NeWater

WP 1.6

TASK 1.6.3

INTEGRATION OF LOCAL AND TECHNICAL KNOWLEDGE FOR ADAPTIVE WATER MANAGEMENT

Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty

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Executive Summary

Overview

This report is the third deliverable of the WP 1.6 of the NeWater Project. The NeWater Project aims at the development and the implementation of methodologies and tools to support a stepwise change process in water management from the current management regimes to a more adaptive one.

Within the NeWater frame, WP 1.6 - *Transition to advanced monitoring systems* will define a monitoring system to support adaptive management process. the WP 1.6 aims at defining the architecture of a new monitoring system able to overcome the limits imposed by the data scarcity, particularly in data-poor regions. To reach these aims different sources of information have to be integrated.

The Task 1.6.3 aims to identify alternative sources of information, both technical and societal, that can be used to support Adaptive Management of water resources in areas characterized by lack of information due to deficiencies in current monitoring system. A review of methodology and technology to gather data from different sources is carried out in this task. Particularly, the suitability of local knowledge and expert knowledge to monitor the state of the environmental resources is deeply investigated. The architectures of Community-based Monitoring System (CBMS) and Expert System (ES), as modules of the Advanced Monitoring Information System (AMIS), are described at the end of this work.

The project has started in January 2005 and will run until December 2008.

The Adaptive degree of the AMIS

In the previous deliverable (D 1.6.1), the properties of an Advanced Monitoring Information System (AMIS) have been defined. Among them, the capability to use different sources of data and information has been highlighted. The AMIS can be considered as the platform through which the scientific knowledge, resulting from the implementation of "formal" monitoring activities, can be integrated with that deriving from a stakeholders based approach.

This approach recognises that science alone cannot provide all the answers, and must be combined with a structured process of local participation that emphasises shared learning and locally-relevant indicators and methods. The challenge is to bring local and scientific knowledge systems together into a single structured information system.

Alternative sources of information for water management

Local knowledge is increasingly recognized as an important source of information for the environmental resources management. It could fill important information and data gaps, particularly in data-poor region, contributing to build a full picture of local environment.

Incorporating local knowledge into the decision-making process and creating community-based resources management can have several benefits for both the communities and the water management agencies.

Nevertheless, the use of local knowledge in environmental resources monitoring and management has been hampered by several shortcomings. First is the data credibility. In fact, local knowledge is not subject to the same peer review as the scientific knowledge, nourishing the scepticism of the scientists and the decision makers. The local knowledge tends to be qualitative rather than quantitative, and may vary in precision, reducing the possibility to compare the data collected by local communities with those coming from other sources. The contribution of local knowledge is limited due to a general lack of understanding on what local knowledge is and how it can be explored. The data completeness represents a further problem. In fact, the involvement of local communities in monitoring activities requires a long term engagement which often cannot be guaranteed. Thus, exploring how the local communities express their knowledge of the environmental resources and how make this knowledge usable for the decision process is a particular challenge for our research work.

It’s unrealistic to expect water managers to make use of the Local Knowledge as it is generally presented, because it is not systemically set out and its contents are too vague for them to access and use easily. Therefore, an important preliminary phase concerns the systematization of the Local Knowledge.

Expert knowledge are used in this work both to support the validation of local knowledge and to provide information to monitor environmental phenomena. In fact, when information are not available, experts can make judgements about environmental phenomena through approximate analyses, heuristics and personal expertise. When experts deal with a complex problem, they do a qualitative pre–selection of the context, considering only the aspects of the problem that, according to their judgment, allow them to solve it.

Therefore, expert knowledge about factors influencing the environmental phenomena can be collected. These factors are easily assessable allowing to define the groundwater pollution risk in data-poor areas. For further detail, the reader may refer to.

In this work the architecture of a Community-based Monitoring Information System able to overcome the aforementioned shortcomings is described.

Table of contents

1 Introduction

The information plays a fundamental role in the decision-making process. It allows to define the set of suitable alternatives, to improve the understanding of, and trade-off among, the alternatives (McDaniels and Gregory, 2004). The information reduces the uncertainty and facilitates the definition of alternative scenarios, supporting the decision makers to define the possible outcomes of an alternatives, the likelihoods and the resulting consequences of these outcomes. Information assists in rationalising the choices made in policymaking, founding the choices on objective criteria. Sound knowledge, reliable information and accurate data are vital for good environmental decision-making (Haklay, 2003).

The transition towards an adaptive approach to the water resources management (AM) is leading to a growing demand of information in environmental decision-making. In an AM perspective, the management has to be adaptive, that is, it has to change according to new insights (Pahl-Wostl, 2005). Adaptive management acknowledges that action is necessary although knowledge maybe imperfect (Ringold et al., 1999). Thus, adaptive management is a systematic process for continually improving water management policies and practices by learning from the outcomes of already existing or implemented management strategies.

In an adaptive approach, monitoring becomes the primary tool for learning about the system and assessing the management strategies. Information distilled from monitoring is used both to determine the effectiveness of implementation activities, and to test the hypotheses that originally formed the basis of the management action. Corresponding adjustments are made to implementation activities, management objectives, and any models used to make original forecasts.

In an adaptive perspective of the water management, the information cannot be considered just as an initial input for the decision process, but they have to be pervasive, supporting all the phases of the AM cycle.

The need for monitoring in AM is thus clear, but who should carry it out? In the past, most of attention has been paid on the "professional" monitoring (Danielsen et al., 2005), that is the monitoring based on the scientific knowledge.

Nevertheless, professional monitoring faces several important challenges, especially in developing countries, where financial and human resources are limited. In these areas, the monitoring network cover only small part of the territory or the grid is too sparse, making the monitoring data not suitable for the decision process. Further, the professional monitoring is costly, reducing its sustainability over time. The resulting works may be still valuable as one-off assessments, but they don't provide information about the trends of environmental resources and evolution of environmental phenomena. Thus, often the outcomes of environmental policies are hardly assessable. Moreover, often professional monitoring pays inadequate attention to the objectives of key stakeholders, such as the local communities, whose livelihoods are closely impacted by the environmental resources concerned (Danielsen et al., 2005).

Given the importance of information in adaptive water management, how to deal with data scarcity? What are the consequences of lack of information?

In the perspective assumed in this work, adaptive management is based on the integration between different sources of knowledge. The monitoring system has to be considered as a platform through which the different sources of knowledge that can support the adaptive process can be integrated.

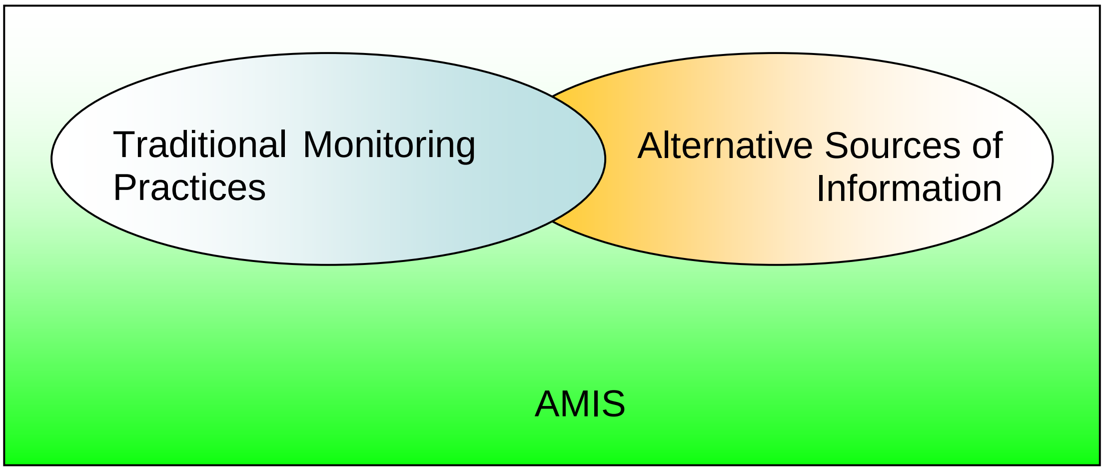

Fig. 1: Integration of sources of information

The focus of this report is on the definition and integration of alternative sources of information. Particularly, how best to integrate the scientific knowledge, resulting from the implementation of "formal" monitoring activities, with that deriving from a stakeholders based approach is our main field of research. These approach recognises that science alone cannot provide all the answers, and must be combined with a structured process of local participation that emphasises shared learning and locally-relevant indicators and methods. The challenge is to bring local and scientific knowledge systems together into a single structured information system.

