aspects were the cold and the wind. Also, some thought it was too much time, that some of the activity was pointless and that the app was buggy. Suggestions for improvements orbited around making a shorter trip, making the trip in good weather. Some other points were to improve the app, use more professional methods and diversify the activity.

The two main aspects of the app that people liked the most were that it was fun to catch animals and that the app is innovative, with an interesting way of gathering data and a potential to citizen science. A few volunteers expressed they didn't like the app at all. Considering what they disliked, the most common was that the app was too slow, crashed and had bugs. Some said it was not working properly and was not user-friendly, while others said that the animal system was childish. Suggestions for improvement were mainly on improving the speed and making it more friendly and stable. Some volunteers said the app needs redeveloping or making a new one and one volunteer suggested a better explanation of usage.

A little under half of the volunteers were male and 35% female, whilst the remaining would prefer not to state their gender. Age-wise the group was very homogeneous, with 65% in the range of 35-44 years old, about 25% a bit younger (25-34) and the remaining 10% were older (45-64).

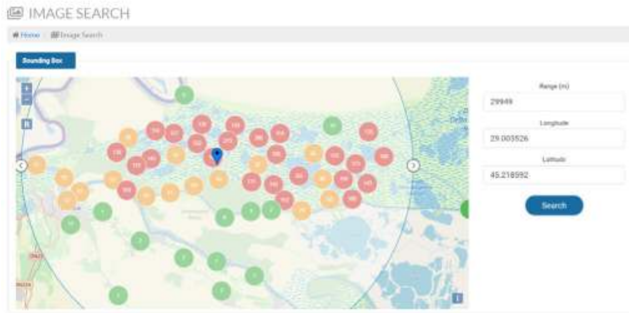

FIGURE 11. **Scent Campaign Manager tool showing results for Sontea-Fortuna land cover campaign.**

During the campaigns in the Kifissos pilot, challenges of technical nature emerged, as well as difficulties related to the particular characteristics of the field, in combination with the weather conditions. Technical challenges included battery-discharging issues as the apps proved energy consuming and internet connectivity. Those were addressed in the second implementation of the campaign by providing portable Wi-Fi hotspots and power banks to the volunteers and furthermore, mobile devices were made available to the participants that did not wish to use their personal smartphones.

In what concerns difficulties of the second category, in both campaigns participants were faced with rather challenging weather conditions ranging from extreme heat to heavy rainfall that rendered exploring the field a demanding and exhausting experience. To this end, the team decided to incorporated more flexibility in future implementations and allocate more days to future campaign in order to be able to reach the participation numbers and the particular goals of each one.

In the Danube Delta, similar problems were encountered. The weather was also challenging in both campaigns and the time in the boat proved to be long, even when reducing from a 6h to 5h journey. Since the area to be covered is extensive, optimization of routes is an option to be explored, as well as more engaging techniques to keep the volunteers interested for a longer period.

D. RIVER DATA COLLECTION RESULTS

After the campaigns, the data reach the Scent Campaign Manager, where the decision-maker can see the resulting images and videos (Fig. 11). These data contain in their metadata the results from the WLET and WVET.

All in all, 9568 pictures and 230 videos were collected through the four campaigns. This translated in 10s of GB data. Specifically during river data collection campaigns, 306 pictures and 230 videos were collected.

We evaluate the results considering:

- The efficiency of the data collection cycle in providing the expected amount of data;

- The quality of the resulting dataset. This is a two-step process:
  - Image classification validity: if the right type of images were obtained;
  - Image/Video quality validity: if the image/video is good enough to have the water level/velocity extracted.

High-quality traditional measurements were collected during the campaigns. In the Danube Delta, Acoustic Doppler Current Profiler data was collected and in Kifissos catchment, flow meter and float methods were among the methods used to measure the water velocity. However, due to the collected data complexity, which vary is space and time, and mainly of water velocities, which vary in magnitude and direction, also considering the developed tools' novelty, assessing the quality of water depth and velocity extraction is not included in this manuscript. Comparisons with traditional measurements are presented in future research.

The amount of data collected during the campaigns is directly related to the number of volunteers performing the task. Volunteers were separated into water level and velocity teams in order to facilitate their understanding, to better adapt to the application and thus to obtain better, more "specialized" measurements. Because velocity measurements are more complicated, two-thirds of the volunteer group would be assigned for velocity and one third to water depth.

