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New approaches to environmental monitoring: the use of ICT to explore volunteered geographic information

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Abstract Citizen participation in environmental monitoring is not a new idea. However, recent developments in information and communication technologies (ICT), such as the social web and the miniaturization of sensors, have created new opportunities to promote citizen participation in environmental monitoring. The analysis of existing citizen initiatives that use ICT tools, identified the need for a framework conceptualizing ways to increase the contribution of volunteered geographic data in environmental monitoring. Environmental Collaborative Monitoring Networks (ECMN) are proposed in this paper as a framework that combines the concepts of traditional environmental monitoring networks with the ideals of the open source movement. Such framework can guide the creation of fixed and mobile monitoring networks and is organized based on three building blocks: (1) Motivated Citizens; (2) Sensing Devices; and (3) Back-End Information Infrastructure. To illustrate the issues involved in the implementation of the building blocks of ECMN, the Senses@Watch project is presented, which explored the use of sensory data as a source of monitoring data.

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Introduction

Monitoring activities seek to measure, assess, and gather information on the state of the environment to reduce and control uncertainty. The notion of risk that motivates the establishment of monitoring activities has pushed monitoring systems to evolve from data centered systems into decision support systems. As in other domains of environmental management, the public is becoming engaged in monitoring activities. Public participation follows different models, which may range from accessing official data to collecting data. The first model is limited to providing information to the public, although it represents a first step to involve citizens in environmental monitoring. On the other hand, public participation in data collection activities, the second model, implies a plurality of legitimate perspectives. In general, both models are pushing the creation of a new type of monitoring system that integrates various types of knowledge from experts to lay persons.

Public participation in environmental monitoring has also benefited from developments occurring in information and communication technologies

(ICT). ICT are one of the central elements of monitoring as well as transformative forces in contemporary society. In environmental monitoring, ICT have been used to facilitate activities such as data collection, data search, presentation, validation and communication among stakeholders. The spatial nature of environmental monitoring data has favored the exploration of geographic information technologies. The relevance of such technologies for environmental monitoring is illustrated by the use of remote sensing data or by the dissemination of information through webGIS applications.

Currently, citizen participation is limited to isolated efforts and ad hoc initiatives. There is the need for a framework that supports citizen initiatives and integrates them in environmental decision-making. According to Whitelaw (2002) the development of such a framework is supported by concepts such as sustainable development, planning theory and practice, public participation, community development and governance.

This paper focuses on the role of citizen participation in environmental monitoring. It presents existing models of public participation and analyses the characteristics of existing volunteer monitoring initiatives. Furthermore, it evaluates the role of ICT in promoting citizen participation in environmental monitoring. Environmental Collaborative Monitoring Networks (ECMN) are proposed as a framework that explores the potential role of ICT in promoting the collection of volunteer monitoring information. Finally, the project Senses@Watch, which promotes the use of sensory data within environmental monitoring, is presented to illustrate the issues involved in the implementation of the building blocks of ECMN.

Environmental monitoring and public participation

Monitoring systems are responsible not only for collecting and registering the baseline data on environmental systems but also for supporting early warning systems and for defining and creating policies to target resource allocation. Accordingly, monitoring systems include data management, assessment, and decision-making. Monitoring can thus be used as an advocacy and communication tool to track the progress towards achieving specific development goals. Nevertheless, according to Vaughan et al. (2003) one of the major limitations of environmental monitoring is provision of timely identification and warning of emerging problems to the public, stakeholders, research personnel, and managers. Additionally, monitoring systems have shown difficulties in providing information that will raise awareness, educate and provide the basis for informed decisions. Even so, these downsides have not restrained the public from participating in environmental monitoring.

Public participation in environmental monitoring systems has benefited from a general social trend that favors citizen involvement in planning, decision-making, and policy implementation (Stokes et al. 1990). This trend is partly driven by the democratic position that those affected by a decision should be involved in the decision-making process (Carver et al. 2001; Roseland 2000). Additionally, Peng (2001) refers to a convergence of new legislative requirements, growing citizen activism, and changing professional values as leading forces in increasing citizen participation in community planning and decision-making process.

Within environmental monitoring, public participation may follow two major models: (1) Access to baseline data that enables citizens to participate in environmental planning and management activities. (2) Citizen participation in environmental monitoring systems development, implementation and management. While often linked, participation and access are distinct issues and they correspond to different levels of power sharing. The two models described above have different impacts in the three forms of empowerment proposed by Elwood (2002). Both models increase access to the information produced by monitoring systems and therefore increase the distributive empowerment, but only the second model has the ability to foster procedural and capacity-building forms of empowerment.

Throughout the world, citizen access to environmental monitoring data is conditioned by public information access policies, as most of the data produced by environmental monitoring systems are owned by the public sector. Access to public information includes regulatory frameworks and the development of the infrastructure necessary to deliver the information. Two examples of regulatory frameworks in the European context are the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (the Aarhus Convention) and the directive 2003/98/EC of the European Parliament and of the Council of 17 November 2003 on the re-use of public sector information.

The infrastructure needed to allow public access to environmental monitoring data also requires regulation. One example, specifically related to environmental policies, is the INSPIRE Directive, which aims to create the European Spatial Data Infrastructure (SDI). Throughout the world, the development of SDI has facilitated public access to environmental information, as this is predominantly spatial.