In data-scarce regions, expert knowledge can be also considered as alternative sources of information to fill in gaps in environmental monitoring data. We refer to expert knowledge as a set of "informal" information, such as rules of thumbs, intuition, personal experiences and judgement, heuristics that allow experts to make decisions also when information are not available (Uricchio et al., 2004; Liebowitz, 1995; Rubenstein-Morano, 2000). Collecting and structuring this knowledge can support environmental monitoring and management.

Furthermore, the knowledge stored in the expert system module can be used to support the process of local knowledge validation, as described further in the text.

This work is organized as following. In section 2 some issues concerning the usability of local knowledge to monitor environmental resources are investigated. The architecture and the performances of a Community-based Monitoring Information System (CBMIS) are deeply described in section 3. Section 4 focuses on how to collect and use expert knowledge in environmental resources monitoring and management. Finally, in section 5 the program of research activities dealing with integration of different sources of information that will be carried out in NeWater case Studies is described.

The CBMIS and the Expert System (ES) will be integrated in the Adaptive Monitoring Information System architecture, as reported in fig. 2. According to the schema, they will be provide to the AMIS information coming from alternative sources, which are considered fundamental in and adaptive perspective of environmental monitoring (Giordano and Vurro, 2005).

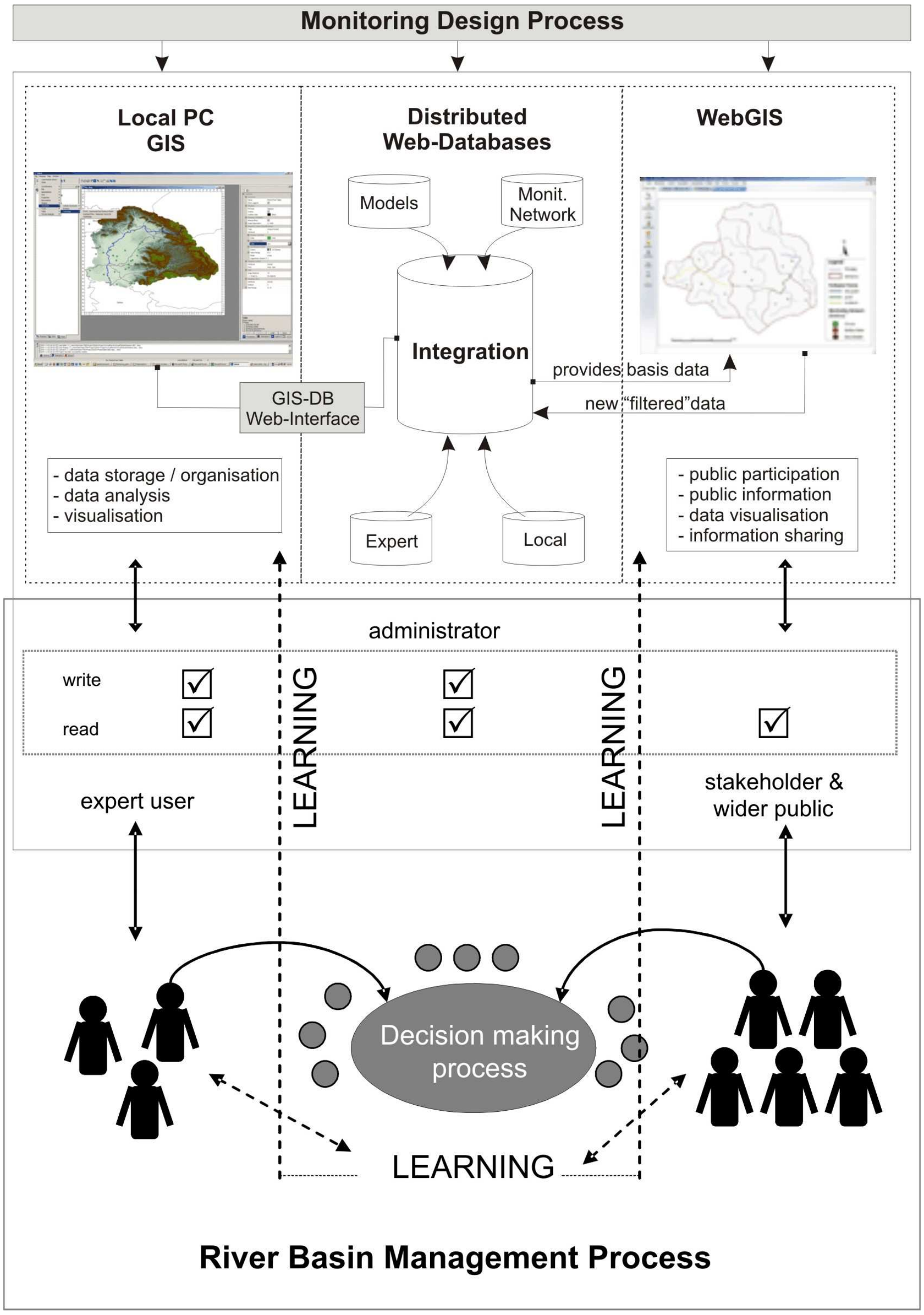

Fig. 2: AMIS architecture (Giordano et al., forthcoming)

2 Local Knowledge to support Environmental Monitoring

Today there is an ever increasing interest in enhancing public participation in the water resource management domain. Public participation is conceived as a way to enhance the democratization of the environmental resources management, allowing to all possible stakeholders to participate to the decision-process.

This is no a small achievement considering the extent modern science have tended to view local people, especially those living in resources-poor community, as part of the environmental problem, not as part of its solution (Hambly, 1996b)

The role of the participatory process in water management has also been established by the European Community Water Framework, which strongly encourages the active involvement of all the affected parties in resource management (Pahl-Wostl, 2002).

The importance given to shared decision processes in water management derives from an awareness of the inadequacy of traditional – i.e. engineering – approaches in dealing with complex and ill-structured problems. Moreover, if the stakeholders are not involved at all in defining and evaluating alternatives, then the decision process outcome could be controversial and the solutions proposed could generate strong opposition, making those solutions unfeasible (Kersten and Concilio, 2002). Unilateral action creates a false efficiency of the decision-making process since although it allows the time, expense and uncertainties associated with a negotiation process to be avoided, implementation problems would almost certainly arise (Susskind and Cruikshank, 1987). There is the hope that participating in decision making will lead people to accept and support those decisions (Raiffa et al., 2002).

One way for people to be involved is to provide *local knowledge* of their environment (Robertson and McGee, 2003). Local knowledge is increasingly recognized as an important source of information for the environmental resources management. It could fill important information and data gaps, particularly in data-poor region, contributing to built a full picture (Ball, 2002).

There is a wide range of literature about the relevance of local knowledge, its use and the importance of integrating local knowledge into more formal research activities (Oudwater and Martin, 2003). Local knowledge can be used to corroborate scientific data and to fill in gaps in scientifically generated data (Scholz et al., 2004). In fact, the scientific knowledge cannot always provide satisfactory answers at local scale, usually because of the site specificity which can lead the scientists to ignore the localized macro-variation and to ask the wrong question through a lack cultural understanding (Ball, 2002). Compared to scientists, local people are often best placed to assess ecological changes and contribute relevant information and actions to solve environmental problems (Hambly, 1996b).

