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Promoting the use of environmental data collected by concerned citizens through information and communication technologies

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Abstract

Public participation within environmental monitoring may contribute to increasing the knowledge on the state of the environment at the same time it promotes citizens' involvement in environmental protection. However, the use of voluntary collected data is limited due to a lack of confidence in data collection procedures. Additionally, data quality is often unknown and the data are usually dispersed and non-structured. Information and communication technologies (ICT) may promote the use of voluntary collected data through the development of a collaborative system that incorporates tools and methodologies to facilitate data collection, access and validation. Furthermore, the use of ICT may promote public involvement within environmental monitoring, since it facilitates communication among all the stakeholders. This paper analyses the role of ICT in developing a system for environmental collaborative monitoring intending to promote the use of volunteer collected data. It starts by analysing the role of volunteers within environmental monitoring and continues analysing the potential of ICT to take advantage of the benefits of using data collected by citizens. A collaborative system that allows the public to express its knowledge on the state of the environment is described. Special emphasis is given to tools that explore non-traditional types of environmental data such as images, sounds and videos in association with spatial information. To illustrate the above mentioned concepts, a case study for beach quality monitoring developed within the Senses@Watch project, is described.
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1. Introduction

Access to the data collected by environmental monitoring (EM) systems is crucial to support public participation within any environmental decision-making process. However, these data are not always available to the public and are not usually available in a format that is understood by all the different stakeholders.

Non-governmental organizations (NGO) and concerned citizens have made some voluntary efforts to collect data contributing to a broad understanding of the environment. An example of such initiatives is the National Audubon Society Christmas Bird Count, which monitors the status of resident and migratory birds across the US. These initiatives intend not only to inform the public about the state of the environment, but also to support citizens and their organizations to take action and participate within environmental decision-making. Additionally, such initiatives can have a strong educational component, enabling volunteers to learn about the environment and the methods to evaluate its quality. The GLOBE project, where primary and secondary students carry scientifically valid measurements in the fields of atmosphere, hydrology, soils and land cover, is an example of such initiatives.

Volunteer monitoring data have been integrated with professional data and used by NGO, researchers and public agencies to overcome spatial and temporal gaps in official monitoring systems (Stokes, 1990; Root and Alpert, 1994;

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Au et al., 2000; Fortin, 2000; Lawson, 2000; Young-Morse, 2000). However, the impact of volunteer collected data is limited since many of these initiatives do not follow conforming sampling procedures and represent isolated initiatives. Data credibility is one of the major obstacles to maximize the use of volunteer collected data. Additionally, access to volunteer collected data is usually difficult, as they are dispersed and non-structured.

Although still limited, ICT have been used to promote the use of volunteer collected data within environmental management activities and environmental decision-making (Fig. 1). Community organizations involved in volunteer monitoring initiatives have used ICT mainly to facilitate data storage, exploration and dissemination.

The spatial nature of the data collected by citizens has favoured the use of geographic information systems (GIS) and associated technologies, such as GPS or remote sensing, by NGO. GIS have been used mainly for data exploration and visualization, improving communication with other stakeholders.

More recently, the WWW has been used to publish the information collected by citizens, thus supporting environmental advocacy activities. Once again, applications that explore the spatial characteristics of the data, such as webmapping applications, have been developed to convey volunteer project results to a wider audience. However, the lack of a framework that integrates volunteer collected data with other sources of environmental monitoring data limits the impact of such initiatives. Furthermore, the lack of such a framework restrains data reuse, since data access and exploration is difficult.

Collaborative spatial information systems may support the development of such a framework since they allow for the integration of multiple sources of data at the same time they facilitate data access, visualization and communication. Various technical and theoretical issues surrounding the use of WWW collaborative systems for public participation within environmental management and planning have been addressed by Shiffer (1995), Carver et al. (1997) and Peng (2001). However, none of these works addressed the specific issues involved within the design of a collaborative monitoring system to promote the use of citizens' collected data.

The design of an Environmental Collaborative Monitoring System (ECMS) implies the development of tools to collect, store, manage, visualize and analyse non-traditional data types such as videos and photographs together with other types of spatial information. The use of multimedia types of information such as ground photos, videos and sound within environmental management are reviewed by Fonseca et al. (1995), Ferreira (1999) and Silva (1999). However, none of these works have explored the use of collaborative tools.

This paper explores the role of the public within environmental monitoring. It argues that volunteer collected data not only contribute to a broader knowledge on the state of the environment but also promote public participation within environmental management. Furthermore, this paper

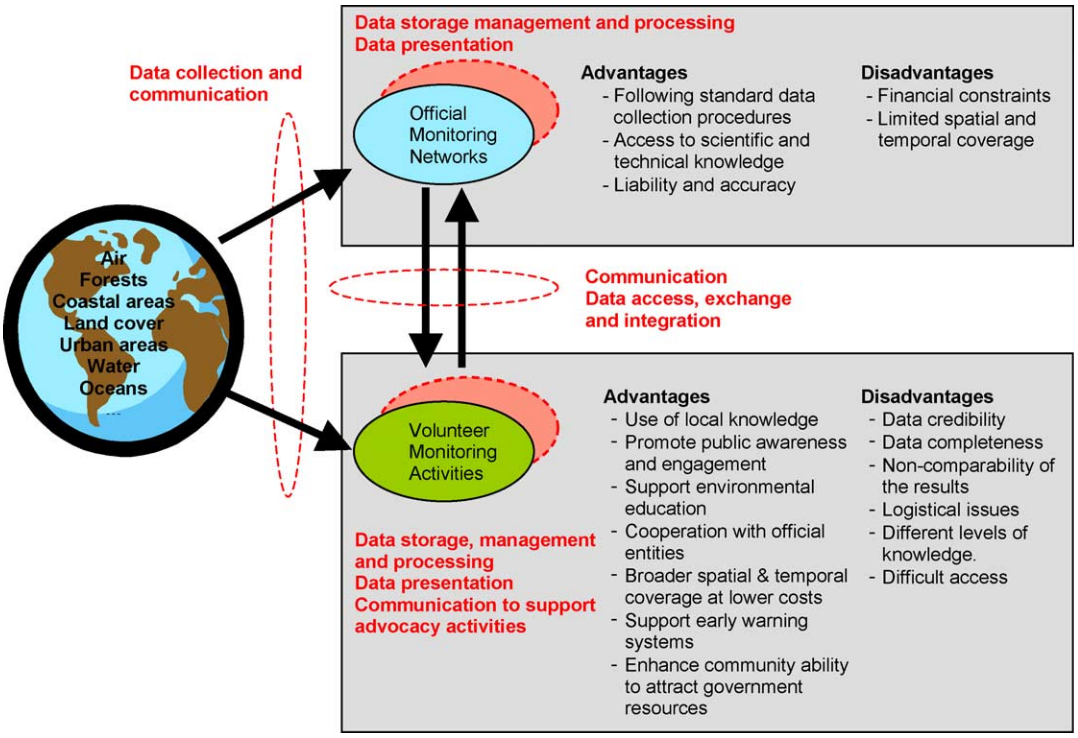

Fig. 1. Environmental collaborative monitoring and the role of ICT.

analyses the role of ICT within environmental monitoring and explores the potential of ICT to promote the use of volunteer collected data. It proposes an ECMS, identifying its structure and tools, to facilitate data collection, validation, access, exploration and communication. Within the tools proposed for such a system, special emphasis is given to tools to explore non-traditional types of environmental data such as images, sounds and videos in association with spatial information. To illustrate the proposed collaborative monitoring system a case study applied to beach quality monitoring is described.

2. Public participation and environmental monitoring

Monitoring systems have been widely used to increase the knowledge of the state of the environment. However, spatial and temporal monitoring gaps restrict the usefulness of such systems. Additionally, the data collected by these systems are not always available to the public, limiting data access and consequently the public debate on the state of the environment.

To support public participation within environmental monitoring, and more broadly within environmental management activities, NGO and concerned citizens have performed volunteer initiatives to collect data on the state of the environment. Using volunteers within EM activities is not a new idea and examples can be found since the early 1900s in projects such as the National Audubon Society Christmas Count and the US Fish and Wildlife Service's Bird Banding Program. For a review of the history of volunteer monitoring please refer to Lee (1994).