The second model of public participation implies the participation of citizens in the design and implementation of monitoring programs. Designations such as volunteer monitoring (mainly in the US) and community based monitoring (mainly in Canada) have been used to refer to this type of model. In this paper the designation of volunteer monitoring is used, since it is wider and may include individual volunteer efforts.

In volunteer monitoring, citizens participate in different activities ranging from scope definition to data collection and dissemination. Public participation is therefore a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track and respond to issues of common concern. Empowerment may occur differently according to the way citizen participation is organized, as well as the way monitoring stakeholders cooperate with each other shaping their community.

Volunteer monitoring has received interest among scholars in the natural and the social sciences who have researched topics such as data accuracy and credibility (e.g. Nicholson et al. 2002), benefits and drawbacks (e.g. Bromenshenk and Preston 1986), best practices (e.g. Fortin 2000), and the educational value of such initiatives (e.g. Cuthill 2000). The major benefits and disadvantages of volunteer monitoring identified in this literature are summarized in Table 1.

The characteristics of volunteer monitoring initiatives vary and their level of formalization ranges from individual complaints by concerned citizens to highly organized volunteer data collection initiatives funded by government agencies. Whitelaw et al. (2003) identifies the following four categories of volunteer monitoring initiatives, which are not mutually exclusive:

– Promoted by official entities. Volunteer monitoring is thought of as a way to complement the actions of official networks and scientific community. The US National Weather Service

Table 1 Benefits and disadvantages of volunteer monitoring

Type	Benefits	Disadvantages
Data	Support the development of early warning systems.	Data credibility. Metadata are scarce. Due to the volunteer lack of specific knowledge and training volunteered geographic information is not always comparable to data collected by others. Unpredictable level of volunteer commitment.
Logistics	The participation of volunteers can be a cost effective method to maintain data collection activities. Augment the geographic area and the time period being monitored.	Public participation may require previous training or closely supervision of volunteer work. Requires the organization of training materials.
Social impacts	More informed and educated public concerning environmental problems and scientific methods. Volunteer monitoring promotes cooperation instead of the traditional "us versus them" approach.	The NIMBY principle, may affect citizen participation, distorting in some cases the goals of the volunteer initiative.

Notes: NIMBY, Not In My Back Yard

Cooperative Observer Program[1] is an example of such an initiative.
- Interpretive approaches, which place emphasis on the educational aspects of monitoring through participation. The GLOBE and the Mapping the Monarch migration in real-time project by the Pathfinders Science are examples of such initiatives.
- Advocacy monitoring where citizens use monitoring data to "push for appropriate action to be taken". The Anacostia RIVERKEEPER®[2] is an example of a volunteer monitoring initiative focusing on policy and land use decisions with impact on the river.
- Multiparty monitoring, which involves individual citizens, private landowners, representatives of civil society organizations, business, government, and others committed to the community. The multiparty approach intends to influence decision-making through cooperation as opposed to advocacy. The Chesapeake Bay citizen monitoring program is an example of such approach.

This variety of initiatives will tend to produce volunteered geographic information with diverse characteristics. Volunteered geographic information resulting from observing and recording the occurrence and distribution of species might generate qualitative and quantitative data, while sampling and measuring physical and chemical parameters, such as temperature or dissolved oxygen, will tend to produce only quantitative data. Surveying and mapping of earth and marine features might generate both quantitative and qualitative data. For a more detailed review of the characteristics of volunteered geographic information that might emerge from different types of data collection activities, see Gouveia et al. (2004).

Volunteer-collected data have a strong spatial and multimedia component and can include: (1) opinions, or individual complaints, through written or spoken messages; (2) objective and factual information, such as the detection of specific species within a geographic area, using texts, photographs, sketches and videos; (3) measurements using sensors such as a pH meter or a GPS. Due to their nature, the first two data types may have a strong sensorial component, because volunteers interact with the environment through human senses.

Volunteered geographic information has been used by researchers and state agencies as a source of environmental data (Root and Alpert 1994; Au et al. 2000; Young-Morse 2000). Examples exist of successful integration of volunteer data with professional data (Fortin 2000). Although some studies compare the data collected by professionals and by citizens (Root and Alpert 1994; Au et al. 2000; Clemons and Conklin 2000; Scinto 2000; Fore et al. 2001; Nicholson et al. 2002), the broader characteristics of VGI require further research. For example, data validation may benefit from the creation of collection and registration procedures that include a measurement of data reliability.

Nevertheless, the dissemination and communication of volunteered geographic information is still a major constraint on the potential impact of volunteer monitoring initiatives in environmental decision-making. Currently, access to volunteer-collected data is difficult since these data are dispersed and not structured, restricting their use. Even in an environment where trust among volunteer data producers and data users has surpassed the major obstacles for data use, data dissemination and communication is limited to isolated efforts and ad hoc initiatives. ICT have been used in several initiatives to overcome such limitations and make volunteer-collected data more widely available. The role of ICT for promoting public involvement within environmental monitoring is analyzed in the next section.