Local environmental knowledge refers to the body of knowledge held by a specific group of people about their local environmental resources (Scholz et al., 2004; Robertson and McGee, 2003). Local knowledge should not be seen as the simple counterpart of the scientific knowledge; they can be combined as partialities of *a whole* knowledge, leading to a hybrid and broad view of local resources management issues (Robbins, 2003).

Involving local communities in monitoring activities is not just a matter of using participatory approaches within a conventional monitoring framework. It's mainly about a radical rethinking who initiates and undertakes the process, and who learns and benefits from the findings.

Many approaches use local knowledge to monitor the environmental resources, namely “Participatory Monitoring”, “Community-based Monitoring”, etc. These approaches are directly linked to environmental resources management, but the entities being monitored vary widely, from individual animals and plants, to ecosystems and habitats (Danielsen et al., 2005).

Anyway, four principles are at the basis of using local knowledge for environmental management:

- participation: opening up the design of process to include those most directly affected, and agree to collect and analyze data and information together;
- negotiation: to reach agreement about what will be monitored or evaluated, how and when data will be collected and analysed, what the data actually means, and how findings will be shared, and action taken;
- learning: the involvement in monitoring activities allows local communities to learn more about their environment. Moreover, in an adaptive perspective, learning becomes the basis for subsequent improvement and corrective action;
- flexibility is essential due to the number, role and skills of stakeholders involved.

Thus, using local knowledge for environmental monitoring and management is not simply a “data-collection” operation, carried out by researchers and in which local people have a passive role. Researchers and practitioners need to collaborate with community members and other stakeholders to assemble and share environmental information. This points to a process of co-producing knowledge. Co-producing knowledge differs from simply collecting data, and it can play a fundamental role in facilitating participation in the decision-making processes (Bessette, 2006).

Incorporating local knowledge into the decision-making process and creating community-based resources management can have several benefits for both the communities and the water management agencies (Gouveia et al., 2004). From the communities side, the benefits obtainable through the public involvement are main related to the promotion of the public awareness of environmental issues, the enhancement of collaboration and cooperation and the promotion of a “two-way” information exchange. On the other side, the water management agencies could increase the available information; they could base their strategies on a more integrated knowledge; the implementation phase could be facilitated since the conflicts could be reduced.

Many efforts have been made to utilize local knowledge in environmental monitoring and management. Robertson and McGee (2003) propose to utilize the memory of a local community to support the wetland rehabilitation in Australia. They demonstrate the role of oral history, integrated with established scientific knowledge, to lead to environment management that is in tune with the ecosystem dynamics. They also recognize that in some areas, particularly in developing countries, local community’s memory is the only available sources of historical information. The information was collected through semi-structured and unstructured interviews with local stakeholders and natural resources managers. The aim was to collect information about the flooding, ecology and environmental management. Comparisons with aerial photographs, hydrological modelling study and digital elevation model were used to validate oral histories.

Scholz et al. (2004) integrate fishermen’s knowledge in geospatial analysis to support marine protected area planning process in California. Their work aims to collect local knowledge to be integrated with scientific knowledge, in order to fill important data gaps. The research project was designed to elicit fishermen’s knowledge and test ways of incorporating their knowledge into the decision-making process. To elicit the local knowledge, the authors conducted semi-structured interview to local fishermen. During each interview, fishermen were asked a series of questions on four core analytical areas: demographics (home harbour, years fishing experience, species targeted, gear and techniques used), oceanographic information (prevailing local weather and currents, weather-dependent fishing locations, observations about fish distributions based on physical oceanography, critical anchorages and transit passages, effects of ocean regime), biological information. The knowledge collected during the interview has been spatially represented in a GIS form.

Interesting researches deal with the definition of grassroots indicators to evaluate changes and degradation in ecosystem (Hambly, 1996). Some plants are used by local communities as an indicator for land degradation. Most indicator species of soil fertility are locally specific plant and animal species. In an experience in western Kenya, farmers have reported more than 50 species of plants, to indicate poor or improving soil fertility. Farmers have also reported the habits of certain insects and birds as important indicators of changing soil composition, i.e. the loss of organic matter and unexpected fluctuations in moisture regimes, including impending drought (Hambly and Angura, 1996).

In several cases, local knowledge has been used to monitor the biodiversity at local level (see for example Hellier et al., 1999; Danielsen et al., 2000; Danielsen et al., 2005). In one case, local knowledge has been used as a valuable source of information on the status and trends of individual species (Hellier et al., 1999). Local people were interviewed as to how the vegetation had changed in their life-time or in village history, and how the abundances of utilised species had changed over the same period. Maps were drawn to represent the local community’s knowledge. The authors found some shortcomings mainly related to the qualitative aspects of local knowledge. Danielsen et al. (2000) proposed a simple biodiversity monitoring system, based on the involvement of local people and staff of protected areas to detect trends of species and resources use.

Other authors developed methodologies to compare and combine local knowledge of soil and scientific survey using a GIS as an integration domain (Oudwater and Martin, 2003). One of the most interesting aspects of this research concerns the investigation of GIS as a tool to support the integration among different sources of information. The local knowledge collected in this work regarded the farmers’ classification systems for soils and farmers’ spatial knowledge and ability to map the distribution of different soils. Transect walks and individual households were conducted to get an understanding of farmers’ soil classification, of the used criteria and of how farmers relate their knowledge of soil to their farmer practices. Participatory soil maps were drawn.

The use of local knowledge in environmental resources monitoring and management is still limited because of several shortcomings. Firstly the data credibility. In fact, local knowledge is not subject to the same peer review as the scientific knowledge, nourishing the scepticism of the scientists and the decision makers. The greater challenge for local knowledge lies in enduring suspicious and prejudices against local knowledge and its value as measurement of environmental phenomena (Hambly, 1996).

The local knowledge tends to be qualitative rather than quantitative, and may vary in precision, reducing the possibility to compare the data collected by local communities with those coming from other sources. Another issue that has to be dealt with concerns the scale of local knowledge. If it’s too local, i.e. at community level, then it maybe too site specific, and it would be impossible to compare regions (Fraser et al., 2006).

The contribution of local knowledge is limited due to a general lack of understanding on what local knowledge is and how it can be explored and used (Oudwater and Martin, 2003). The data completeness represents a further problem. In fact, the involvement of local communities in monitoring activities requires a long term engagement which often cannot be guaranteed. Thus, exploring how the local communities express their knowledge of the environmental resources and how make this knowledge usable for the decision process is particularly interesting.

Our research work aims to define methodologies and tools to face the above mentioned shortcomings of local knowledge. All of them are used to define the architecture of a Community-based Monitoring Information System (CBMIS).

3 Community-based Monitoring Information System

As reported in previous section, local knowledge can be considered as a valuable source of information, particularly in areas characterized by lacks of current monitoring information systems, and by human and financial resources not enough to improve them.

Nevertheless, given the drawbacks of local knowledge described above, it's unrealistic to expect water managers to make use of it as generally presented, because it is not systemically set out and its contents are too vague for them to access and use easily. Therefore a Community-based Monitoring Information System has to be able both to support the collection of local knowledge through the involvement of local communities in monitoring activities, and to enhance the accessibility to this knowledge by decision makers.

The use of local knowledge in environmental monitoring claims for systems guarantying equal access to data and information for all sectors of the community; and equal possibility to provide knowledge in a way that can be understood by the other members (Ball, 2002). Therefore, a Community-based Monitoring Information System (CBMIS) should promote the access and exploration of the already stored data and information; it should facilitate the input of local knowledge and the integration among the community-based information with data from "scientific" monitoring system.

Moreover, the CBMIS should promote the communication among the stakeholders facilitating cooperation and the creation of synergies. The creation of virtual monitoring communities should enable all the stakeholders to share their perspectives on the state of the environment increasing their knowledge and their will to work to improve it (Gouvia et al., 2004).

In the following, the different steps to design and develop a CBMIS and the methodologies adopted to overcome the aforementioned drawbacks are described.