In view of that, the expected results for the river data collection measurements were:

- Sontea-Fortuna:
  - Water level: for each PoI, 4 volunteers (2 per boat) were expected to take pictures, 1-2 pictures each. It was expected at least 4 pictures per PoI.
  - Velocity: for each PoI, 10 volunteers (5 per boat) were expected to make videos. For small rivers, the ball would be thrown in the middle of the river (1-3 times) and, for large rivers, the ball would be thrown in three locations (near banks and in the middle, 1-3 times in each location). Therefore, it was expected at least 10 videos per PoI.
- Kifissos catchment:
  - Water level: for each PoI, 5 volunteers were expected to take pictures, at least 1-2 pictures each. It was expected at least 6 pictures per PoI;
  - Velocity: for each PoI, 10 volunteers were expected to make videos. The ball would be thrown in the middle of the river (1-3 times). Therefore, it is expected at least 10 videos per PoI.

In Table 4 and Table 5, results in terms of collected number of pictures/videos are provided. Due to technical issues, there was a problem with video uploading in the Sontea-Fortuna case study and no videos were collected through the tool. Videos collected outside the app were inserted into the platform.

In the Sontea-Fortuna case, it is visible that the total number of images has been very positive in the first two days of the campaign, while there was a decline in Day 3. In Kifissos, it is clear that the minimum expected numbers were reached or surpassed.

In terms of videos for Sontea-Fortuna, the cause for the very low amount of videos compared to the expected one was the technical issues, which is connected to a poor internet connection, as the number expected videos were easily surpassed in Kifissos where that was not an issue.

As described in Section III, collected images are received by the system and sent to the image classifier and afterwards to the Data Quality Engine. Images that for technical reasons did not reach the classifier were counted as 'Not available'; classified images are either 'Valid' (there is a gauge in the image) or 'Undecided', being sent for further manual annotation at Scent Collaborate. These statistics are presented in Table 6. In Sontea-Fortuna, most of the images that reached the tools were valid, while in Kifissos, human confirmation is needed for about a third of the dataset.

After classification validation, image quality for water depth extraction was automatically evaluated by the WLET. Because this dataset is very new and the data quality control routine is being tested, manual evaluation was also performed.

The manual process allowed for a diagnosis of the images collected (Fig. 12). For the Sontea-Fortuna area, more than

TABLE 4. Number of expected and collected pictures (water level).

Day	Sontea-Fortuna		Kifissos catchment	
	Expected/ Updated[a]	Collected	Expected/ Updated[a]	Collected
1	60/40	73	66/54	69
2	48/40	61	42/36	14
3	88/72	38	30/30	51
4	52/28	0	18/0	0
Total	248/180	172	156/120	134

[a]Considering the number of PoIs visited

TABLE 5. Number of expected and collected videos (velocity).

Day	Sontea-Fortuna		Kifissos catchment	
	Expected/ Updated[a]	Collected	Expected/ Updated[a]	Collected
1	150/100	3	110/90	106
2	120/100	2	70/60	99
3	220/180	8	50/50	92
4	130/70	20	30/0	0
Total	620/450	33	260/200	297

[a]Considering the number of PoIs visited

TABLE 6. Number of unavailable, undecided and valid pictures collected (water level).

Day	Sontea-Fortuna			Kifissos catchment		
	N/A[a]	Undecided	Valid	N/A[a]	Undecided	Valid
1	10	6	57	2	18	49
2	7	4	50	2	3	11
3	5	0	33	1	23	27
4	0	0	0	0	0	0
Total	22	10	140	5	44	87

[a]N/A: not available

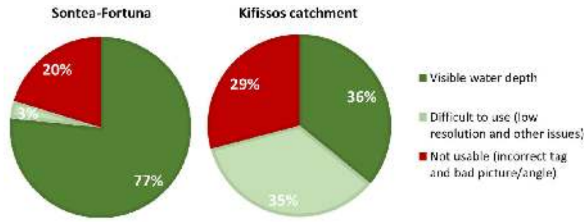

FIGURE 12. Water depth manual evaluation of pictures classified correctly.

TABLE 7. Evaluation of the automatic image quality control routine.