The role of ICT to support public participation in environmental monitoring

The establishment of more scientifically valid environmental monitoring systems is closely related to the development of information technologies. Remote sensing techniques are one example of information technologies that have fostered new approaches to environmental monitoring. The evolution from information technologies to ICT has enabled monitoring systems to evolve from functioning as data acquisition and management systems to serving as decision support systems.

[1] For more information please refer to http://www.nws.noaa.gov/om/coop/.

[2] For more information please refer to http://www.ecc1.org/anacostiariverkeepers.php.

The capabilities of ICT enable the creation of information systems that manage large volumes of heterogeneous multimedia data together with communication tools that allow different stakeholders to collect and share data on the state of the environment. ICT have been used in different tasks in environmental monitoring: from data acquisition and storage to data processing, management and communication (Dvornich et al. 1995; Embley 1996; Rosen et al. 1998; Larsen 1999; Hale et al. 2000; McLaughlin et al. 2001). Distributed database systems and geospatial based tools, such as GPS and Geographic Information Systems (GIS), supported by the pervasive use of the Internet and mobile communications are widely used applications of ICT in environmental monitoring (Gouveia et al. 2004). Further, the integration of wireless communication, computers and sensors into units about the size of cell phones is producing new opportunities for environmental monitoring (Gouveia et al. 2007).

Within environmental monitoring, ICT have been used to facilitate public access to timely, accurate and understandable environmental information, which is the focus of the first model of citizen involvement. The Internet facilitates data access, blurring temporal and spatial obstacles. Additionally, the world-wide web enables the creation of spatial multimedia systems that are appropriate for disseminating environmental information to different types of audiences, and this allows creation of multidimensional representations of the issues at stake (Fonseca and Gouveia 2006). The role of ICT in supporting public participation in environmental monitoring systems development, implementation and management (the second model), have been analyzed by Gouveia et al. (2004). ICT emerge as a tool to facilitate data collection and processing, data access and exploration, and data validation and communication by stakeholders (Table 2).

Increases in computation power, storage capacity and miniaturization associated with multiple communication channels have facilitated data collection and registration by a broad audience. The use of GPS is a prime example of such. Data validation and communication have been supported by the multiple Internet communication channels and mobile communication systems that enable social interactions and knowledge exchange among experts and non-experts. Moreover, these technological trends favored the emergence of Web 2.0 practices that allow different types of users to create and explore multimedia data through easy-to-use geo-referenced tools. Google Earth is an example of such tools. It makes land-use data available to the common citizen, enabling him or her to perform spatial multimedia operations such as flyovers, multimedia searches, and 3D modeling, operations that were previously restricted to professional GIS experts.

The exploration of Google Earth as a participatory tool augments citizen empowerment in similar ways to community mapping through GIS, usually designated as Public Participation GIS (PPGIS) (Corbett and Keller 2006; Laituri 2003). Laituri (2003) offers several components and continuums for assessing existing PPGIS projects, posing three fundamental questions about these projects: who is informed, who is empowered and who benefits from the technology. The emergence of Web 2.0 is having an impact on these issues as it strengthens relationships among users and facilitates the creation of virtual communities. It is also changing the nature of processes by enabling users to generate and share content. These transformations are empowering citizens to share content ownership, and giving them the possibility to decide the meaning and the usage of the content they produce. This ownership empowers individuals when facing organizations and favors the creation of communities that share goals, processes and results (which are the same ideals of the open source model). All these features highlight the importance of Web 2.0 philosophies and tools in environmental communities and VGI. Nevertheless the questions posed by Laituri (2003) are still relevant for citizen empowerment through the use of ICT.

The major drawbacks of using ICT to promote public participation in environmental monitoring are related to technology access and use, as in many other participatory processes. The associated costs may restrict citizen participation, creating a bias in the type of problem engaged and in the geographical areas monitored. Moreover, the technology may not be in a stage that can be used by everyone. The emergence of smart sensor networks is an example of an ICT development with potential to support citizen involvement in environmental monitoring, but which is not available. Or, the technology may exist, but there may be a lack of social and institutional framework to support its use by citizens.