3.1 Community-based Monitoring design

One of the basic assumptions of the CBMS is the involvement of local communities and stakeholders in all phases of monitoring activities, starting from the monitoring design.

In our research work the Information Cycle methods (Timmerman and Mulder, 1999) has been adopted to support the monitoring design phase. The information cycle (Figure 3) is a framework to describe the adaptive approach to monitoring design (Giordano et al. forthcoming). It describes how monitoring in the broad sense of collecting information to support integrated water management should be developed and implemented.

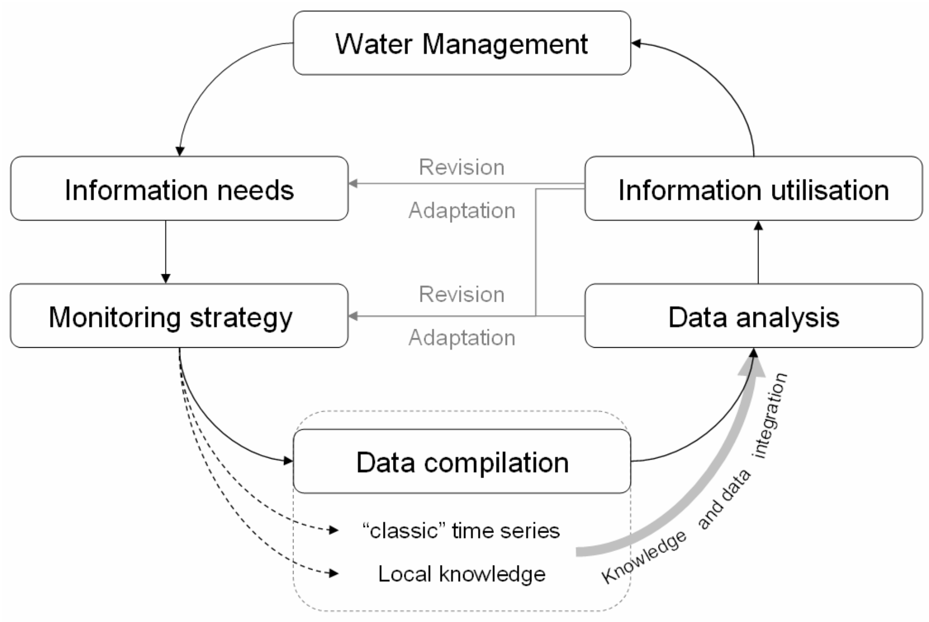

Fig. 3: The information cycle

In the information cycle, information users in close dialogue with information producers decide upon the characteristics of the information that is needed: the information needs.

Specification of information needs is a means to make a translation from a policy problem into an information management issue in the information cycle; the water policy and management objectives are translated into information expectations that in turn forms the basis for an information production network. Information needs are specified in close interaction between information users and information producers.

Among the several methods that have been developed to support the information needs definition, we focus on the information needs hierarchy (Timmerman and Mulder, 1999). This method provides a five-step plan that enables managing the information needs definition process.

The process starts with the exploration phase, setting the scope and boundaries of the study. After exploring the scope, the study is initiated by developing a conceptual model of the system, based on the integrating decision-model, and identifying gaps and controversies in the information model. The available (policy) plans are considered through the conceptual model and the derived aspects will lead to the fundamental objectives. The information users as stakeholders play an important role in this step. A first structured breakdown in the form of an information needs hierarchy is discussed in this phase with the identified stakeholders leading to a broad understanding of the process as well as of the problem. After the initiation, the information needs have to be further elaborated and compared to the present information situation. The information model is further explored and elaborated, and the structured breakdown is detailed into a fully-fledged working scheme in an iterative way in this step. The existing, real world situation is included in the analysis and the results are discussed with the identified stakeholders in the conclusion step. A comprehensive overview of the results is produced after this in the completion step making the results transparent for those people that were not involved in the process and transferable to the actors that take care of the implementation of the results (Timmerman and Mulder 1999).

In our approach, the information needs hierarchy has been changed because the decision-making contexts analyzed by Timmerman and Mulder is different from that in which a CBMIS will work. The differences are mainly related to the role that participants to information definition process will play in environmental monitoring. In fact, Timmerman and Mulder dealt with a decision-making context in which information users and producers are different. Contrariwise, in a participatory perspective of monitoring, local communities play a twofold role. From one side the information has to be easily accessible for non-expert people allowing them to participate in the decision-making process. Thus, local communities can be considered as information users. On the other side, the use of local knowledge in environmental monitoring is fundamental to overcome the limits imposed by data scarcity. Local communities can be considered also as information producers.

Therefore, while Information Needs Hierarchy focuses on the decision the stakeholders have to take, based on available information, the aim of our approach is mainly to discover the knowledge hold by local communities that can be used for the decision process, and how this knowledge can support the Adaptive Water Management.

In our approach, the process starts from the definition of community's mental models of the local environment and monitoring activities, using Cognitive Maps. This involves identifying concepts and relationships between concepts through an in-depth interviewing process. Interviews may be done with individual or small groups of people.

The questions can be grouped in four main classes, aiming at investigate different aspects of the interviewees perspective. The design of a monitoring system adopting a bottom-up approach starts establishing the goal of the whole project. Thus, the actors in the process must reflect on the most important environmental problem at local level, strengths and opportunities around which goals and strategies can be developed (Fraser et al., 2006). In this step, Soft System Methodologies (SSM) (Checkland, 1981) can be useful. The soft system approach moves from focusing on the optimal solution of a given problem to focusing on the problem situations (Patel and Patel, 2003). SSM is intended as a methodology to explore, question and learn-about ill-structured problem situations (Lane and Oliva, 1998) in which individuals continually negotiate and re-negotiate with others their perceptions and interpretations of the real world outside themselves. According to this assumption, each individual has his own perspective in defining and interpreting a problem situation (Lane and Oliva, 1998). The expected outcome of a SSM study is a set of insights that emerge from the comparison of individual perspectives (Lane and Oliva, 1998), forming the richest possible picture of the problem situation (Checkland, 1981). This information can be used to define goals and strategies for the community-based monitoring information system. The establishment of goals and strategies can also provide a way of identifying and resolving conflicts between the participants (Fraser et al., 2006).

In the second step, the monitoring targets can be identified. Starting with the main environmental problems, through specifying different aspects of these concerns, more detailed objectives are developed. To this aim, the interviewees are asked to think to possible elements affecting the environmental phenomena and/or that can be affected by the phenomena.

The identification of indicators is directly connected to the previous step. The set of indicators has to support the monitoring of the factors. Broadly speaking, the set of indicators has to meet at least two criteria: it has to be defined according to the goals of the monitoring system; it has to be easily usable by local communities (Fraser et al., 2006). Given the nature of local knowledge, indicators are very often qualitative and linked to the daily experience of community members. Furthermore, indicators developed by researchers often carry little meaning for local communities. Therefore, meaningful participation of local community is essential in indicators identification, evaluation and selection (Reed and

Dougill, 2002). Many attempts have been made to involve local communities in defining environmental indicators. In all of them, the indicators are easy and rapid to use, relevant to the target area, they use existing skill and knowledge, and they should be monitor visually and on a daily basis. On the other side, bottom-up indicators have been criticized for not being objective enough (Fraser et al., 2006). Therefore, the aim of this step is to identify indicators to express local knowledge of environment.

The final step concerns the collection of data that can be used by communities to monitor the environmental resources. The methods used to collect, interpret and display the data must be easily and effectively used by local communities (Fraser et al., 2006)

3.2 Requirements for a Community-based Monitoring Information System

3.2.1 Knowledge collection

As told previously, the CBMIS has to facilitate the collection of the knowledge held by local people. To this aim, the CBMIS has to be able to manage qualitative information, such as stories, opinions, as well as images, sounds, videos, etc.