Volunteer monitoring initiatives can be found applied to a variety of environmental issues such as water quality, land use changes, coastal zones protection and biodiversity. An extensive directory of monitoring initiatives organized by NGO and schools within the US is available at the EPA homepage (USEPA, 1998b). The level of formalization of volunteer monitoring initiatives varies and range from individual complaints about environmental problems by concerned citizens to highly organized data collection initiatives funded by government agencies. Information on the less formalized initiatives is dispersed and non-organized making the analysis of their contribution more difficult. Additionally, the data collected by such ad hoc initiatives are not easily accessible.

The environmental data collected by citizens have been used to keep communities, elected officials, and government agencies informed about the problems that need to be addressed, increasing public awareness. Generally, the data collected intend to support citizens' actions to protect the environment. Nevertheless, many volunteer initiatives, such as the GLOBE project, focus on educational purposes.

The tasks performed by volunteers within data collection activities vary and determine data characteristics (Table 1). The data collected by volunteers have a strong spatial and multimedia component and can include the following types of information:

- Opinions, from questionnaires or from individual complaints. Such information is usually in the form of written or spoken messages and has a strong sensorial component.
- Objective and factual information. An example of this type of information is the detection of specific species within a geographic area. It can include texts, photographs, sketches and videos. Although objective it can be based on human senses.
- Measurements using sensors such as a pH meter or a GPS.

The data collected by concerned citizens in individual initiatives are mainly based on human sensory information (Table 2). As environmental sensors, humans are subjective and their accuracy varies according to their individual characteristics (Molhave et al., 1991). One strategy adopted to overcome such limitations is to use sensors, which need to be portable, to support data validation (Table 2). Câmara (2002) presents a review on the use of sensors to collect environmental data. Further research is needed on how to extract useful environmental information from human sensory data and on how to validate such data.

The benefits of involving concerned citizens within EM, as identified by Bromenshenk and Preston (1986), Stokes (1990), Root and Alpert (1994), Au et al. (2000), Young-Morse (2000) and Nicholson et al. (2002) are:

- Promote public awareness on environmental issues: the participation of citizens within monitoring generates a more informed and educated public concerning environmental problems. Moreover, it introduces the public to science and scientific methods. The high number of projects with educational purposes supports such a statement.
- Enhance collaboration among all the stakeholders: development of a cooperation culture where citizens develop a sense of being involved in assessing environmental quality. Moreover, since citizens develop a better understanding of the issues involved, the use of volunteers promotes cooperation instead of the traditional 'us and them' approach.
- Financial benefits: the participation of volunteers can be a cost effective method to maintain data collection activities under limited funding. Furthermore, the use of volunteers allows to widen the geographic area and time period monitored since volunteers can gather data at odd hours and cover wider geographic areas. According to Byron and Curtis (2002) volunteer initiatives may enhance community ability to attract government resources.

Table 1
Data collection activities performed by volunteers within monitoring initiatives

Tasks	Data type	Observations	environmental field	Examples of projects
Identify and record the occurrence and distribution of species.	Quantitative data, qualitative data, photographs, sketches, videos	Photographs and videos are used by experts to verify identification of species. Geo-referencing the data can be an issue.	Streams and Lakes (Macroinvertebrates are the species more often monitored.)	The stream quality monitoring project by the Ohio Division of Natural Areas and Preserves' Scenic Rivers (http://www.dnr.state.oh.us/dnap/monitor/sqm.html)
			Marine and coastal zones protection	Maine phytoplankton monitoring program (Young-Morse, 2000)
			Biodiversity	National Audubon Society Christmas Bird Count (http://www.audubon.org/bird/cbc/index.html)
Identify and record the presence of pollution	Qualitative data, photographs, sketches, videos	Partially based on human sensory data. Subjectivity can be an issue.	Air pollution	Investigation of odor problems associated with wastewater treatment facilities in North Carolina (http://www2.ncsu.edu/ncsu/wrri/reports/srs6.html)
			Marine and coastal zones protection	Coastwatch (http://www.geocities.com/RainForest/Canopy/1595/index.htm)
			Stream and lakes	Storm drain monitoring team (http://www.fortworthgov.org/DEM/news061402a.htm)
Observe and record the behaviour of species	Qualitative data, quantitative data, photographs, sketches, videos	The data collected can be used to produce maps.	Marine and coastal zones protection	Spanish dolphins by Earth Watch (http://www.earthwatch.org/expeditions/canadas.html)
			Biodiversity	Mapping the Monarch migration in real-time (http://kancrn.org/monarch/wave/)
Sampling and measurement of physical and chemical parameters (e.g.: PH, temperature, dissolved oxygen)	Quantitative data	Use of equipment such as secchi disks. Educational projects have developed measurement kits.	Stream and lakes	The Chesapeake Bay citizen monitoring program (http://www.acb-online.org/citmon.cfm)
			Soils	The GLOBE project (http://www.globe.gov)
			Weather	US National Weather Service Cooperative Observer program (http://www.nws.noaa.gov/om/coop/index.htm)
Surveying and mapping.	Annotated maps, quantitative data, qualitative data, photographs	May include visual surveys. Use of maps, GPS and compass. Volunteers can help to find map errors.	Land cover and earth features	USGS Earth Science Corps (http://interactive.usgs.gov/Volunteer/EarthScienceCorps/index.asp)
			Marine and coastal zones protection	The shoreline alteration citizen monitoring protocol—The Beach Watchers project (Scinto, 2000)

Table 2
Data collection activities performed by volunteers based on human senses and example of sensors to support such tasks

Human senses	Environmental problems	Task	Examples of sensors to support data collection
Vision	Biodiversity, land use changes, water pollution, air pollution, solid waste management, urban management, including traffic	Identify and record the occurrence, distribution and behaviour of species as well as the presence of pollution	Photographic cameras, video cameras, optical remote sensing devices, GPS
Odor	Water pollution, air pollution	Identify the presence of pollution.	Electronic noses, gas detector tubes, optical remote sensing devices, GPS
Hearing	Noise pollution, biodiversity	Identify and record the occurrence of noise. Identify different levels of annoyance according to the existent noise. Detect the presence of species based on the noises made by such species.	Sound level analyser, sound recorder, mobile phones, GPS
Taste	Drinking water contamination	Identify the presence of water contaminants.	Electrochemical sensors, photometer, GPS

- Support the development of early warning systems: volunteers can collect real-time data providing an almost instantaneous picture of what is happening.

On the other hand, Bromenshenk and Preston (1986), Stokes (1990), Au et al. (2000) and Mackney and Spring (2001) identify the following major disadvantages to involving volunteers within monitoring activities

- Data credibility: data quality is often unknown. Metadata on data sampling and collection are also scarce, making potential users sceptical about the data. Additionally, if the volunteer project objectives are not clear, data objectivity is also an issue.
- Non-comparability of the data: the data collected by citizens should be comparable to the data collected in other assessments using the same methods. However, due to the volunteers lack of specific knowledge and training that is not always true.
- Data completeness: there is the need for more frequent samples and longer records. The level of commitment from volunteers is highly unpredictable. Byron and Curtis (2002) refer to the importance of maintaining the engagement of local people within watershed initiatives. However, Stokes (1990) indicates that the importance of long term-commitment and data quality varies with the type of activity carried by volunteers.
- Logistical issues: the involvement of volunteers may require previous training or close supervision of volunteer work, which creates some logistical challenges such as the organization of training materials.

Nevertheless, the overall assessment of involving concerned citizens within environmental monitoring is positive. However, such involvement should be adequate to the type of environmental problems and to the tasks that need to be performed, which should be reflected within the design of the volunteer monitoring project.

NGO have developed strategies to overcome some of the identified disadvantages of involving volunteers within monitoring initiatives (Table 3). The involvement of all stakeholders, including scientists, official network managers and elected officials, is a key factor to develop a trust environment that promotes data credibility and at the same time increases data use by third parties.