		Sontea-Fortuna		Kifissos catchment	
		Manual control		Manual control	
		Valid [%]	Invalid [%]	Valid [%]	Invalid [%]
WLET	Valid [%]	73	9	32	19
	Invalid [%]	0	18	4	45

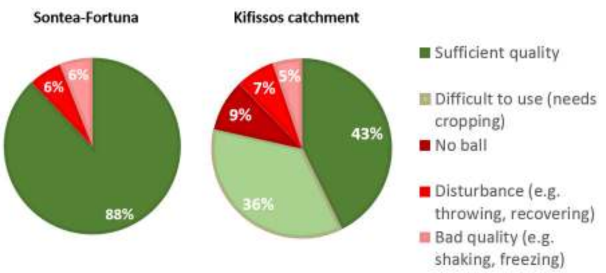

FIGURE 13. Water velocity manual evaluation of videos.

three-thirds of the images are good to be used, while in Kifissos, the usability of images is reduced, once the water gauges were more distant from the volunteers. Examples can be found in Appendix B.

The automatic control obtained similar percentages. For Sontea-Fortuna, 82% of the images passed the control, while for Kifissos 51% passed (Table 7). The routine performed well, with 9-23% of errors, mainly by missing invalid images in Kifissos case study.

Upon preliminary screening of the WLET results, it became clear that even using gauges that follow international standards, there was a diversity of the water level indicators that were available in the two pilot areas. The tool was trained to identify two digits of the same size but in the Danube pilot, the indicator had a larger number to indicate the meter and a smaller one for the centimetres, not following the traditional pattern. The in-depth quality assessment of extracted results and its usability is not included in this study.

For water velocity, videos were also evaluated manually (Fig. 13). In order to diagnose their overall quality, many aspects were assessed, including if the camera was following the ball, if the ball throw was recorded, etc.

Based on this analysis, results for the Sontea-Fortuna area indicate that most videos are suitable for automatic velocity data extraction. The main challenge for the Sontea-Fortuna pilot was the fact that there were many floating obstacles,

TABLE 8. Evaluation of the automatic video quality control routine.

		Sontea-Fortuna		Kifissos catchment	
		Manual control		Manual control	
		Valid [%]	Invalid [%]	Valid [%]	Invalid [%]
WVET	Valid [%]	36	0	19	32
	Invalid [%]	51	12	24.5	24.5

mainly small branches in many of the videos, affecting the results of the optical flow calculation and the overall water surface velocity calculation.

Similarly to images, for Kifissos, less than half of the videos were satisfactory for automatic extraction. About a tenth of the videos were uploaded without the ball being recorded. In the field, the main challenge was the mechanism, the fishing rod, used to secure the floating object and ensure that it would be collected from the river. Many videos include the part where the ball is reeled, affecting enormously the extracted value. If videos contributed by citizens could be cropped to extract the part without issues, more 35% of the videos could be used.

Considering the quality control mechanism (Table 8), around half of the data was correctly filtered. Although a smaller percentage compared to the images, this is an expected result, as more aspects were considered in the manual evaluation than in the automatic evaluation. The high number of false negatives for the Danube Delta is probably connected with the difficulty in identifying the ball when the water colour was close to the colour of the tennis ball, or due to the sun reflection, affecting detection.

Thus, overall, the number of images and videos has fairly covered the minimum expected outputs. Technical issues, related to attempting to upload data in a very low connectivity area, were the main cause of lower numbers in the Sontea-Fortuna case study. Another important point is that there is an inherent loss of data through the collection process. This is due to the automated processing but also reflects that training could be improved, for example to reduce the amount of videos where the tennis ball is recorded being thrown/recovered. Regardless, the manual validation allows us to conclude that a significant parcel of the dataset has sufficient quality for measurement extraction and that the control mechanisms, which can be improved, already help in filtering bad data. In a separate study, the quality of the extracted values in comparison to traditional field measurements (e.g. Acoustic Doppler Current Profiler), will be evaluated.

Based on results obtained so far, local authorities involved in the project were able to identify potential uses for the collected data in decision-making within their institutions.

In the Danube Delta, the Danube Delta Institute for Research and Development has been working on increasing their understanding on the drivers of biodiversity loss in the region. This includes the knowledge of low flows, which can be monitored through citizen river collection campaigns. In what concerns Region of Attica, land use/ land cover data collected during the pilots provide accurate and updated input on a small spatial scale that will facilitate a more precise recording of the conditions of Kifissos riverfront. As the area is densely urbanized, these preliminary datasets, as well as an ongoing reporting element, will enable responsible authorities to monitor and control unauthorized uses and remove artificial obstacles both from the riverbanks as well as the riverbed that may pose further risk in case of a flooding, while addressing maintenance needs more efficiently and promptly. Furthermore, river data collection, in conjunction with meteorological data and updated land use mapping, will help Region of Attica configure more accurate flooding trails and flood risk maps. Such data will allow for the identification of the most vulnerable areas and citizens and the preparation of appropriate evacuation plans. Thus, Region of Attica will enhance its capacity for risk management and response to natural disasters.