Many efforts dealing with local knowledge collection are mentioned in the scientific literature. Most of them are based on the use of ICT, which is considered able to radically change the nature of decision processes and the stakeholders' role. The ICT allows to overcome the "one-way" knowledge diffusion approach, privileging a "collaborative" knowledge exchange perspective (Kersten e Concilio, 2002).

Broadly speaking, the ICT innovations can support participatory planning by:

- providing a virtual environment to organize forums allowing the community members to give their knowledge and to discuss;
- using argumentative maps in order to locate opinions, suggestions, criticism.

One of the most important ICT innovation is the Public Participation GIS (PPGIS). Using the web, PPGIS provide easily access to information, spatial planning models and GIS tools to support public involvement in the planning process. The PPGIS allow users to input their opinions and knowledge directly on maps.

The web is a suitable platform to build a system designed to promote community participation in environmental monitoring. The citizens can contribute with their knowledge on local environmental condition and communicate with others to gain support for collective actions anytime anywhere.

Concerning the aim of our research, the CBMIS has to support the input of qualitative data.

Three main groups of data input tools can be considered to facilitate data collection:

- Annotation tool: this toll has to be designed to support both the input of qualitative information, such as stories, opinions, etc, and the following knowledge structuring process through cognitive maps. Thus, annotation tool can be conceived as a semi-structured questionnaire.
- Multimedia tool: to facilitate the collection of multimedia contributions.
- Geographical tool: to support the participants in reducing the ambiguity of a reference to a place or location. This tool can support the user to indicate the name of the place or to identify it on a map or orthophotos.

Considering that the system targets different types of users, the above mentioned tools should have an easy-to-use interface.

Nevertheless, the extent to which IT-based tools can help the achievement of a more democratic and useful level of information for citizens is not univocally agreed upon. On one side, many authors emphasize the ICT potentialities in shared decision processes, characterized by the involvement of several social groups with different interests, problems, perceptions and knowledge, thanks to the effective knowledge sharing, a precursor for a successful collaborative process.

On the other side, the limited familiarity with the ICT can impede wide portions of the community to access to these technologies, causing a drastic reduction of participation in decision process. Terms like *digital divide* or, more recent, *informational divide*, are often used to point out the risks related to an excessive optimism towards the use of ICT to remove cognitive barriers in decision-making processes.

In our work, we start from the idea that Community-based Monitoring Information System should be particularly helpful in developing countries, characterized by lack of "professional" monitoring system. Moreover, in these areas the diffusion of ICT is very limited, hampering the use of web-based system to support knowledge collection from local communities.

Many examples of local knowledge collection in developing countries are mentioned in the scientific literature. A range of techniques are used to elicit information, i.e. transect walks, community mapping, questionnaires, interviews, etc. All of them are based on the direct interaction with local people. Participatory mapping seems particularly interesting since it facilitates the comparison between local and scientific knowledge.

Even if these methodologies got good results in collecting local knowledge in developing countries, some changes are needed to use them in community-based monitoring. In fact, they require several phases that cannot be repeated frequently, as needed in environmental monitoring.

Thus, in community-based monitoring, the local knowledge collection can be divided in two main phases, namely "preliminary" and "routine". The former is mainly devoted to design the monitoring system adopting a participatory approach, (i.e. main environmental problems, indicators, way to collect data, etc.). The second concerns the collection of information to monitor the environmental state.

The preliminary phase has been already described in previous section. It can be carried on interacting with local community. Concerning the routine phase, the knowledge collection phase will be different according to the participant's familiarity with the ICT. To facilitate the knowledge collection, two different interfaces should be defined, i.e. an electronic interface (computer and web) and a human interface. In the first case, the user can login to the system and add the information, leaded by the easy-to-use interface.

The ICT is not so diffused not only in developing countries, but also among some social groups in developed countries (e.g. farmers). In these cases, the participants can interact directly with some human interface (NGO, environmentalists, farmers associations, etc.) which collect local knowledge and input it in the CBMIS. The contents, the frequency of collection and how to collect knowledge have already been discussed during the monitoring design phase. Thus, it can be assumed that the participants agree on them.

The process of data collection can be schematized as in the figure 4:

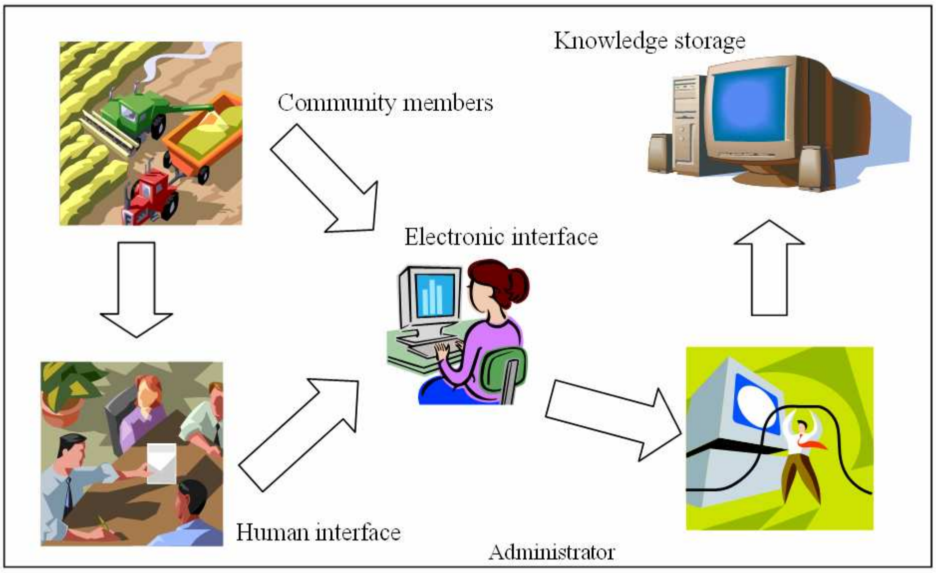

Fig. 4: Local knowledge collection

3.2.2 Knowledge structuring

As told previously, local knowledge cannot be used as normally expressed. Thus a preliminary phase of structuring is fundamental. Therefore, tools able to facilitate the knowledge structuring are required.

Some authors propose to adopt a formal language to give a structure to local knowledge improving its comprehensibility also outside of local community (Wilkes and Shicai, 2004). These approaches are characterized by an heavy influence of the researchers which collect data.

Different methodologies dealing with the structuring of qualitative knowledge are mentioned in the scientific literature. In our research work, the Problem Structuring Methodologies (PSM) and the GIS technology have been taken into account for their potentialities in making qualitative knowledge suitable for the decision making process.

Mostly, PSM have been used to facilitate group work within business organisations. New approaches are attempting to apply these methodologies in more complex shared decision processes such as participatory natural resource management (e.g., Hjorsto, 2004; Ozesmi and Ozesmi, 2003). PSM aim at disclosing the point of view, the knowledge, of each stakeholder on a particular issue, their perception of the related problems and which of the alternative solutions are suitable in their opinion.

To structure the knowledge expressed by the different stakeholders, making it comprehensible for the decision-makers and functional for the decision process, we refer to SODA methodology. SODA is a general problem identification method that uses cognitive mapping as a modelling device for eliciting and recording individual views of a problem situation. The cognitive maps are defined using verbal protocols, allowing the contents of a discourse to be structured and the qualitative data contained to be analysed (Cerreta et al., 2004).

The Cognitive Map aims to disclose individual perceptions of consequences and explanations associated with concepts and it is used by participants to communicate their understanding of the nature of the problem (Hjorsto, 2004). A Cognitive Map can be defined as a map made up of concepts linked to form chains of action-oriented argumentation (Eden and Ackermann, 2004). Cognitive maps have been used to represent cognition at both individual and group levels.

In our research works the Cognitive Maps are used to structure the stakeholders knowledge in different phases, starting from the monitoring system design.

During the monitoring system design, the Cognitive Maps are used to structure the mental models of local community members regarding local environment. The aim is to identify the elements needed for monitoring system design, as described in the previous section.