Table 2 Potential of ICT developments to support public participation within VGI

VGI activities	Volunteer tasks	Examples of ICT developments
Data collection and processing	Collect and register the data. Geo-reference the data. Report the data. Create metadata. Process the data (e.g. calculate means, select the most meaningful record).	Multimedia technologies enable storage and management of heterogeneous types of data, characteristic of volunteer monitoring initiatives. Mobile computing and communication enables citizens to collect and register environmental data anytime anywhere. Information gadgets, from data loggers to smart sensors, are increasingly available to citizens (e.g. cell phone cameras). Tools such as the ones included in location based services and mobile GIS facilitate data collection.
Data search and presentation	Access, search and visualize heterogeneous sources of data from different platforms (e.g. Desktop PC, PDA and mobile phones). Perform spatial, temporal and thematic searches. Identify data gaps and overlays. Create visualizations of the data (e.g. maps, graphs, videos).	Public participation GIS and spatial multimedia systems provide visualization and exploration tools that allow citizens to explore geo-referenced data and build alternative future scenarios (Shiffer 1992; Fonseca et al. 1995; Al-Kodmany 2001; Kingston et al. 2000; Peng 2001). The WWW facilitates data dissemination and allows integration of tools that were otherwise restricted to small audiences. (see examples proposed by Carver et al. 2001). The emergence of specific semantics such as the Semantic Geospatial Web may facilitate data search and retrieval (Egenhofer 2002). Wireless networks support the creation of mobile environmental information systems available anytime anywhere (Antikainen et al. 2004).
Data validation	Analyze the data (e.g. compare with other data sources). Analyze data collection procedures. Promote the use of standard data collection practices and concepts consistency. Involve official entities and scientific community to promote knowledge transfer and data verification.	The use of sensors may promote data quality and facilitate data comparison. The large amounts of data handled by databases created the need for metadata catalogues as way to facilitate data search and retrieval. Websites can be used as collective repositories of knowledge by including data collection protocols and other tutorial materials.
Community building	User registration. Advocacy activities (e.g. networking). Send and receive requests to fulfill temporal, spatial and thematic information gaps. Receive feedback on the monitoring initiatives (e.g. quality of the data). Communication among volunteers and also with the official entities and scientific community. Sharing views among stakeholders. Promotion of information exchange and teamwork.	Discussion support tools to assist group interaction may support the development of online communities. The Web 2.0 developments provide the tools that citizens need to publish independent reports of events as they are happening. Blogs, wikis, RSS and their mashups can acts as a new way for catalyzing collective action and support the development of early-warning monitoring systems. Communication tools provided by ICT such as emails, blogs, SMS and MMS are becoming increasingly used to promote social activism.

Notes: SMS, short messaging system; MMS, multimedia messaging system; RSS, really simple syndication

The use of ICT and their potential to promote public participation in environmental monitoring suggest that they may be useful in supporting the creation of a collaborative framework that encourages volunteer initiatives. In such a framework, the role of ICT is to facilitate monitoring tasks and increase the impact of volunteer initiatives.

A framework for volunteered geographic information in environmental monitoring

The framework we describe here is intended to accommodate a diversity of citizen initiatives and at the same time maximize the benefits of using ICT, overcome the major obstacles to volunteer monitoring, and promote the use of volunteered geographic information. Environmental Collaborative Monitoring Networks (ECMN) are proposed as a framework that takes advantage of monitoring networks concepts and practices combined with the ideals of the open source movement.

In an ECMN, the nodes are citizens or groups of citizens willing to participate in environmental monitoring, and the links show relationships or flows between the nodes. The values underlying an ECMN are similar to the ideals of open source projects, where collaboration is open to all and results are shared as a way to promote continuous improvement. The open source movement and its characteristics have been described by Raymond (1999). He compared the organization of open source projects, a bazaar where the interactions are diverse, to the process of building a cathedral, where the operations follow a strong and centralized management. Since then, the open source movement has spread to other disciplines such as social sciences and information systems (von Hippel and von Krogh 2003; Rothfuss 2002) and is proving to be an effective means of production, particularly in knowledge creation (Goetz 2003).

What is needed to make an ECMN? The building blocks of an ECMN are: (1) citizens motivated to participate within volunteer initiatives; (2) Sensing devices to detect and register environmental variables; and (3) a back-end information infrastructure that supports the activities of citizens and augments the impact of volunteer initiatives. The characteristics of each building block of an ECMN are presented in Table 3 together with the identification of ICT major contributions.

The tasks that citizen may perform while participating in environmental monitoring require a significant effort. Motivation is therefore a key issue. It may range from an individual agenda such as reputation, anticipated reciprocity, personal learning and enjoyment, to more altruistic motives such as the commitment to certain values (Kollock 1999). ICT may support citizen tasks by facilitating networking activities through the creation of different channels of communication. Additionally, ICT communication tools may help citizens manage social dynamics, recruit new nodes, promote social interaction and reward desirable behaviors.

Data characteristics are one of the major obstacles for using volunteer monitoring information. Sensing devices can be a useful tool to support public participation in environmental monitoring because their use can be one way to promote data credibility and comparability. Additionally sensors may increase the range of detection of variables (spatially and temporally). The use of ICT to promote sensor data together with other sources of data for EM, has been documented by Vivoni et al. (2002) and Câmara (2002).

A back-end information infrastructure allows citizens to contribute with their knowledge to a broader system and communicate with others to gain support for collective action. Information infrastructures can make the following major contributions to the development of an ECMN:

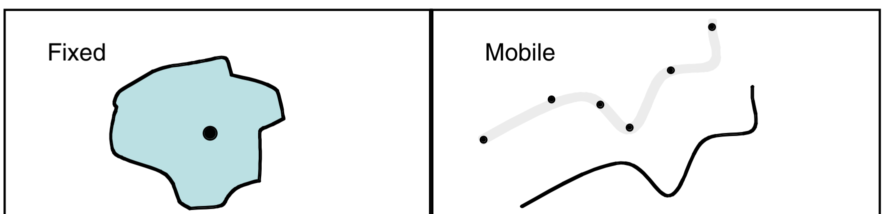
(1) Data and metadata.
(2) Standards and guidelines to promote data consistency and data sharing.
(3) A clearinghouse to facilitate data access and exploration.