Confirming the success of such initiatives, volunteer collected data have been used by researchers and state agencies as a source of environmental data (Root and Alpert, 1994; Au et al., 2000; Wilson, 2000; Young-Morse, 2000). Furthermore, 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) there is a need to conduct further research on assessing the validity of the volunteer collected data and the methods available.

The use of information collected based on human sensory data requires additional caution. The study done by Young et al. (1996) presents a methodology on the application of taste and odor to identify the threshold concentrations of potential potable water contaminants. However, due to the multidimensional characteristics of sensory data further research on methodologies to measure and validate the data based on human senses is needed.

Nevertheless, even in an environment where trust among volunteer data producers and data users have surpassed the major obstacles for data use, the dissemination

Table 3
Examples of strategies adopted by groups of citizens

Disadvantages to involve volunteers within environmental monitoring.	Examples of good-practice
Data credibility	Development of quality assurance and quality control (QA/QC) plans. Close collaboration with the scientific community. Creation of metadata to document data characteristics. Promote the use of sensors and standard methods for data collection. Perform parallel testing.
Non-comparability of the results	Creation of metadata to document data characteristics. Close collaboration with the scientific community. Development of tutorials targeting volunteer data collection activities. Examples of such tutorials can be found at several volunteer initiatives homepages. The EPA manuals on methods for volunteer monitoring are a reference. Promote the use of sensors and standard methods for data collection.
Data completeness	Involvement of the stakeholders through feedback from official entities and decision-makers and good leadership from NGO. Real impact on the decision-making process to maintain the volunteers' level of commitment. Technical and financial support from official entities to increase citizen involvement.

and communication of project results still constrain the impact of volunteer collected data within environmental decision-making. Currently, data dissemination and communication is limited to isolated efforts and ad hoc initiatives.

To overcome such limitations, there is the need for an institutional framework that supports citizens' initiatives and integrates them within environmental decision-making. The Lake Michigan Volunteer Network (Lawson, 2000) is a good example of such a framework although it was designed to mainly accommodate formalized volunteer monitoring initiatives leaving behind individual efforts. Further research is needed to explore the creation of a framework that accommodates both types of public involvement within environmental monitoring and considers the specificities of human sensory data as a source of environmental information.

On the other hand, the lack of such a framework restricts data access making data reuse difficult. Currently, the access to volunteer-collected data is difficult since they are dispersed and not structured, which restricts data use. ICT have been used in several initiatives to overcome such limitations and make volunteer-collected data more widely available.

3. The use of information and communication technologies to facilitate public participation in environmental monitoring

ICT can have a significant role in providing public access to timely, accurate and understandable environmental information, which has been a major issue within environmental monitoring (USEPA, 1998a). Examples of ICT application to environmental monitoring exist within all the major activities: from data acquisition, storage and management to data processing and communication (Dvornich et al., 1995; Rosen et al., 1998; Larsen, 1999; Hale et al., 2000; McLaughlin et al., 2001; Laurini, 2001). Based on the experience of existing projects-initiatives it is possible to observe diverse uses of ICT tools within environmental monitoring (Table 4).

Within ICT, the use of distributed database systems and spatial based tools has an impact across all the EM activities due the large volumes of temporal and spatial data collected within monitoring systems. The use of distributed database systems for environmental monitoring and the issues involved in data integration from different sources have been documented by Rosen et al. (1998), Hale et al. (2000) and McLaughlin et al. (2001). The role of GIS in environmental monitoring has been analysed by Larsen (1999) and Gao (2002).

On the other hand, the pervasive use of the Internet (Rosen et al., 1998; Larsen, 1999; Hale et al., 2000) and mobile communication (Vivoni, 2002) is having a major impact in all EM activities, since it has created new forms of data collection, access, processing and communication. Additionally, it has made it possible to provide environmental monitoring information to the general public in near real time.

The use of ICT to provide real-time environmental monitoring data is described by Rosen et al. (1998). The Real-time System for Managing Environmental Data (REINAS) provides an integrated problem solving and visualization environment to support individual and collaborative analysis of geospatial data. According to MacEachren (2001), this project was one of the first collaborative environments designed to support analysis of geospatial data. Additionally, REINAS includes a set of tools to configure and collect data from instruments in the field in real time. The use of ICT to promote sensor collected data together with other sources of data for EM has been documented by Vivoni (2002) and Câmara (2002).

Table 4
Examples of EM projects that use ICT based tools

EM Activity	ICT tools	Project examples	Brief description	Dates
Data collection	GIS plus GPS	Environmental monitoring activities at Fernald Environmental Management Project by USEPA (http://offo2.epa.state.oh.us/FERNALD/fernald.htm)	GPS equipment to determine sampling locations. GPS data are entered into a local database for GIS analysis and interpretation.	1995
	Online forms	Naturdetektive (http://www.naturdetektive.de/2002/dyn/1407.htm)	School children can input their nature observations into an Internet-based database. The data is represented over satellite images. Photos are also available.	1998
	Mobile communication and computing	Software Tools for Environmental Field Study-STEFS (http://web.mit.edu/envit/www/)	An integrated system for data collection on mobile computers. STEFS uses a GPS and a water-quality sensor, to collect data, which are sent through a wireless network, to a database server. Mobile mapping software records and maps the exact locations where the environmental readings are taken.	2001
Data storage and management	DBMS	EPA STORET (http://www.epa.gov/storet/)	A US national repository for water quality, biological, habitat and physical data. The first version was implemented on a mainframe system.	1965
	GIS	NatureMapping Program (http://www.fish.washington.edu/naturemapping/)	GIS is used to capture the data collected by a network of research and government agencies and volunteers.	1993
	Database backed up web sites	Scorecard (http://www.scorecard.org)	Scorecard ranks and compares the pollution situation in areas across the US.	1998
Data access and exploration	HTML pages	Los Angeles River water test results (http://www.lalc.k12.ca.us/target/units/river/tour/wtests.htm)	Test results in the Los Angeles River watershed conducted by the Los Angeles Regional Water Quality Control Board.	1996
	Database backed up web sites	EPA STORET (http://www.epa.gov/storet/)	WWW interface for data browsing and download.	1999
	WebMapping	EnviroMapper (http://www.epa.gov/enviro/html/em/)	A web-based GIS application that dynamically displays maps with EM data for the US.	1998
	Visualizations, spatial data mining	REINAS: a real-time system for managing environmental data	A system for collecting and distributing real-time data and support data acquisition, visualization and modeling by single or multiple users.	1992
	GIS	Squam Lakes project (Schloss, 1994)	GIS is used to evaluate water quality and to link watershed characteristics and land cover to water quality. Includes volunteer collected data on water quality.	1991
Data processing	Mathematical models and GIS	Eagle System (Thorkilsen et al., 1997 cited by Larsen, 1999)	EAGLE is a GIS based system that controls the aquatic environment close to the construction site of a bridge and tunnel project. It uses monitoring data as input to models.	1997
Communication	Visualizations	Ozone mapping project by the USEPA (http://www.epa.gov/airnow/)	Provides animated maps, which are.gif images, showing atmospheric ozone levels for US and Canada.	1996
	Email alerts	Air alert by Sacramento Metropolitan Air Quality Management District (http://www.sparetheair.com/)	Sacramento county air quality monitoring website. Emails are sent automatically anytime ozone reaches unhealthy levels.	1997
	Online complaint forms	Texas citizen pollution complaint action page by Public Research Works (http://www.reportpollution.org/tnrcc/complaint.cfm)	Send comments or a complaint to the Texas Natural Resource Conservation Commission and State Legislators	–[a]
	Email based list servers and Forums	Stream monitoring by Pathfinder Science (http://pathfinderscience.net/stream/index.cfm)	Threaded discussion areas are used by the Pathfinder Science initiative, which intends to support students and teachers to learn science by doing it.	1997
	Mobile communication	Viv'aPraia by the Portuguese Water Institute (http://www.vivapraia.com/)	Citizens can receive by short message system (SMS) or multimedia message system (MMS) information on water quality of their local beach	2001

[a] Not possible to identify.