The individual Cognitive Maps can be aggregated to obtain the local community CM. From an organizational cognition perspective, the most interesting approaches describing methods to aggregate the individual cognitive maps are (Tegarden and Sheetz, 2003): congregate maps, shared maps, group maps and oval maps. Although these approaches are based on different methodologies, in all of them to successfully merge the individual maps, creating a collective cognitive map, sufficient congregating labels or themes, i.e. common semantic nodes, must be identified. This tends to be very difficult and time consuming process. Moreover, in most of these approaches the identification of common labels and themes is carried out by the interviewer and not by the interviewees. The identification of common labels is often based on some measures of similarities.

The community cognitive map are used both to design the monitoring system and to support the knowledge acquisition phase. The logical framework based on local knowledge can be used to define the interface able to lead the participants in providing their information. In other words, the questions to be asked to participants follows the logical framework of community cognitive map. In this way, the collected knowledge is already structured according to local community perception.

During the system routine phase, the structuring process mainly concerns the usability of qualitative data. Fuzzy logic can play a fundamental role, since it allows to take into account linguistic variables, that is, variables whose values are not numbers but words or sentences in a natural language (Zimmermann, 1991). The motivation for the use of words rather than numbers is that linguistic characterizations are less specific than numerical ones (Zadeh, 1973). In the CBMIS, the use of Fuzzy linguistic variables can facilitate the participants in providing their knowledge, since it can be expressed in human language, and not necessarily in a "formal" (i.e. numeric) way.

Linguistic variables can be used both to give a qualitative value to the indicators and to locate information. Concerning the last one, a linguistic variable "distance", with terms such as "close to" or "far from", can facilitate the information input and the definition of a local knowledge map.

The use of fuzzy linguistic variables is fundamental also to deal with qualitative knowledge. In fact, the participants are allowed to provide information using their natural language. This information cannot be used directly from the decision-makers. To facilitate the access to local knowledge, fuzzy functions linking the qualitative information with the environmental phenomena under investigation can be useful. As an example, if the environmental problems is the soil degradation, a useful fuzzy function links the quantity of plants to the degree of degradation. Fuzzy functions can be defined integrating local and scientific/expert knowledge. After fuzzification and defuzzification steps, qualitative information on soil degradation can be provided.

Very often, the local knowledge has a strong geographical connotation. Therefore, the local knowledge has to be "spatially" represented, creating "indigenous GIS" (Robbins, 2003) that can support the use of local knowledge in the environmental resources management decision process.

Many efforts have been made to create GIS maps based on local knowledge (e.g., Oudwater and Martin, 2003; Anuchiracheeva et al., 2003; Hellier et al., 1999; Scholz et al., 2004). The incorporation of local knowledge in a GIS can be used either to challenge the existing "scientific" spatial document, or to supplement the existing information (Robbins, 2003). In the latter case, GIS is the platform to integrate local and scientific knowledge, leading to a hybrid and broad view of the local resources management (Oudwater and Martin, 2003; Robbins, 2003). However, extending GIS access to grassroots groups and other non traditional users is beneficial because it enables development of alternative knowledge and its inclusion in the decision-making (Elwood, 2002).

Some researchers, recognizing the exclusion of certain types of knowledge, have sought ways of extending the representational capacities of traditional GIS to include "non-traditional" knowledge, such as narratives, alternative cartographies, videos, pictures (Elwood, 2002; Gouveia et al., 2004). These "extended" GISs supports non-traditional users to construct and to promote their own perspective or to re-examine those produced by others (Elwood, 2002). Most of the extended GISs have some multimedia functionalities. The use of multimedia techniques can support non-expert users to understand the GIS information, providing tools to interactively maps and associated data (Ball, 2002). Moreover, they can assist the users to publish their information, drawing other peoples' attention to their findings (Gouveia et al., 2004).

3.2.3 Knowledge validation

The usability of local knowledge in environmental monitoring is hampered by the scepticism of decision makers, since local knowledge is not subject to the same peer review as scientific knowledge.

Thus, any system that intends to promote the use of local knowledge should contain a framework for knowledge validation. Such framework may include tools and methodologies to support local community members to produce information of known quality (Gouveia et al., 2004).

A close relationship between citizens and scientific communities is a way to promote data quality within community-based monitoring. This interaction can facilitate the exchange of knowledge and training materials, to educate community members about environmental monitoring issues and monitoring methods. The development of tools and methodologies that support participants during the monitoring activities may promote knowledge validation.

An example of tool developed to support community members in environmental monitoring is reported in fig.5:

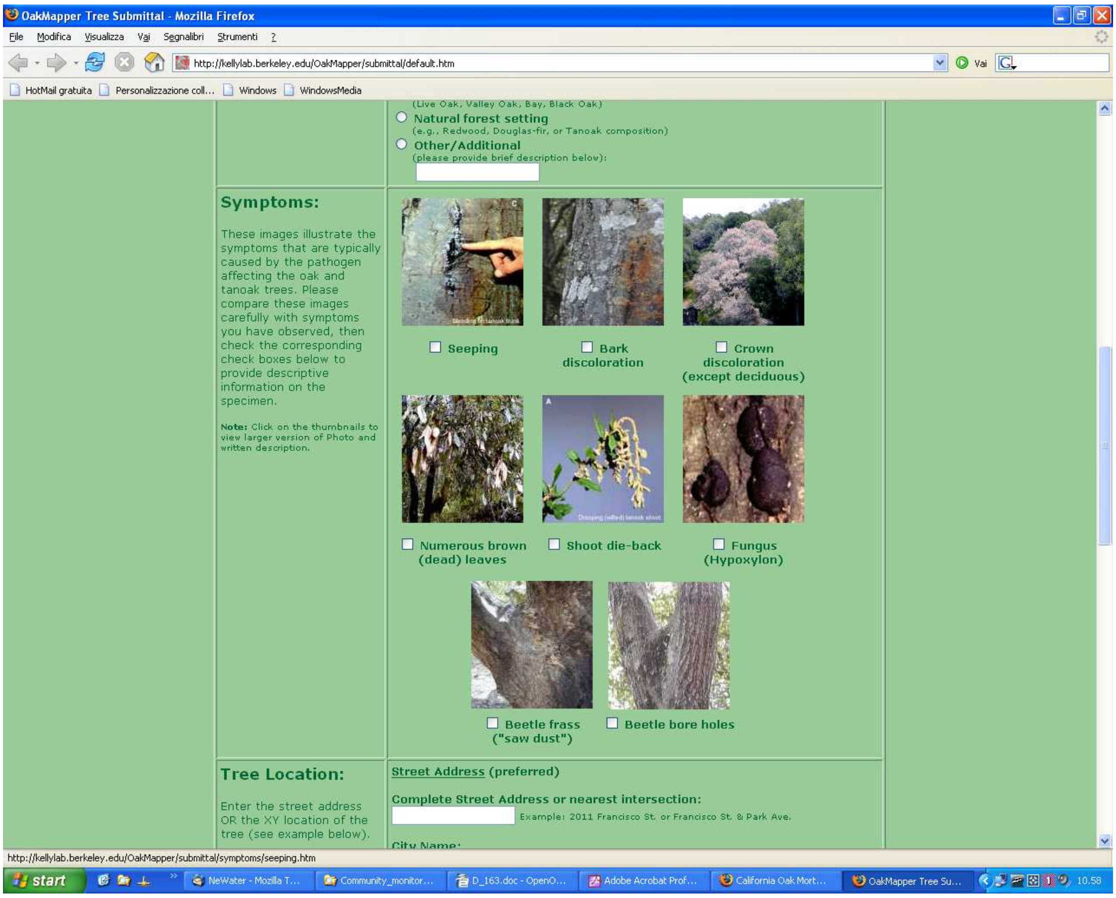

Fig. 5: OakMapper user interface

Through an easy-to-use interface, the system provides useful information to lead the participants in providing their knowledge.