As in traditional environmental monitoring networks, data collection is the central activity in an ECMN. Through data collection citizens may contribute to increasing knowledge on the state of the environment. According to data collection procedures, citizen initiatives may create fixed or mobile collaborative networks (Fig. 1).

The characteristics of data collection activities are determined also by the ICT available to volunteers. In fact, the present ability of integrating mobile communication and computing together with sensing devices in small units (such as mobile phones)

Table 3 Major features of ECMN building blocks and the role of ICT

ECMN building blocks	Major characteristics	ICT major contributions
Motivated citizens	Citizens must be willing to collect and register data, enable data access by others (citizens, scientists or governmental agencies) and perform advocacy activities. Motivations to participate are diverse. Citizen commitment may vary from immediate involvement such as the case of early warnings to long-term such as the contribution for time-series.	Diverse channels of communication: from synchronous to asynchronous and from one-to-one to many-to-many. ICT facilitate the exchange of information and knowledge, which is particularly important because involved citizens have different levels of knowledge and commitment.
Sensing devices	Sensors range from devices that register human sensory data to equipment that monitor variables not detected by human senses, such as carbon monoxide. Sensors such as imagers, e-noses and e-tongues and microphones due to their relation to human senses hold great potential for citizen initiatives. Criteria such as usability and affordability are particularly important when choosing sensors for volunteer monitoring.	ICT have supported the development of micro-sensors integrated onto a single chip with a processor—the so-called smart sensors. Although still in an early stage, this new breed of sensors is creating new opportunities for environmental monitoring.
Back-end information infrastructure	It supplies: (1) Communication services; (2) Resources such as ancillary data, training materials and guidelines; (3) Collaborative tools for data storage, access, analysis and communication such as annotation tools. Due to the spatial nature of the data, volunteer monitoring could take advantage of existing SDI.	Web services, such as webmapping, that enable the seamless integration of online geo-processing services allows to create a new generation of SDI that is more user centered. Google Earth is an example of a service that does not require users to have specific software to perform functions such as geo-referencing or 3D modeling.



Fixed	Mobile
Spatial coverage is constant and may be represented by a point or an area.	Spatial coverage is variable and may be represented by a set of points or a line (continuous or discrete measurements).
Favors the creation of temporal data series.	Favors spatially and temporally isolated data collection points.
Data collection is associated to a location.	Favors collection of personal exposure data and sensory data.
Favors collection of indoor variables.	Favors collection of outdoor variables
Easier to setup and maintain measurement devices.	Measurement devices have to be portable and easy to carry.

Fig. 1 Characteristics of fixed and mobile collaborative monitoring networks

represents one practical way to equip citizens for collecting and communicating environmental data. Phone cameras are one example of widely available gadgets that can be used to collect environmental multimedia monitoring data.

However, the role of an ECMN goes beyond facilitating data collection. This framework supports the development of communities of people that cooperate in ways not before possible. For example, this collaborative system includes a back-end infrastructure intended to facilitate data storage, access and reuse by others. Moreover, in such a framework the use of ICT allows improvement of activities such as coordination and management.

ECMN increase public visibility of volunteer initiatives and facilitate access to the data collected by volunteers. By making it easier to get information on citizen efforts and their impacts, ECMN may encourage more people to become motivated and involved in monitoring the environment. Another issue that may hamper citizen commitment is privacy protection, which should be addressed in the development of an ECMN. ECMN accommodates organized initiatives and isolated efforts. Moreover, it may facilitate the integration of different perspectives from citizens to experts, which may favor data triangulation (LeCompte and Goetz 1982) and increase data validity and reliability.

The tasks involved in the creation and management of an ECMN are time consuming and may require specialized work. Tasks are not limited to data collection and in an ECMN context a significant effort is needed to create and maintain the backend information infrastructure and the motivation and the commitment of volunteers. According to Castells (2001) the ability of citizen networks to reach out a broader user base is highly dependent on institutional support from open-minded administration. The open source movement can bring some insights on organizational and institutional arrangements that support the creation of an ECMN. On the other hand an analysis of projects that illustrate different approaches to ECMN building blocks may help foster an understanding of the major issues involved in the creation of such a framework. The experience from Senses@Watch project is described in next section.

Lessons learned from the Senses@Watch project

Senses@Watch is a research project intended to create and evaluate strategies promoting the use of volunteered geographic information collected through citizens' senses. It involved the use of ICT and sensing devices to support and promote a wider use of the data collected by citizens. The development of the Senses@Watch project illuminates some of the issues involved in the implementation of an ECMN framework.

Table 4 summarizes the major characteristics of the Senses@Watch project with respect to the ECMN building blocks. The first building block, motivated citizens, was an important component in the development of the Senses@Watch project. The use of human sensory data to evaluate environmental quality variables requires the design of data collection methodologies that produce information that is not biased by citizens' motivations and understanding. Sensing devices were also a building block in the Senses@Watch project. Sensors were used to limit volunteered geographic data credibility problems. Their use within the Senses@Watch project allowed exploration of issues such as usability, costs and accuracy.

In the Senses@Watch project, the challenges of creating a back-end information infrastructure were illustrated in the development of a collaborative website and a case-based library. The collaborative website was supposed to support citizens' efforts to collect and manage the data in isolated initiatives, while the case-based library was intended to raise awareness about the sensory component of environmental problems.