The role of ICT within volunteer monitoring initiatives is the same as identified for general environmental monitoring projects. The volunteer monitoring projects that make a more inclusive use of ICT come from the educational arena. Initiatives such as GLOBE, NatureMapping or Naturdetektive use the WWW to create systems that support data input, data access, visualization and communication among all partners of the project. Additionally, such projects use their web sites as a knowledge-repository, which includes tutorial materials and the participation of experts, supporting the creation of virtual communities.

Nevertheless, volunteer initiatives have specific requisites related to the participation of citizens (Drescher and Furfey, 1994; Embley, 1996; Hale et al., 2000; Schloss, 2000). The involvement of citizens, with different levels of knowledge and commitment, may require: (1) access to the technology; (2) ICT training to overcome the lack of familiarity with the technology; (3) easy-to-use tools to facilitate data exploration and communication among volunteers, experts and decision-makers and (4) creation of tools to promote collaboration. Although not restricted to environmental monitoring, the specificities of using ICT tools within a public participation context have been documented by Shiffer (1995), Gouveia (1996), USEPA (1998a), Pickles (1999), Carver et al. (2001) and Peng (2001).

Additionally, the characteristics of the volunteer monitoring data imply the development of specific tools that allow to: (1) integrate data from different sources; (2) explore multimedia data types and human sensory data; (3) validate the data and (4) to configure and manage sensors. GIS have been used for data integration; however, the use of such tools to integrate data from volunteer monitoring initiatives should be further investigated due to data characteristics and data collection specificities. The use of images, videos and sounds as a source of environmental data has been explored by Fonseca and Câmara (1997), Holland et al. (1997), Ferreira (1999), Silva (1999) and Câmara (2002). Nevertheless, the use of such data types together with the use of sensors within volunteer monitoring activities should be further investigated as a way to promote data accuracy and credibility. Sensors to support volunteer monitoring initiatives should be easy to use and affordable.

Outside of the environmental monitoring context, examples exist of ICT use to promote and facilitate public participation within environmental planning and decision-making. The analysis of such developments can contribute to better understand the potential of using ICT to promote public participation within environmental monitoring.

Table 5 presents examples of environmental and planning public participation systems, identifying the available tools devoted to support public participation. Some of the features of these systems might be usable in an environmental monitoring context.

Most of the systems presented have been developed within the context of Public Participation GIS (PPGIS) (for a definition please refer to Weiner et al., 2001) where particular emphasis is given to the provision of tools to facilitate public participation considering the spatial nature of the environmental and planning topic.

Three major types of features can be identified, emerging differently in these systems, according to the components of the public participation process they intend to address: (1) promotion of group interaction; (2) decision-making support and (3) data exploration and visualization.

The systems that are focused on improving group interaction (Shiffer, 1992; Kingston et al., 2000) explore presentation and collaborative tools that may support the idea generation and the identification of what is common within a group. These systems include from spatially based annotation tools that allow people to communicate and share their comments, to spatial multimedia features that provide multiple representations of the same phenomena and more complete knowledge of the discussion subjects.

The use of discussion support tools to assist group interaction is reviewed by Rinner (2001). He proposes the use of argumentation maps as an easy-to-use interface for public participation and identifies the questions that still need to be answered to evaluate their uses in participatory contexts. Rinner defines a rigorous structure for argumentation and spatial references of arguments that allow the connection of geographic objects that do not have a direct spatial relation, but are related through the arguments of participants.

Nevertheless, environmental collaborative monitoring requires tools that not only support discussion and group interaction but also assist volunteers to publish their information, drawing other peoples' attention to their major findings.

Another set of examples is more focused on providing tools for public participation in decision-making. In some of these systems public participation is promoted through the use of multicriteria decision support techniques, that include various decision models integrating individual and group derived evaluation criteria (Carver et al., 1997; Jankowsky, 1998; Harrop et al., 2001; Peng, 2001).

Other systems explore more deeply the visualization component, providing tools to interactively explore maps and associated data (Shiffer, 1992; Fonseca et al., 1995; Al-Kodmany, 2001), allowing in some cases, the possibility of building alternative future scenarios (Kingston et al., 2000; Peng, 2001). These systems may include models linked to GIS visualization tools and also the exploration of advanced spatial visualization tools, such as virtual reality and multimedia animation. For a review on the use of collaborative visualization environments refer to MacEachren (2001).

Collaborative exploration and visualization of environmental data may benefit from the developments in the fields of spatial data mining and agents. Data mining techniques use machine learning, statistical and visualization techniques to discover and present knowledge in a form, which

Table 5
Environmental and planning public participation systems and tools

Environmental and planning public participation systems	Brief description	System components	ICT tools
Collaborative planning system (CPS) (Shiffer, 1992, 1995)	A standalone spatial multimedia system that combines the activities of tool usage, information access and collaboration. It intends to increase access to relevant information leading to a greater communication amongst participants in a group-planning situation, exploring the use of multiple representation aids. Based on a spatial multimedia approach, this standalone system was used in public hearings.	Data collection	Audio annotation on text, graphics or video; Alternative scenarios rating scores.
		Data processing	SMART multicriteria analysis based on a multimedia interface.
		Data access and exploration	Hypermedia navigation and access to spatial and multimedia data on the study area. On-screen video navigation, animation techniques associated to models, superimposition of video sketching onto a video, access to graphics with sounds.
		Communication	Multimedia brainstorming component based on the sketchpad metaphor; Map-based audio annotation during meetings; Multimedia multicriteria evaluation.
EXPO'98 spatial multimedia environmental exploratory system (Fonseca et al., 1995; Fonseca and Câmara, 1997)	A standalone system that explores the use of spatial multimedia for environmental analysis and communication of information, within an environmental impact assessment (EIA) context.	Data access and exploration	Hypermedia navigation Spatial multimedia tools, associated to the different EIA phases, to explore data on the study area: morphing operations to visualize project' impacts, navigating images, sound icons, flyovers, walkthroughs, animations.
URSA-MATIC (Bosworth and Donovan, 1998)	A standalone PPGIS for the Metropolitan area of Portland Oregon, allowing planners, elected officials and citizens to compare alternatives for metropolitan urban growth, by weighting the different factors in different ways	Data collection	Tools to collect people weighting choices.
		Data processing	Multicriteria evaluation techniques.
		Data access and exploration	GIS tools to explore data on the different scenarios during meetings.
Open spatial decision-making on the Internet (Carver et al., 1997)	An online GIS-based spatial decision support system for sitting nuclear waste disposal facilities. People can use spatial data to identify suitable sites according to their own individual preferences as to what factors are important in the sitting process.	Data collection	Online survey for the location of nuclear waste disposal sites.
		Data processing	Multicriteria evaluation techniques.
		Data access and exploration	Online mapping system allowing the access to data on the area; spatial visualization of survey results.
		Communication	Online survey; email.
Virtual Slaithwaite planning support system (Kingston et al., 2000)	A planning support system including a virtual model of the village, which allows the local community to interact with a virtual GIS, providing social, physical and environmental information related to the geographical features on a map.	Data collection	Online survey; online map-based annotation tool for public comments.

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Table 5 (*continued*)

Environmental and planning public participation systems	Brief description	System components	ICT tools
		Data processing	Multicriteria evaluation techniques; tools for spatial analysis of people's choices.
		Data access and exploration	Map-based tool to access to data on the village and to access to the public comments.
		Communication	Online survey; map-based annotation tool; email.
Spatial understanding and decision support system (SUDSS) (Jankowsky, 1998)	An online GIS-based system developed to allow participation in the environmental decision-making process from different locations and different times.	Data collection	Online survey.
		Data processing	Multicriteria evaluation techniques.
		Data access and exploration	Webmapping tool to access and explore multimedia data on the study area and on the survey results.
		Validation	Data security tools that verify user identity, user status and user input.
		Communication	Email; newsgroups.
Georgia Basin Digital Library (Harrop et al., 2001)	An online community decision support tool for investigating suitable development in the Georgia Basin region, Vancouver, B.C.	Data collection	Online survey to collect users preferences based on QUEST (http://www.envisiontools.com/)
		Data Processing	Dynamic modeling tools to forecast and backcast community models.
		Data access and exploration	Webmapping tool; semantic networks navigation; dynamic views of two-dimensional maps; game-like interface.
		Communication	Online survey; email.
Pilsen project (Al-Kodmany, 2001)	An online collaborative planning system to measure community's preferences by using the web and Lynch's urban design model as a framework for the survey. It explores the access to spatial and multimedia data (aerial photos, maps, ground photos) and tools.	Data collection	Multimedia online survey for measuring visual preferences.
		Data processing	Multicriteria evaluation techniques.
		Data access and exploration	Hypermedia navigation and data access on the study area; GIS image database; Multimedia tools: single directional views; linear side views; serial views; four side views; panoramic views.
		Communication	Multimedia online survey; Email.
Web-based public participation system (WPPS) (Peng, 2001)	An online spatial collaborative system designed to enhance public participation in the planning and decision-making process, allowing users to evaluate, comment, select and above all formulate their own alternatives.	Data collection	Tools to allow users to add local data to the system; Online editing and drawing tools for scenario building.
		Data processing	Tools to determine and present alternatives results; 'What-if-analysis' associated to analysis models (e.g. urban transportation planning models).
		Data access and exploration	Webmapping tool to access and explore multimedia data on the study area. Basic spatial analysis functions.
		Communication	Online editing and drawing tools for scenario building, including access to user-sketched plans by other users. Multimedia discussion forum; email; instant messaging and map-based online chatting.