Furthermore, the reliability of local knowledge can be assessed using the knowledge stored in the Expert System module, as described further in the text.

3.2.4 Knowledge access and exploration

The involvement in environmental monitoring of citizens with different levels of knowledge requires easy-to-use tools to facilitate data exploration and communication among local community members, experts and decision makers.

The access to information and the information exchange among the actors play a fundamental role. Information becomes gradually embedded in the understanding of actors in the community; it becomes embedded in the thoughts, practices and institutions of a community, thereby influencing actions.

Many efforts have been made in the ICT field to create tools able to support the access and sharing of data and information. Most of them are directly linked to GIS technologies. The focus is on visualization tools that can increase the comprehensibility of information also for non expert people. An interesting research field regards the definition of virtual decision environmental. Virtual environments are digital simulation of situations in which users are able to participate. It is generally agreed that such participation must be engendered so that users are able to feel that they are present within the environment and are able to interact with the simulation.

Virtual reality technology can be useful when good participation requires animated graphics, often more than maps because it can represents built environment through user can move and fly (Hudson-Smith et al., 2002). These kind of virtual reality is often truly interactive. Several type of software and media can be used to make information available in such virtual environment, from the most sophisticated tools to create graphics and visualising real environment to basic text and data.

ICT tools can help people to comprehend information, then derive knowledge, allowing them to become participants in the decision process in its first stage. For an exhaustive description of ICT tools to facilitate the access to information the reader is referred to Gouveia et al. (2004).

Moreover, the information accessibility can be enhanced by an adaptive user interface, able to support the knowledge access and exploration for different user profiles. Thus, at least three user-friendly interface can be defined. The first one can be referred to “professional user” who are familiar with GIS technology and who have a certain degree of knowledge in environmental system behaviour. All necessary and available features will be incorporated in this interface. A second interface with less functionality and with a focus on user-friendliness will be provided for decision-makers or non-scientists. The third interface will provide the public with information and enabling everybody to provide their knowledge on local environment. The WebGIS technology can be suitable to this aim.

In any case, all of these tools are based on the assumption that possible users are familiar with ICT. While the aim of our research work is to define a monitoring information system to support adaptive management also in data poor regions. In these areas, the ICT is a prerogative of a small portion of the population. The accessibility to data and information can be enhanced using the “human interface” (see section on knowledge collection). Anyway, the information has to be easily understandable from lay people. The format to be used to diffuse the information has to follow the results of the participatory system design.

4 Expert System Module

An Expert System is a computer program that emulates the behaviour of a human expert in solving problem in well defined domain (Liebowitz, 1995).

Knowledge-based systems represent one of the most interesting applications of artificial intelligence, and their use is spreading rapidly in different cognitive domains. Their performance depends strictly on a knowledge-base (Fay, 2000) that stores rules, objects, facts, general cases, exceptions and relations that can help a human decision-maker solve a problem, even if information is not available. Thus, it is crucial that the knowledge base should be complete, consistent and accurate (Liebowitz, 1995).

The inference engine is another important module in a ES. It is a mechanism for manipulating the encoded knowledge base, forming inferences and drawing conclusions. Since the knowledge base is a repository of human knowledge, which is imprecise in nature, it is usually the case that the knowledge base is a collection of rules and facts which are neither totally certain, nor totally consistent (Zadeh, 1983).

As a consequence the management of uncertainty plays an important role. Thus, the inference engine has to be equipped with computational capabilities to analyze the transmission of uncertainty from the premises to the conclusions and associate the conclusions with some measure of uncertainty that is understandable and properly interpretable by the user (Zimmermann, 1987).

In many expert systems, to manage the uncertainty fuzzy set approaches have been adopted. Fuzzy logic and approximate reasoning are used meaningfully in expert systems for both the knowledge representation and inference mechanisms (Zimmermann, 1987). With regard to the latter, while classic expert systems adopt the same logical inference engine, based on dual logic, in a fuzzy knowledge-based system different kinds of inference methods can be adopted (e.g. the max–min inference method, the max-dot inference method, etc.). In the next section, an explanation of how fuzzy logic was used in the proposed system is provided.

Many attempts have been made to use ES to support environmental resources management. ESs have been traditionally applied to select the most suitable alternative to solve an environmental problem, starting from submitted data.

Given the aim of the ESM, critiquing expert system approaches are really interesting. These systems don’t provide a solution, but support the users to evaluate their proposed solution, providing them a critique (Shepherd, 1998). The critique includes alternatives, explanations, justifications, warnings, and additional information to consider. Thus, the users have an active role and they can improve their own problem-solving style, rather than be forced to emulate the experts.

Critiquing ES are particularly useful in complex and ill-structured domains, with multiple acceptable problem solving approaches and solutions. Moreover, providing suggestions to the users about how to improve their solutions, these ESs support learning-by-doing process. Learning occurs as a result of the problem solving process (Shepherd, 1998).

As told previously, the Expert System Module (ESM) will be developed to reach a twofold aim:

- support the local knowledge validation phase;
- provide information to the AMIS.

4.1 Local Knowledge validation

In scientific literature, interesting studies can be found dealing with data and knowledge validation. Some of them are based on the use of Expert Systems.

Concilio and Conte (2004) described a KBDSS to support data validation and data analysis in an air pollution monitoring system. Through semi-structured interviews and observation sessions, the knowledge used by the expert to validate the data coming from monitoring networks was collected. The authors make a distinction between the observation-derived knowledge, acquiring by the expert in his daily work, and theoretically-oriented knowledge, deriving form the expert's education. The collected knowledge was stored in the knowledge-base of the system in an *if…then* form and declare valid or not valid a data.

Thus, one of the aim of our research is to define an ES able to validate the environmental knowledge collected by local communities.

Given the importance of the knowledge-base in ESs, two important issue related to knowledge collection have to be addressed before implementing the system, i.e. which experts can be involved? What kind of knowledge has to be collected?

A preliminary phase of developing a knowledge-based decision support system following the approach proposed is the selection of the experts to involve. This choice is crucial because the knowledge base is founded on the experts' heuristics, their logic, their opinions and intuitions. Consequently, the experts selected leave a clear imprint on the developed system. In this work we propose to involve experts from different domain, both scientific and technical, which are familiar with the environmental problem at stage. It seems particularly interesting to involve experts currently working with environmental monitoring and environmental data.

Developing an ES for local knowledge validation requires the acquisition of two different kind of knowledge: domain knowledge and critiquing knowledge (Shepherd, 1998). The former refers to knowledge used by the experts in dealing with environmental phenomena. The latter is the knowledge used to define the reliability of information.

Referring to the work of Concilio and Conte (2004), the domain knowledge is theoretically-oriented, while the critiquing knowledge is acquired by the expert in his daily work with environmental data.

A multi-step process of knowledge acquisition can be adopted in this work.

In the first step, general knowledge about the considered domain, along with specific information from the literature can be acquired. In this step, the fundamental features of the problem are defined. The second step aims to define the logical patterns that allow the experts to formulate a judgment on the information reliability of information. In the steps that follow, weights can be assigned to the factors influencing expert judgment.

To formalize information gathered from the experts' judgment, expressed in linguistic terms, fuzzy logic approach can be adopted. In fact, fuzzy logic provides an effective conceptual framework for dealing with uncertainty and imprecision. Fuzzy logic makes it possible to formalize the experts' knowledge using fuzzy rules. A fuzzy rule is a conditional statement: IF (fuzzy proposition) THEN (fuzzy proposition). The rules can be characterized by a weight which can be considered as the degree of truth of the statement. In the present study, the weights of the rules are expressed by the experts in terms of linguistic statements according to the importance of the factors involved in the statement. Therefore, fuzzy linguistic variables can be used.

As stated frequently in previous sections, local knowledge cannot be used directly in decision making process due to comprehensibility issue. Therefore, the cannot be able to assess the reliability of local knowledge as it's presented by the communities. The validation phase has to be done after the local knowledge have been structured.