The motivated citizens building block was the least explored aspect of the Senses@Watch project. With respect to what motivates citizens to participate in an ECMN, Senses@Watch underlines the need to carefully design the methodologies for data collection and registration. These methodologies should be adequate to participatory contexts, allowing for evaluating citizens motivation and the factors that might promote or restrict it.

In terms of sensing devices, the project explored the use of sensors to validate or register sensorial information. The number of sensors that are adequate to be used in a participatory context is still small and their precision does not match the needs of volunteer monitoring initiatives. Additionally, most of the existing sensors (except mobile phones) require citizen training. The sensors used in the Senses@Watch encountered problems mostly associated with their lack of precision, demanding volunteer work and skills without a corresponding infrastructure to accommodate and explore their results. Thus, the question of how to equip citizens with sensors and make them

Table 4 Summarizes the main characteristics of Senses@Watch project according to the ECMN framework

ECMN framework building-blocks	Description	Details
Motivated citizens	Senses@Watch has sought a quantitative relationship between sensory information collected by citizens with other measurements of the same variable. Citizens were involved in the different case studies but not as a true ECMN. The use of human senses to evaluate environmental quality variables has been explored in the field of sensory analysis, which uses techniques and methodologies designed for a laboratory context. It was thus necessary to analyze if the methodologies used in sensory analysis were applicable to a participatory context.	Four case studies where designed and implemented: (1) Taste: to detect chlorine flavors in tap water. Citizen sensory data were collected in two different contexts: laboratory and participatory; (2) Smell: to detect the odors produced by a paper pulp mill. Citizens' records of bad odors registered on a diary were compared with the data obtained from an air quality monitoring station, belonging to an official network. Such information was then related to the meteorological conditions; (3) Hearing: to understand the citizens' ability to quantify noise from city traffic and the use of different types of scales; (4) Vision: the use of photographs to communicate beach quality issues. The quality criteria defined by the European eco-label blue flag have been used as an example.
Sensing devices	Different sensors where used according to the case study topic. The sensors were used to validate or register sensorial information.	The popularity of *mobile cellular phones* makes them an attractive device to support volunteer monitoring initiatives. The major barriers are related to the large variety of mobile devices and the communication costs involved.
Back-end information infrastructure	A collaborative site was developed using a distributed approach that promotes interoperability with diverse content providers. It is based on the WWW, although an interface for data input on mobile phones was conceived.	The collaborative site includes: Tools to support *data collection and processing*—(e.g. geo-reference, annotate data and create metadata); A *case-based library* intending to support the creation of multi-sensory messages. The clipart metaphor was used to design the case-based library; *Data access and visualisation tools*, namely thematic, temporal and spatial searches based on web mapping tools.

more accurate sensors through sensorial training remains.

The back-end information infrastructure is the ECMN building-block that was explored in the most detail in this project. The development of the collaborative site and the case-based library revealed the pragmatic implications of using ICT to support citizen participation in environmental monitoring. Senses@Watch underlined the need to have tools to support tasks such as data collection, data access, data management and community building. The tools we developed were intended to facilitate data collection and management, such as data annotation tools, and were integrated in a collaborative system that targeted specific needs of volunteers.

Finally, the Senses@Watch project attempted to take advantage of bottom-up initiatives. Another lesson of the project stems from the institutional and organizational framework required to support the logistics involved in volunteer projects. Activities such as recruiting new nodes and maintaining the motivation of the existing ones require a framework that facilitates communication and collaboration among the people involved. Different organizational models can be followed but more research is required to analyze which organizational and institutional models favor the creation of ECMN. The development of the collaborative site was important but it was still apparent that besides the information component, the institutional set-up is also very important. The project did not address these institutional aspects, but further investigation is required in this domain to identify the institutional configuration that may promote the formation of online monitoring communities and increase the involvement of the public, official entities and experts. Accordingly, such a site should include a strong communication layer to support the creation of online monitoring communities. This may include new developments to explore the use of the system to facilitate the creation and management of the network and the availability of easy to use tools to support the management node tasks.

Nevertheless a workshop was organized during the project, involving different stakeholders. This workshop allowed us to get a better sense of the different perspectives of the environmental community in Portugal and to reflect on the institutional framework required to set up an ECMN. Most stakeholders showed interest in facilitating volunteer monitoring, but identified data credibility and the costs of setting up a framework to support such initiatives as major concerns.

Conclusions

This paper has proposed and illustrated the utility of ICT for overcoming existing disadvantages that limit citizen participation in environmental monitoring. We argue that the diverse characteristics of citizen initiatives (from individual complaints to formal data collection initiatives) and the diversity of tasks involved (from data collection to advocacy activities) require a framework that uses a multiplicity of tools ranging from sensors to collaborative systems. We argue that the three key components of an ECMN that can address these needs are: (1) citizens and their motivations, (2) sensing devices and (3) back-end information infrastructure.