easily comprehensible to humans (Frawley et al., 1992; Miller and Han, 2001). On the other hand, spatial agents can support negotiation within a geospatial problem context (Ferrand, 1996). However, these developments will not be explored in this paper.

The presented examples demonstrate the impact of the Internet in this domain, allowing a wider and more effective dissemination of public information. Carver et al. (2001) evaluates online spatial decision support systems and discusses the benefits of web-based public participation to the environmental planning process. He refers examples in which GIS and the WWW can be used together to provide the general public with a powerful mechanism for becoming more involved in environmental decision problems. According to Carver et al. (2001), the existing examples demonstrate the possibilities of the approach, although public involvement in the planning and the decision-making process is still very much limited and constrained by traditional practices and power relationships.

Peng (2001) reviews Internet GIS applications from its early developments, when considered as a way to disseminate spatial data (Coleman and MacLaughlin, 1997; Peng and Nebert, 1997), to the recent advances, which explore distributed components and three-tier system architecture (Sarjakoski, 1998; Andrienko and Andrienko, 1999; Chang et al., 1999; Kingston et al., 2000). He argues that new approaches give more functionality to the user and are more efficient and scalable. He proposes a taxonomy for a web-based public participation system (WPPS) that could range from simple information browsing, to online communications, to interactive information search and query, and finally, to scenario development and online editing. Finally, he describes a WPPS, which integrates Internet GIS, Internet communications, web technologies and analysis models to allow the user to participate in the community planning and decision-making process anywhere at anytime.

Application areas other than public participation, such as web publishing, interfaces for spatial information systems, learning and gaming, have developed tools that could be useful for the development of an ECMS. A selection of examples of ICT tools was performed in this paper, based on their applicability to an ECMS (Table 6), identifying the tasks where they can potentially be used within such system.

Environmental collaborative monitoring requires easy-to-use tools for data managing and publishing, interactive data visualization and multiple user interactions. Internet developments, such as, weblogs and online data manipulation (e.g. Descartes) may support such tasks.

Developments associated to the publication and access to spatial information on the Internet, namely in what concerns communication and data sharing and the creation of a specific semantics to facilitate search and retrieval of data, can have significant impacts in this area. The Geography Markup Language (GML), which is an OpenGIS Consortium specification, allows the combination of data from different OpenGIS compliant servers. GML includes both the spatial and non-spatial properties of geographic features. A new framework for geospatial information retrieval based on the semantics of spatial and terminological ontologies, the Semantic Geospatial Web, is another reference in this context. It will enable users to retrieve more precisely the data they need, based on the semantics associated with these data (Egenhofer, 2002).

The mobile computing and communication has supported the development of location-based services and multimedia data processing and acquisition, such as multimedia messaging systems. These developments can bring a value-added to the support of volunteer monitoring activities. Additionally recent developments on gaming (online and wireless) and learning applications (e.g. the creation of virtual environments) may support collaboration and knowledge transfer among volunteers.

The rapid evolution of ICT, associated to the dissemination of mobile computing, might contribute to the creation of systems increasingly more capable of supporting and promoting public participation in the future. Another technological development capable of having a significant impact in the public participation domain is interactive TV.

Based on the previous review, Section 4 discusses the major requirements of an ECMS and presents the system proposed by the authors.

4. Environmental collaborative monitoring system

Public participation within environmental monitoring would benefit from the existence of a framework that supports citizens' initiatives to monitor the environment. Such framework should promote access and exploration of the data collected by citizens at the same time it facilitates the integration of volunteer collected data with other sources of environmental data, namely data from official monitoring networks. It should also promote communication among all the stakeholders facilitating cooperation and the creation of synergies.

The development of such framework would benefit from the existence of a collaborative system to explore the capabilities of ICT based tools for data collection, access, exploration, validation, and communication by the different stakeholders. Furthermore, the existence of a system for collaborative environmental monitoring contributes to improve the knowledge on the state of the environment since it promotes the integration of environmental data from different sources. On the other hand, ICT may facilitate the creation of virtual environmental monitoring communities facilitating communication and cooperation among the different stakeholders. Additionally, such system could support the development of an alert system, facilitating collection, access and communication of real-time data.

The WWW is a suitable platform to build a collaborative system designed to promote public participation within

Table 6
Other ICT tools usable in an environmental monitoring public participation context

Examples of ICT projects	Type	Brief description	Potential use for ECMS
Weblog (Winer, 2003)	Knowledge management and personal web publishing	Software and services to create, manage, and share content on the Web. Posts are organized automatically over time. Weblogs allow people to join a community of personal publishers.	Data collection, data access and exploration, communication
AlexWarp (Warp, 1996)	Online image manipulation	An image-warping program developed using Java. The user is able to interactively distort existing images.	Data access and exploration, communication
Datria's VoCarta® voice empowered (Laurini, 2001)	Multimedia data acquisition	A speech-to-database software tool that can be used to collect information in the field in a simple, fast and accurate way.	Data collection
Live sketch (Nobre and Câmara, 1999)	User interface for data input and communication	The use of sketching to define and simulate the evolution of graphical objects in a background. This user interface applies the principles already tested in successful drawing software.	Data collection, communication
Descartes (Andrienko and Andrienko, 1999)	Interactive data exploration tool	Software system designed to support visual exploration of spatial data.	Data access and exploration
WebPark (Krug et al., 2003)	Location-based services (LBS)	A European project that intends to provide location-aware services to visitors of protected and recreation areas. These services will enable users to request information from several databases from their mobile phone or PDA and filtering the information based on location, time and user profile relevance.	Data access and exploration, communication
LiveAnywhere traffic (YDreams, 2002)	Location based services	A system that captures data from traffic cameras, road sensors or text databases and processes these according to user requests. Then it sends the processed data back to the end-user, automatically formatting the data to be correctly displayed on the mobile device being used (mobile phone, PDA, smartphone, tablet PC).	Data access and exploration, communication
NICE (Roussos et al., 1999)	Collaborative virtual environment	The Narrative based, immersive, constructionist/collaborative environment (NICE), is a tool designed to support learning by groups of children. They are able to create virtual environments and simultaneously generate a narrative about that creation process.	Data collection, communication
SIMS online (Barthelet, 2003))	Multiple users online game	The game incorporates text chat, instant messaging and a wide variety of new gestures for a game character to use when communicating with other characters. Users can create their own avatars and living environments.	Communication

environmental monitoring, since citizens may contribute with their knowledge on local conditions, adding data to a broader system and communicate with others to gain support for collective action any time any where. Moreover, the WWW allows to develop spatial multimedia information systems that are appropriate to explore and manage the qualitative and sensory characteristics of the data collected by volunteers. On the other hand, the WWW may back up the development of applications to support volunteer monitoring using other platforms such as mobile devices.

The design of an ECMS may benefit from a more detailed description of the system requirements and system components, which are presented in Section 5.