V. CONCLUSIONS AND RECOMMENDATIONS

In this study, we conceptualized the full cycle of data collection in the case of citizens' campaigns organized to fulfil stakeholders' data needs. The cycle started with the identification of data needs for data collection, in which it was identified that water-related data collection is necessary for the Sontea-Fortuna pilot and that higher resolution land cover data is important for the scale and quickly changing urban conditions of Kifissos catchment. The campaign manager tool used to link such data needs to the campaign execution has worked well, although it has not been tested single-handedly by authorities.

Considering the campaign execution, fostering and sustaining engagement for the purposes of the project is proving to be a demanding and challenging task. As it was inferred from the evaluation process, for the campaigns to become more appealing, they should be organised as a holistic experience in nature that focuses more on capacity building and knowledge transfer within the context of the project, rather than an exhaustive route between PoIs. To this end, local partners consider incorporating the aforementioned ideas in the next campaigns. Despite the difficulties, the number of volunteers is still considered good overall.

In terms of the experience of the gamified application, it was stated that it consumed considerable energy and had bugs and crashes, even though part of the volunteers appreciated the gamification.

Lastly, the experience of having the data going through the Scent Toolbox in low connectivity environments culminated in loss of data. It is recommended that experiments are done prior to the campaign and that monitoring of the data stream is done in real-time during the campaign. The number of images received corresponds to expectations, as well as videos for the Kifissos case study. From the initially expected volume of pictures and videos, 34% and 19% were valid for water depth and velocity extraction, respectively, 50% if considering only videos of Kifissos case study and 92% if such videos are treated to remove problematic parts.

TABLE 9. Data needs identified and addressed in the Sontea-Fortuna case study.

Data need	*Addressed?*
Water level	Yes
Water temperature	No
Air temperature	No
Water surface velocity	Yes
Digital elevation	No

TABLE 10. Data needs identified and addressed in the Kifissos catchment case study.

Data need	*Addressed?*
Land cover/Land use	Yes
Digital Elevation	No[a]
Soil conductivity	No
Soil Moisture	Yes
Air temperature	Yes
Water level	Yes
Water surface velocity	No
Water temperature	No
Water flow obstacles	Yes[b]
Hydrographic network	No
Geological and hydroleogical map	No

[a]Research on this topic was made during the project but not incorporated in the toolbox
[b]The collection of this type of data was incorporated in the toolbox but acquisition of data is complex and thus was not prioritized.

FIGURE 14. Quality of water depth images in Sontea-Fortuna.

FIGURE 15. Quality of water depth images in Kifissos Catchment.

Overall, we conclude that it is feasible to implement author-centric citizens' campaigns and that the campaigns were successful for the pilot applications. The quantitative water-related dataset (306 images and 230 videos) is in itself a valuable contribution to the citizen science and water resources community, as such a volume has been scarcely reported in the scientific literature, mainly in remote areas such as the Sontea-Fortuna area. The implemented novel technologies were pivotal to allow for such volume to be collected. Throughout the cycle, there were data losses due to technical issues, logistics, natural conditions and quality of citizen measurement. These losses were significant and there is a need to improve the whole process to reduce them. Mainly, further work lies in evaluating the value of data in comparison to traditional measurements. Also, the value of data to authorities: to evaluate if/how the land cover maps and the water level and velocities measurements were used by decision makers. By doing so the last step in the proposed conceptual framework is completed and new, more targeted data needs can be derived, in an iterative design. Finally, further work also lies in performing a cost-benefit analysis of executing citizens' campaigns.

APPENDIX A

The data needs identified by workshops with stakeholders in the pilot areas are listed in Table 9 and Table 10. It is indicated if each data need has been addressed in the composition of the Scent toolbox.

APPENDIX B

Volunteered water depth data quality was manually validated by visual inspection. The data was classified according to their usability:

- Visible depth: accurate readings (1-2 cm uncertainty)
- Difficult to use: readings are possible with less certainty due to low resolution of the image and other issues (10 cm uncertainty)
- Not usable: images that do not have a water gauge in them, the water surface is not captured or the gauged is too tilted.

Examples of these categories are presented in Fig. 14 and Fig. 15.

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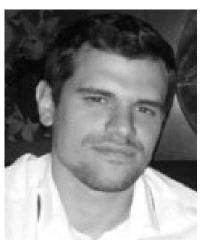

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