As an example, if we refer to soil degradation (see section on grassroots indicators), before using the ES to validate the data, the presence of a kind of plant has to be translated in a land degradation index.

4.2 Expert Knowledge for environmental monitoring[1]

Expert knowledge can be used also to monitor environmental phenomena when no enough data are available.

There are many complex mathematical models to simulate environmental phenomena, however, most of them need a lot of detailed information and/or data which is often unavailable, incomplete or inaccurate. Using such models with low-quality data could lead to errors following from oversimplification of a modelled system. Expert knowledge in this context could be thresholds of different parameter values and if-then relationships for instance.

As an example, we may refer to groundwater pollution risk. Many mathematical models can be applied to assess the risk degree. They are based on an equation describing flow conditions in the soil, considering both soil and pollutant characteristics. These models are able to evaluate the amount of pesticide that leaches along the soil profile until it reaches groundwater by simulating various phenomena that influence the environmental fate of pesticides. These models, however, require a lot of detailed information often not easily accessible.

To overcome the shortage of reliable information, qualitative knowledge can be considered. Such a knowledge is elicited interacting with human experts. In fact, when, for any reason, it is impossible to use complex models, experts can evaluate an environmental risk through approximate analyses, heuristics and personal expertise (Liebowitz, 1995). When experts deal with a complex problem, they do a qualitative pre–selection of the context, considering only the aspects of the problem that, according to their judgment, allow them to solve it.

Therefore, expert knowledge about factors influencing the environmental phenomena can be collected. These factors are easily assessable allowing to define the groundwater pollution risk in data-poor areas. For further detail, the reader may refer to (Uricchio et. al, 2004).

Expert knowledge may be used in flood prevention. A model that is designed to predict floods is used in a particular river basin. The data required by the model is not sufficiently available, but the model is used anyway. Obviously the results will be highly uncertain and maybe useless. Using empirical expert knowledge and modelling results parallel could lead to reduced uncertainties.

Precipitation, evapotranspiration, soil moisture conditions, riverbed morphology, and land cover are amongst others important parameters influencing the discharge in a river basin. But often climatic data is the only available data and as a rule models need more input. A monitoring system using only real time precipitation data improved by empirical if-then relationships and threshold values could produce warning messages automatically.

To conclude, capturing heuristics that allow experts to make a judgement on environmental phenomena and incorporating them into a knowledge base can be really useful to monitor environmental resources in data poor regions.

[1] This section has been written with the contribution of Stefan Liersch

Particular attentions is needed in managing the uncertainty associated to the use of such a knowledge instead of monitored data. To overcome this drawback, a fuzzy linguistic set “reliability” may be introduced. The degree of membership in these fuzzy set depends on the availability of the information and on its importance.

5 Architecture of CBMIS and ES

Given the requirements of a monitoring information system able to use alternative sources of information to support environmental resources monitoring, the architecture of CBMIS and ES can be schematized as in fig. 6:

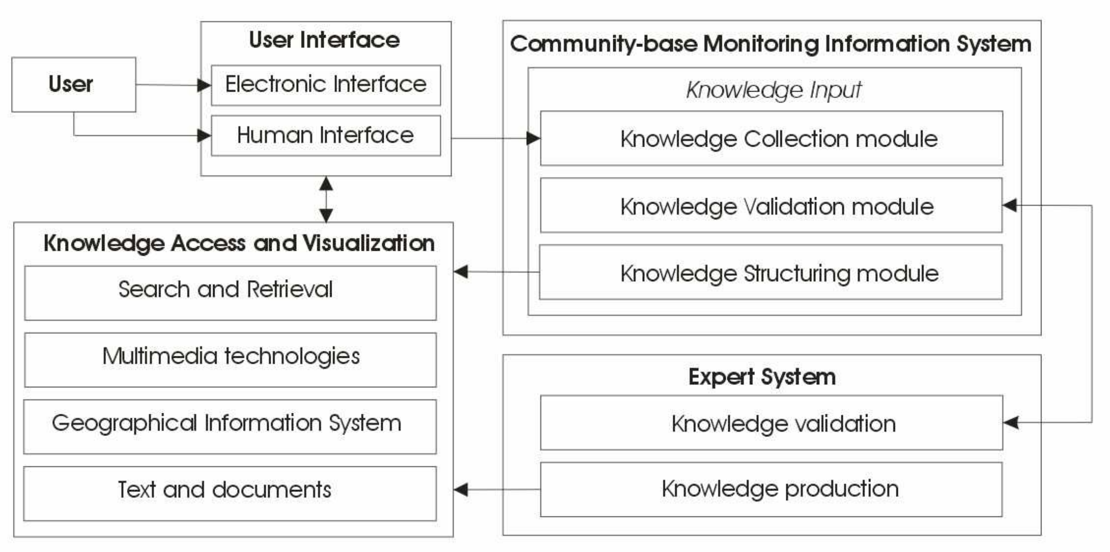

Fig. 6: CBMIS and ES architecture

As described previously, two different interfaces have been included in the architecture to support access to monitoring system also to people not familiar with ICT.

The interfaces support users both in inputting data in the CBMIS and to retrieve and visualize information stored in the monitoring information system.

The CBMIS is composed by three main module. The first one is devoted to support the collection of knowledge from local communities. This knowledge has to be validated by the second module and structured before going in the “knowledge access and visualization” module.

This module shows collected knowledge in different forms, according to the users requirements. In this module, the knowledge collected by local communities is integrated with those coming from elicitation of experts heuristics.

6 Conclusions

In an adaptive perspective of water resources management, information collected through monitoring system plays a fundamental role. In fact, Adaptive management refers to a “learning by doing” process in which the outcomes of the implemented strategies are used to iteratively refined and improve management policies.

The main aim of WP 1,6 efforts within NeWater framework regards the definition of an Adaptive Monitoring Information System (AMIS) able to support the adaptive water management.

According to our approach, the AMIS should play the role of the platform through which different kind of knowledge can be integrated to support water resources management, particularly in developing countries, characterized by lacks of current monitoring information systems, and by human and financial resources not enough to improve them. The integration between scientific knowledge and local knowledge, based on the involvement of local communities in monitoring activities, is particularly interesting for our research.

In this work, the characteristics of a Community-based Monitoring Information System (CBMIS) and an Expert System (ES) are described. The CBMIS and ES should be considered as a module of the AMIS, devoted to collect alternative sources of knowledge to support environmental monitoring.

The involvement of local communities in environmental monitoring has a twofold benefit. From one side, it aims allows to increase the availability of information to support Adaptive Water Management in areas characterized by lacks of traditional monitoring systems. On the other side, it contributes to increase the awareness of local people on environmental issues.

Different pieces of knowledge are taken into account to obtain the whole picture of local environmental, adopting a social approach to the construction of reality. According to the Soft System perspective, individuals continually negotiate and re-negotiate with others their perceptions and interpretations of the real world outside themselves. According to this assumption, each individual has his own perspective in defining and interpreting a problem situation. The expected outcome of a SSM study is a set of insights that emerge from the comparison of individual perspectives, forming the richest possible picture of the problem situation.

Therefore, the quality of decision processes is potentially greater than that of traditional approaches since different knowledge and perspectives are taken into account and integrated. Furthermore, the interaction that takes place during a participative decision process can facilitate the exchange of information and knowledge, leading to a better comprehension of environmental problems through a social learning process.

To support this learning process, the CBMIS has to aim to enhance the cognitive capacities of participants, by facilitating the access to knowledge and information, and to support the interaction networks within a local communities.

The integration between quantitative and qualitative knowledge lead to the achievement of hybrid knowledge nuanced understanding of environmental, social and economic system interactions that are required to provide more informed inputs to local sustainable water resources management.

The usability of local knowledge is under investigation in two NeWater case studies. These experimentation addresses important research issues concerning the limits of local knowledge, such as data credibility, qualitative nature of data, comparability of data, scale of data.

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