The Senses@Watch project is an example of a project whose main goal was to promote the use of volunteered geographic information. The main motivation of citizens in Senses@Watch was to identify environmental problems and access and explore the data contained in citizens' complaints. The technologies used included a collaborative website with a mobile interface and a case-based library. The project's main strength lies in its effort to explore the use of ICT to promote collaboration. Nonetheless, because this was a research project, we were not equipped to develop a sustainable institutional framework, nor carry out field-testing to evaluate the permanence of volunteers and their level of satisfaction. Drawing on other related research, we suspect that volunteer satisfaction may be driven by the extent to which the results of their work influence decisions or are in fact used by the responsible public authorities (Ramasubramanian and Quinn 2006).

The framework proposed in this paper addresses some key issues relevant for the VGI research agenda. By using environmental monitoring as an example of application where VGI might be employed, this paper develops a systematic identification of potential VGI tasks, initiatives and roles. Moreover the framework proposed here reflects upon possible ways to minimize data credibility problems. Finally it also contributes to the analysis of the role of existing technologies and technological trends in augmenting the impact of VGI initiatives.

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References

Al-Kodmany, K. (2001). Supporting imageability on the World Wide Web: Lynch's five elements of the city in community planning. *Environment and Planning B: Planning and Design, 28*(6), 805–832.

Antikainen, H., Bendas, D., Marjoniemi, K., Myllyaho, M., Oivo, M., Colpaert, A., et al. (2004). Mobile environmental information systems. *Cybernetics & Systems, 35*(7–8), 737–751.

Au, J., Bagchi, P., Chen, B., Martinez, R., Dudley, S. A., & Sorger, G. J. (2000). Methodology for public monitoring of total coliforms, *Escherichia coli* and toxicity in waterways by Canadian high school students. *Journal of Environmental Management, 58*(3), 213–230.

Bromenshenk, J., & Preston, E. (1986). Public participation in environmental monitoring: A means of attaining network capability. *Environmental Monitoring and Assessment, 6*(1), 35–47.

Câmara, A. (2002). *Environmental systems—a multidimensional approach*. Oxford: Oxford University Press.

Carver, S., Evans, A., Kingston, R., & Turton, I. (2001). Public participation, GIS and cyberdemocracy: Evaluating online spatial decision support systems. *Environment and Planning B: Planning and Design, 28*, 907–921.

Castells, M. (2001). *The internet galaxy, reflections on the internet, business, and society*. Oxford: Oxford University Press.

Clemons, J., & Conklin, M. (2000). A comparative study of globe and USGS water quality monitoring data. In US EPA (Ed.), *Proceedings of the Six National Volunteer Monitoring Conference*, Austin, Texas. http://www.epa.gov/owow/volunteer/proceedings/sixth/session5.html#globe/. Accessed December 2007.

Corbett, J. M., & Keller, C. P. (2006). An analytical framework to examine empowerment associated with participatory geographic information systems (PGIS). *Cartographica, 40*(4), 91–102.

Cuthill, M. (2000). An interpretive approach to developing volunteer-based coastal monitoring programmes. *Local Environment, 5*(2), 127–137.

Dvornich, K. M., Tudor, M., & Grue, C. E. (1995). NatureMapping: Assisting management of natural resources through public education and public participation. *Wildlife Society Bulletin, 23*(4), 609–614.

Egenhofer, M. J. (2002). Toward the semantic geospatial web. In *Proceedings of the Tenth ACM International Symposium on Advances in Geographic Information Systems* (pp. 1–4). New York: ACM Press.

Elwood, S. A. (2002). GIS use in community planning: A multidimensional analysis of empowerment. *Environment and Planning A, 34*, 905–922.

Embley, B. (1996). Displaying your data and beyond. In US EPA (Ed.), *Proceedings of Fifth National Volunteer Monitoring Conference*, Madison, Wisconsin, Publication No. EPA 841-R-97-007.

Fonseca, A., & Gouveia, C. (2006). Spatial multimedia for environmental planning and management. In M. Campagna (Ed.), *GIS for sustainable development. Bringing geographic information science into practice towards sustainability* (pp. 143–165). London: Taylor and Francis.

Fonseca, A., Gouveia, C., Câmara, A., & Silva, J. P. (1995). Environmental impact assessment with multimedia spatial information systems. *Environment and Planning B: Planning and Design, 22*, 637–648.

Fore, L. S., Paulsen, K., & O'Laughlin, K. (2001). Assessing the performance of volunteers in monitoring streams. *Freshwater Biology, 46*(1), 109–123.

Fortin, C. (2000). Minneapolis-St Paul area volunteer monitoring: A coordinated approach. In *Six National Volunteer Monitoring Conference*, Austin, Texas. http://www.epa.gov/owow/volunteer/proceedings/sixth/session2.html#paul. Accessed December 2007.

Goetz, T. (2003). Open source everywhere. *Wired Magazine, 11*(11). Retrieved from http://www.wired.com/wired/archive/11.11/opensource.html.

Gouveia, C., Fonseca, A., Câmara, A., & Ferreira, F. (2004). Promoting the use of environmental data collected by concerned citizens through information and communication technologies. *Journal of Environmental Management, 71*, 135–154.

Gouveia, C., Fonseca, A., Condessa, B., & Câmara, A. (2007). Citizens as mobile nodes of environmental collaborative monitoring networks. In J. Drummond, R. Billen, D. Forrest, & E. João (Eds.), *Dynamic & mobile GIS: Investigating change in space and time* (pp. 237–261). London: Taylor and Francis.