5. Requirements for an environmental collaborative monitoring system

5.1. Data collection

A collaborative monitoring system should allow any NGO or citizen to input data on the state of the environment, promoting the visibility of such information and data reuse by others. The system should provide tools to input multimedia data such as images, sounds, videos and text as well as quantitative data, which are the data types that might be collected by citizens. Additionally, the system should include interfaces to input data from sensors and mobile devices.

Three major groups of data input tools can be considered in such a collaborative system:

- Annotation tools to help users to express their points of view.
- Geo-referencing tools to support users to reduce ambiguity of a reference to a place or location. Ortho-photos, maps and gazetteers could be used to support geo-referencing.
- Semantic tools to allow the extraction of knowledge from textual data contributing to feed the system database without overload the user. An example of a semantic tool is the use of text recognition techniques together with gazetteers to identify geographic locations referred within text messages.

Considering that the system targets different types of users (citizens, environmental experts and students) all the above mentioned tools should have an easy to use interface, aiding users to feed the system. On the other hand, to avoid inappropriate uses, automatic and non-automatic filtering mechanisms may be added to the system, being the later assisted by the system moderator.

The ECMS should be backed up by a database management system to store and manage the data collected by citizens and allow to compare them with other sources of data. This database management system should be able to manage different categories of users as well as their personal profile data. The design of such database system incorporates not only the support of data collection but also the other major system requirements such as data access and exploration, data validation and the creation of online monitoring communities.

5.2. Data access and exploration

One of the system major goals is to facilitate data access and exploration. Thus, the system should include search and retrieval tools that are enabled to deal with quantitative and qualitative data. Multimedia searching and retrieval tools allowing users to query the system independently of the data type represent another requirement to address in such a system.

The ECMS should enable users to perform spatial, thematic and temporal searches. Considering the spatial nature of environmental information the search and retrieval tools will use geographic information for data access, navigation and exploration. The use of geographic data should not be limited to maps but also include gazetteers, ortho-photos and satellite imagery. Webmapping tools that allow users to access seamlessly to different sources of geographic data, remotely and locally, and interact with them are other important capabilities of the system.

Spatial Data Infrastructures (SDI) that intend to facilitate access and integration of geo-referenced data, may support the development and operation of the ECMS. Data and metadata catalogues available through SDI may support data collection activities such as data geo-referencing. On the other hand, the coordination role of SDI may avoid duplication efforts in data collection. Although the ECMS can make use of the infrastructure available, it requires tools targeting volunteer specificities such as data collection, evaluation and validation as well as communication among stakeholders.

Furthermore, the system should favour visual data interaction, such as virtual field trips, to allow to access to multidimensional expressions of surrounding community issues. Visualizations as well as other data mining techniques should be used to compare volunteer collected data with official data. The multimedia characteristics of the data enable to explore multidimensional representations of the phenomena being analysed.

5.3. Data validation

One of the major obstacles to use data collected by citizens is data credibility. Therefore, any system that intends to promote the use of such data should contain a framework for data validation. Such framework may include tools and methodologies intending to support volunteers to produce data of known quality as well as to help system users to extract useful information from the data collected by citizens. The development of quality assurance project plans, as proposed by the USEPA (1996), is an example of such type of tools and methodologies for data validation that aim at enhancing data quality within volunteer monitoring activities.

The tools and methodologies contained in the ECMS aim at:

- Improve citizens awareness on environmental monitoring methods and equipments, their strength and limitations.
- Promote the use of easy-to-use sensors within data collection.
- Provide mechanisms to assess data quality.
- Facilitate knowledge extraction from the data collected by citizens.

Training materials, to educate users about environmental monitoring issues such as environmental problems, sampling design, site selection among others, are important sources of information to support and promote the involvement of the citizens. These training materials should also address standard and alternative monitoring methods, underlying their strengths and limitations. Much of this information is already available on the WWW; however, it is necessary to facilitate the users' task to find it.

Along the same line, it is important to include information on how to extract environmental data based on human senses. Within this topic there is the need to provide methodologies and tools for data acquisition that facilitate data validation. The use of images videos and sounds should be encouraged as a way to register the data and allow further validation. The work of Ferreira (1999) and Holland et al. (1997) present examples of image processing tools to extract air quality parameters and coastal variables from video images. The development of tools that train citizens to become more accurate within their monitoring activities may promote data validation. An example of such tools is the Waterwatch Habitat Survey (Waterwatch Victoria, 2000) where users assessments are compared with judgments made by experts on landscape quality.

Besides training materials, the participation of experts facilitating the contact among volunteers and scientists may fulfill the citizens' needs. A close relationship between citizens and the scientific community is a way to promote data quality within volunteer monitoring activities.

Another important component of the necessary framework for data validation is the inclusion of tools and methodologies that support users to evaluate data quality included in the system. Such methodologies and tools should allow users to compare the data collected by volunteers with data from other sources mainly from official monitoring networks. Data visualizations, which can make use of statistic and dispersion models to allow for data comparison accounting at the same time for spatial and temporal variations, are examples of such tools.

The tools and methodologies to validate volunteer collected data need to be supported by a data management system that tracks data input and allows volunteers to document their data as well as their data quality. These metadata will facilitate data reuse and will also enable to build indicators of data liability. For example, data quality indicators can be built based on the history of each individual in what concerns his contribution to the system.

5.4. Creation of online monitoring communities

The development of an ECMS may generate the creation and development of a virtual community of volunteers, scientists, environmental technicians and elected officials that are involved within environmental monitoring. The creation of online monitoring communities should enable all the stakeholders to share their views on the state of the environment and work together to improve it. The creation of online environmental monitoring communities will benefit from already established rules for web community building. It implies the existence of tools to support communication, information exchange as well as teamwork among the stakeholders.

Communication of data findings is one of the major issues involved within volunteer monitoring. Not only citizens need to publicize their findings, but they also need to receive feedback and information from other stakeholders, namely from decision-makers or scientists. The existence of feedback mechanisms is a key issue in any public participation support system since it promotes citizens' commitment to participate. Moreover, volunteers also need to communicate among themselves to support the organization of monitoring activities. Therefore, an ECMS should include diverse communication channels as identified in Table 7. Additionally, group calendar systems and shared project planning systems to support volunteer activities management and planning can also be explored.

Another important component within the creation of online communities is the need to have tools for information exchange among the stakeholders. The client–server architecture available on the WWW supports different

Table 7
Examples of communication media to support the creation of online monitoring communities

	One to one	One to many	Many to many
Synchronous	Instant messaging, telephone, mobile phones	Online moderated interviews	Chat rooms, Tele-conferencing
Asynchronous	Email, electronic postcards, SMS, MMS	Mailing list	Bulletin boards, news groups

mechanisms for data exchange being the ftp protocol one of the most known. The collaborative monitoring can use the mechanisms available but should prefer mechanisms that facilitate multimedia data exchange and access.

A collaborative monitoring system should allow all the stakeholders to work together and evaluate the existing data on a specific issue for example, to identify data needs. Moreover, the system may be able to allow users to propose solutions for a specific issue and comment on specific data. Online-shared edition tools to support teamwork and alternative scenario building tools are examples of tools that may support these collaborative tasks.

Considering the complexity of the relationships existing among all the stakeholders that are part of the online monitoring communities, the ECMS would greatly benefit from the existence of a moderator. The system moderator would facilitate the extraction of information from the data collected by citizens where automatic mechanisms are not available. Furthermore, the moderator would promote equal opportunities for all participants and would facilitate the development of consensus building processes.

The creation of online monitoring communities should be backed up by a database management system that allows users to register in the system and create users profiles that help the system to target user needs and preferences.

6. System components

The implementation of the ECMS implies the development of a front-end and back-end solution to enable data collection, access and exploration. At the front-end, the issues involved are mainly related to interface design.

Interface design should facilitate the exploration of the spatial and temporal dimensions of environmental data. Therefore, it should use map-based metaphors with visual cues that allow users to explore multimedia data. Additionally, interface design should consider different access platforms: desktop computers and mobile phones.

At the back-end, it is important to have a distributed approach that promotes interoperability with diverse content providers, at the same time it enables total control of the front-end display. The ECMS is being developed according to a four-tier architecture: the data tier, the logic tier, the presentation tier and the communication tier (Fig. 2). They have been designed to:

- Handle heterogeneous sources of information (Data tier).
- Easily accommodate for more data sources, logic operations and presentations in a client/server environments (three-tier architecture), or distributed environments (distributed three-tier, or *n*-tier) (Logic tier).

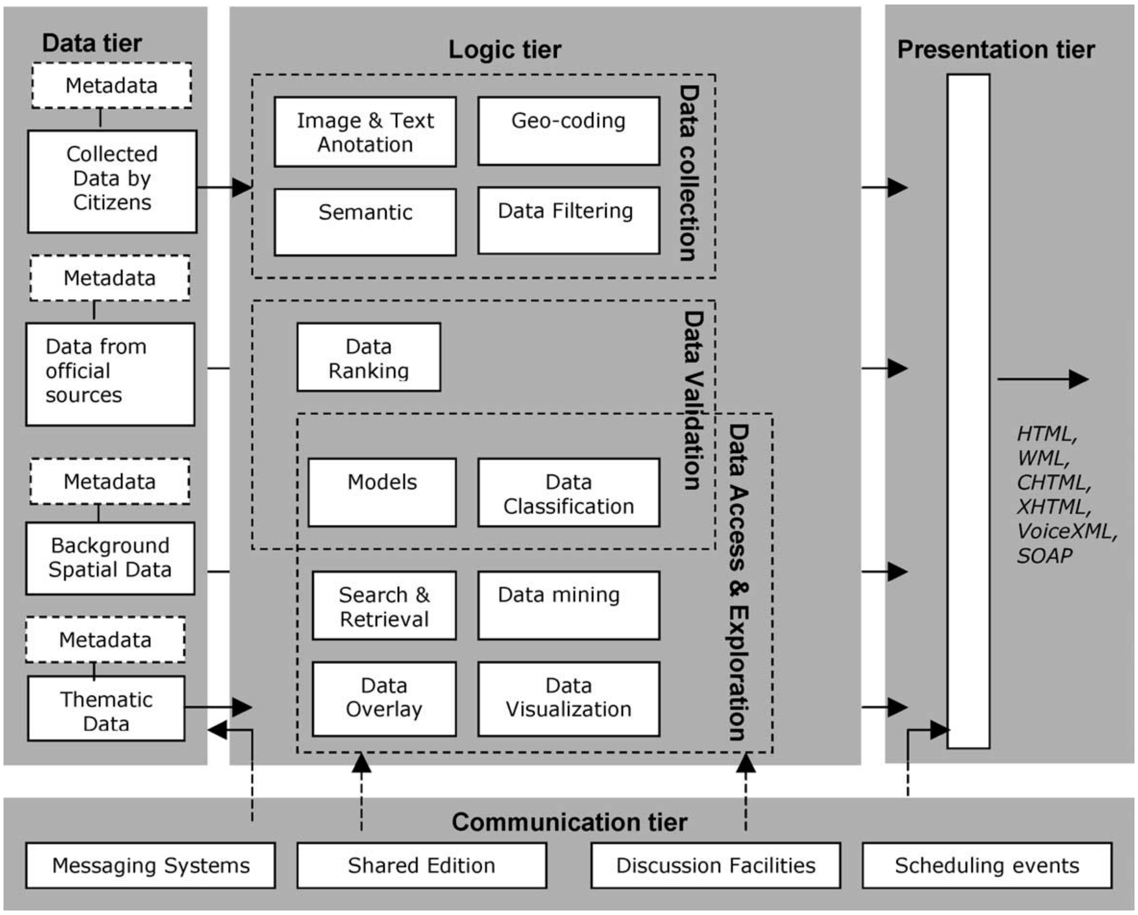

Fig. 2. Back-end components of the ECMS.

- Allow the presentation of the services in all wired and wireless devices (HTML, WML, DHTML, XHTML, VoiceXML and SOAP) (Presentation tier).
- Promote multiple communication mechanisms (Communication tier).

6.1. Data tier

The data tier includes environmental monitoring data, collected by citizens and official monitoring networks, as well as the corresponding metadata. The data contained in the ECMS includes:

- Data collected by citizens, which need to be geo-referenced.
- Data from official monitoring networks, which may include real time data.
- Background spatial data, which include ortho-photos, satellite images and maps to be used as background information and to support users to reduce ambiguity of a reference to a place or location.
- Selected thematic data, which are used for the development of training materials about environmental issues. The development of these training materials will make use of the information available on the WWW.

6.2. Logic tier

The logic tier consists of several modules such as: geocoding, image and text annotation, data overlay among others. The modules will be developed according to the system needs. These components communicate among them and the user has total control over the data flow. This data can also be redirected, at any place, to third-party components. The use of XML to allow communication among the components is one the possibilities under investigation.

6.3. Presentation tier

The presentation tier intends to allow the customization of the system output to almost any device, from regular HTML for Web browsers, passing by several wireless flavours such as WML, CHTML and XHTML, to VoiceXML, that allows the use of voice on a regular cellular phone.

6.4. Communication tier

Environmental collaborative monitoring requires a wide range of communication tools from synchronous to asynchronous and from public to private mechanisms (Table 7). Additionally, data exchanged among the different stakeholders can be used as input to other tiers, for example user participation within a discussion forum can feed a user profiles' database. Therefore, it is important to back up the communication tier with a database management system that communicates with other tiers components. The use of XML is again one possibility.

7. A case study—monitoring beach quality

To illustrate the proposed ECMS, a prototype applied to beach quality monitoring is under development. The prototype is integrated in a research project, named Senses@Watch, which has two major goals:

- To promote the use of environmental data collected by citizens through their senses (smell, taste, hearing, vision).
- To explore the use of collaborative systems to facilitate human sensory data collection, access, visualization and communication.

The prototype being developed aims at providing tools to facilitate beach monitoring data input, access and visualization. Furthermore, it intends to use the sense of vision to identify environmental problems that occur in beaches and to explore the use of photographic and video cameras to collect and validate such data. The Senses@Watch prototype is based on the WWW although an interface for data input and access through SMS and MMS, using mobile phones, is being developed.

The first version of the prototype focuses on beach quality monitoring and uses the eco-label Blue Flag as an indicator of quality. The award of a European Blue Flag, which is run by the Foundation for Environmental Education (FEE), is based on the compliance with 27 criteria covering the following aspects: (1) water quality; (2) environmental education and information; (3) environmental management and (4) safety and services. If some of the imperative criteria are not fulfilled during the season or the conditions change, the Blue Flag will be withdrawn.

Citizens can use the Senses@Watch prototype to publish their data on a specific environmental problem and send them to the official entities in charge of the area and also to the media. Additionally, the Senses@Watch prototype intends to support citizens, staff from official entities, environmental researchers and journalists to work together, increasing the data available on environmental problems.

Citizens can send image, sounds or videos on beach quality issues and associate textual comments to the multimedia files. The data collected by citizens will be classified according to the blue-flag criteria, stored in an online database and then sent to the official entities responsible for monitoring beach quality. The blue-flag criteria, which are available in the Senses@Watch prototype in a hypertext version, are also used to structure the data stored in the site.

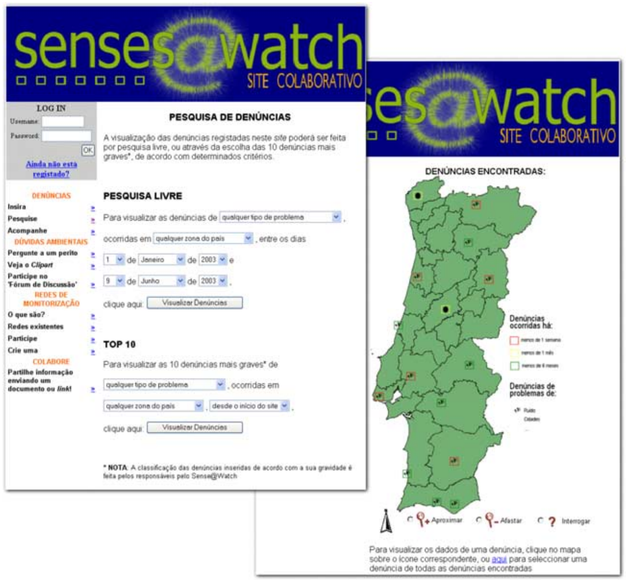

Fig. 3. Illustration of the Senses@watch prototype interface.