Hale, S., Bahner, L., & Paul, J. (2000). Finding common ground in managing data used for regional environmental assessments. *Environmental Monitoring and Assessment, 63*(1), 143–157.

Kingston, R., Carver, S., Evans, A., & Turton, I. (2000). Web-based public participation geographical information systems: An aid to local environmental decision-making. *Computers, Environment and Urban Systems, 24*(2), 109–125.

Kollock, P. (1999). The economies of online cooperation: Gifts and public goods in cyberspace. In M. Smith & P. Kollock (Eds.), *Communities in cyberspace* (pp. 220–239). London: Routledge.

Laituri, M. (2003). The issue of access: An assessment guide for evaluating public participation geographic information science case studies. *URISA Journal, 15, APA II*, 25–32.

Larsen, L. (1999). GIS in environmental modeling and assessment. In P. Longley, M. Goodchild, D. Maguire, & D. Rhind (Eds.), *Geographic information systems 2* (pp. 999–1007). New York: Wiley.

LeCompte, M., & Goetz, J. P. (1982). Problems of reliability and validity in ethnographic research. *Review of Educational Research, 52*, 31–60.

McLaughlin, R. L., Carl, L., Middel, T., Ross, M., Noakes, D. L. G., Hayes, D. B., et al. (2001). Potentials and pitfalls of integrating data from diverse sources: Lessons from a historical database for Great Lakes stream fishes. *Fisheries, 26*(7), 14–23.

Nicholson, E., Ryan, J., & Hodgkins, D. (2002). Community data—where does the value lie? Assessing confidence limits of community collected water quality data. *Water Science and Technology, 45*(11), 193–200.

Peng, Z. R. (2001). Internet GIS for public participation. *Environment and Planning B: Planning and Design, 28*, 889–905.

Ramasubramanian, L. M., & Quinn, A. C. (2006). Visualizing alternative urban futures: Using spatial multimedia to enhance community participation and policy making. In M. Campagna (Ed.), *GIS for sustainable development. Bringing geographic information science into practice towards sustainability* (pp. 467–486). London: Taylor and Francis.

Raymond, E. (1999). *The cathedral and the bazaar: Musings on Linux and open source by an accidental revolutionary*. CA: O'Reilly, Sebastopol.

Root, T. L., & Alpert, P. (1994). Volunteers and the NBS. *Science, 263*(5151), 1205.

Roseland, M. (2000). Sustainable community development: Integrating environmental, economic and social objectives. *Progress in Planning, 54*(2), 73–132.

Rosen, E. C., Haining, T. R., Long, D. D. E., Mantey, P. E., & Wittenbrink, C. M. (1998). REINAS: A real-time system for managing environmental data. *International Journal of Software Engineering and Knowledge Engineering, 8*(1), 35–53.

Rothfuss, G. J. (2002). A framework for open source projects. Master Thesis in Computer Science Register No. 97-711-915. Department of Information Technology, University of Zurich, Zurich.

Scinto, L. (2000). The shoreline alteration citizen monitoring protocol—a project developed by Island County/Washington State University Beach Watchers. In US EPA (Ed.), *Proceedings of the Six National Volunteer Monitoring Conference*, Austin, Texas. http://www.epa.gov/owow/volunteer/proceedings/sixth/session2.html#coastal. Accessed December 2007.

Shiffer, M. J. (1992). Towards a collaborative planning system. *Environment and Planning B: Planning and Design, 19*, 709–722.

Stokes, P., Havas, M., & Brydges, T. (1990). Public participation and volunteer help in monitoring programs: An assessment. *Environmental Monitoring and Assessment, 15*(3), 225–229.

Vaughan, H., Whitelaw, G., Craig, B., & Stewart, C. (2003). Linking ecological science to decision-making: Delivering monitoring information as societal feedback. *Journal of Environmental Monitoring and Assessment, 88*(1), 399–408.

Vivoni, E. R., Camilli, R., Rodriguez, M. A. A., Sheehan, D. D., & Entekhabi, D. (2002). *Development of mobile computing applications for hydraulics and water quality field studies. Hydraulic Engineering Software IX*. Montreal: WIT Press.

von Hippel, E., & von Krogh, G. (2003). Open source software and the private-collective innovation model: Issues for organization science. *Organization Science, 14*(2), 209–223.

Whitelaw, G. (2002). Organizing community based ecosystem monitoring in Canada. Draft research report for the Canadian Nature Federation and the Ecological Monitoring and Assessment Network Coordinating Office. Environment Canada. http://www.ccmn.ca/english/library/whitelaw/intro.html. Accessed January 2005.

Whitelaw, G. S., Vaughan, H., Craig, B., & Atkinson, D. (2003). Community based environmental monitoring in Canada. *Environmental Monitoring and Assessment, 88*, 409–418.

Young-Morse, R. (2000). Real-time detection of phytoplankton. In US EPA (Ed.), *Proceedings of the Six National Volunteer Monitoring Conference*, Austin, Texas. http://www.epa.gov/owow/volunteer/proceedings/sixth/session2.html#paul. Accessed January 2005.