The data entered in the site will be available to other users of the system, that can comment on the data and reuse them (with the authors' permission) to reinforce their own contributions to the system. Citizens' complaints and their follow ups are also accessible through the Senses@Watch collaborative website. To avoid inadequate uses of the system the data are filtered by the system moderator.

The Senses@Watch prototype (Fig. 3) gives access to citizens collected data and official beach quality monitoring data. Additionally, it gives access to learning materials on beach quality monitoring available on the WWW.

The prototype includes three major components:

- Tools to insert multimedia data on beach quality data, which include geo-referencing tools, data classification and creation of metadata.
- A clipart that intends to support users to communicate their data using images, while drawing other people's attention to the environmental problem in hand. The clipart includes pre-recorded multimedia data (images, sounds and videos) on beach quality that can be previewed and selected by the user to illustrate a specific environmental problem. Furthermore, it includes annotation tools to allow users to underline specific issues within the images.
- Data access and visualization tools, namely thematic, temporal and spatial searches.

Users, who are encouraged to register in the site, only need to fill a form describing the data to be entered in the Senses@Watch online database. The attributes required are: (1) data collection time and place; (2) thematic classification according to the blue-flag criteria and (3) data type. The major goals are to create metadata that supports the system to assess the data fitness and, at the same time, to keep the data input task simple. The metadata produced by users are stored in a database to support search and retrieval tasks.

Additional metadata are produced, if the user registers in the site. The registration form includes information on the user characteristics, such as scientific background in environmental issues, major theme and area of interest, membership of NGO, among others. Using the site as a registered user allows the system to track users' actions and save that information. The user profile and users actions, which are also stored in a database, enable the creation of data credibility indicators and the creation of customized views of the data. For example, data collected by frequent users will be given a different credibility index than data from occasional users. The user's profile data enables the system to provide a map of the users location showing information collected by citizens for that specific area.

The metadata are defined and structured following the Dublin Core metadata elements, which have been extended to accommodate the geographic dimensions of the data and the creation of the user profile. Additionally, XML has been used to map the ISO 19115 meta-tags elements.

Most citizens' collected data can only be geo-referenced using indirect referencing systems. Geo-referencing is not a straightforward task, particularly outside of urban areas, where geo-reference cannot accurately be done using postal addresses. The wide spread of GPS will facilitate such task, however, few citizens use it for their voluntary monitoring activities. A gazetteer together with maps or ortho-photos can be used to allow users to identify the data collection location and reduce the ambiguity of a reference to a place. The use of mobile phones for collaborative monitoring has the advantage to associate a location to the data collected. An interface to receive data from MMS and SMS is under development.

The Senses@Watch prototype allows users to geo-reference the data using a gazetteer where they can choose the place of reference. The location of place is then displayed over an ortho-photo. If the user wishes, political boundaries can also be shown. Users can accept such location or modify it on the ortho-photo. Such geo-referencing tools were developed using ArcIMS from ESRI.

If the user has logged on as a registered user s/he can use previously identified locations. It is also possible for the user to identify a place not included in the gazetteer and associate that name to a location on a ortho-photo. That type of information after being filtered by the system moderator will be available to other users. Therefore, users also collaborate in the population of the gazetteer.

The clipart has been designed to assist three main purposes: (1) to provide images as examples of beach quality issues; (2) to offer tools to draw other people's attention and (3) to create learning materials on how to use images to corroborate beach quality problems. One of the assumptions behind clipart development is that a major part of the data collected by citizens is based on the sense of vision and such data are best transmitted by images.

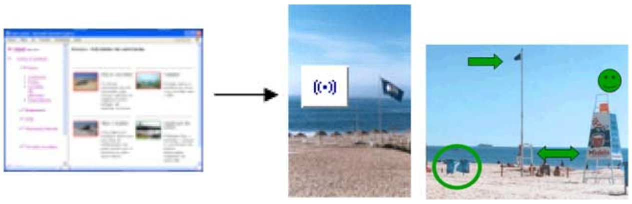

Fig. 4. Clipart interface, a photo showing a Blue Flag Portuguese beach, linked to an ocean sound file and an annotated photo.

The clipart gives access to a directory of images describing good and bad examples of the blue-flag criteria. Associated to the images are textual descriptions of the problems observed within the images. Furthermore, the images can be linked to sounds and videos (Fig. 4). The images and linked files included in the clipart can be used by users to exemplify specific issues.

Additionally, the clipart encourages users to annotate their images to underline specific uses. The clipart will include tools to annotate images using graphics and text, using the sketching metaphor developed by Nobre and Câmara (1999). The clipart concept and interface is currently under usability testing. Three major questions are being evaluated: (1) is the visual information considered sufficient to express the environmental problems or a multi-sensory approach would be more appropriate? (2) Are the tools to annotate the images useful? (3) Is the clipart metaphor clear?

Data search and visualization are based on webmapping tools, which provide the basic spatial navigation aids such as zoom in, zoom out and pan. Maps are used as a navigation and exploration metaphor. Users can select an area and get a map representing a picture of the monitoring data available. The data spots are represented differently according to data theme, data type and data owner. The spatial reference is used to support the integration of data from different sources. Temporal navigation is possible through the use of a time slider.

Using the navigation and exploration tools available in the Senses@Watch prototype it is possible to know the areas and themes that are more incomplete. Such picture may support citizens' efforts to collect data. When the system receives a citizen complaint about a specific environmental problem, that is considered a serious environmental problem by the system moderator, a specific request may be made to registered users to support monitoring efforts within the specified area.

The Senses@Watch is still in an early stage of development. Currently, only tools for data input, search and access have been developed. Some of these tools are still under usability testing to understand if they are easy-to-use by the target users. Further developments include the development of the communication layer, which is needed to support the creation of online monitoring tools and to increase the involvement both of the public, official entities and experts. In such layer special emphasis should be given to the participation of experts and journalists. Other questions such as the representation of the users and the connection with models should be explored to allow not only to store and access monitoring data but also to use the system to find the sources of the problems reported by citizens. More work is needed on how to use the prototype to validate the data.

8. Conclusions and future research

Involving concerned citizens within environmental monitoring has allowed to increase, spatially and temporally, the collected data on the state of the environment. Furthermore, such initiatives have an educative value and promote public engagement within environmental protection. However, major questions remain: Are the data collected by citizens valid? For what purposes are the data valid? How to promote the use of citizen's collected data? The scientific value of volunteer data has been assessed by several studies (Nicholson et al., 2002; Au et al., 2000). Nevertheless, further research is required for example in the development of methodologies to extract useful information from human sensory data.

Information and communication technologies come out as a tool to facilitate data collection, validation, access, exploration and communication. Through the use of sensors, ICT may support data validation and promote the use of human sensory data as a source of information on the state of the environment. At the same time, ICTs make possible the creation of a framework that supports public participation within EM since; they promote collaboration among stakeholders and allow the integration of volunteer collected data with other sources of data. However, it is important to evaluate the performance of ICT based tools and methodologies to promote citizens' participation. Along the same line, further research is needed for the development of easy-to-use tools to support public participation within EM.

In this paper, the requirements of an ECMS were identified and described based on the analysis of the role of ICT in promoting the use of volunteer collected data. The requirements identified were used as the basis for the development of an ECMS for monitoring beach quality, which is presented in this paper. The prototype of such a system, developed within the Senses@Watch project, is still under development. The data input component and the clipart are currently under usability testing.

The recent ICT developments such as the third generation of mobile phones and the interactive TV are both promising for promoting environmental collaborative monitoring. Therefore, the design of a collaborative monitoring system should consider three platforms to collect, access, explore and communicate environmental data: the personal computers, mobile phones and interactive TV. The four-tier components proposed for the ECMS intend to accommodate different platforms for data input and access. At this stage of development it is suggested that the WWW work as the backbone of an ECMS. However, there is the need to study the tools and interface available for each type of platform.

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