WP 1.6

DELIVERABLE 1.6.5 (B)

MONITORING DESIGN PROCESS IN AMUDARYA RIVER BASIN

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

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Executive Summary

Overview

The deliverable 1.6.5 is the concluding part of WP 1.6 and it tries to summarize the experienced made during the implementation of Adaptive Monitoring Information System (AMIS) in the NeWater case studies and to describe the lessons learnt.

The deliverable is composed by three main parts:

- part (a) describes the experiences made in Tisza river basin. In this case study, the most important research needs about information production and management concern the flood forecasting and flood management. AMIS implementation has been focused on the integration among different information sources.

- part (b) describes the lessons learnt during AMIS implementation in Amudarya river basin. In this case study AMIS has been focused on the usability of local knowledge to support the monitoring of environmental support.

- part (c) summarizes the results obtained during NeWater implementation and describes the properties of the AMIS, updated considering the lessons from the implementation in both Tisza and Amudarya.

The AMIS implementation in the Amudarya river basin

Two different environmental issues were taken into account in this case studies. In one case, the AMIS was implemented to support the soil salinity monitoring. In the other case, the focus was on the collection of data for the assessment of wetland ecosystem state.

In both cases, the integration among scientific and local knowledge was considered as fundamental in order to increase the availability of information without increasing the costs of monitoring. Three important practical issues had to be addressed to define the locally-based monitoring plan:

- *the involvement of local community has to be guarantee for long time*, otherwise the results of the monitoring activities cannot be used to support AM. To this aim, keeping the monitoring system as simple as possible and perfectly integrated in the daily activities of local communities is fundamental.

- to be useful for AM, *the information has to be acceptable by decision makers*. To this aim, the integration of the locally-based monitoring within the institutional framework can enhance the acceptability of this information.

- the integration between local knowledge and scientific knowledge has strong positive effects on the *reliability of the locally-based information*.

In this deliverable the experiences done in the Amudarya river basin to address these issues are described and discussed. Moreover the GIS-based system developed to deal with qualitative information is presented.

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1 Introduction

Decision making in water resources management is widely acknowledged in literature to be a rational process, based on appropriate information and modelling results (a.o. Allen et al., 2001; Denisov and Christoffersen, 2001; Gouveia et al., 2004; Haklay, 2003; Hollick, 1981; Musters et al., 1998). Information plays a fundamental role in improving our understanding of the consequences of, and trade-off among, the alternatives in water resources management (McDaniels and Gregory, 2004; Raiffa et al., 2002).

Environmental monitoring networks have the potential to provide a great deal of information for environmental decision processes. Monitoring is widely used to increase our knowledge both of the state of the environment and of socio-economic conditions (Gouveia et al., 2004; Timmerman and Mulder, 1999). Environmental monitoring has demonstrated its capacity within resource management to support decision processes providing knowledge of baseline conditions, to detect change, to establish historical status and trends, to promote long-term understanding or prediction, and to establish the need for, or success of, interventions (Boyle et al., 2001; de Jong and Timmerman 1997; de Rosemond et al., 2003; IWAC 2001).

Our knowledge of the complexity of water system processes is increasing, together with our awareness of the uncertainty and unpredictability of the effects of water management on system dynamics. Consequently, the demand for environmental information is growing (Timmerman et al. 2001), posing new challenges to monitoring system.

One learning process being developed to face complexity and uncertainty is Adaptive Management (AM) (Holling 1978). Learning in AM leads to a focus on the role of feedback from the implemented actions. Such feedback-base learning models stress the need for monitoring the discrepancies between intentions and actual outcomes (Fazey et al., 2005). Monitoring systems are required to support critical reflection providing both negative and positive feedback in the iterative evaluation of both the continued desirability of objectives and progress toward their achievement (Lessard, 1998). Corresponding adjustments are then made to implementation activities and management objectives. Monitoring becomes the primary tool for learning about the system and its performance under different management alternatives (Campbell et al., 2001).

Thus, a monitoring system for AM has to be able to support the identification of changes in system behaviour due to management actions, i.e. to identify thresholds. A threshold can be broadly defined as a breakpoint between two states of a system. When a threshold is exceeded a change in system function and structure results. Such changes regard the nature and extent of feedback, resulting in changes of directions of the system itself (Walker and Meyers, 2004). The changes can be reversible, irreversible or effectively irreversible (Walker et al., 2006). In AM detection of negative thresholds, that is early stage of undesirable system development, is particularly important to suggest actions in order to avoid exceeding the threshold.

To this aim, it is essential to address certain issues related to complex system dynamics. The issue of spatial and temporal scale must be tackled, since complex systems have structures and functions that cover a wide range of spatial and temporal scales. The impact of a given management action may vary at different scales (Campbell et al., 2001), e.g. the impact can be positive at local scale and negative at larger scale. Also the time horizon influences the evaluation of impacts. Collecting long time series of data allows to define trends in system dynamics, facilitating the identification of system changes. Moreover, structures and processes are also linked across scales. Thus, the dynamics of a system at one particular scale cannot be analysed without taking into account the dynamics and cross-scale influences from the scales above and below it (Walker et al., 2006). This emphasizes the importance of gaining reliable information about different parts of these spatial and temporal continua (Moller et al., 2004).

Taking into consideration these issues, AM often results in a demand to monitor a broad set of variables, with prohibitive costs if the monitoring is done using only traditional scientific methods of measurement, impeding the economic sustainability over time of the monitoring system. The resulting work may still be valuable as a series of one-offs assessment, but it cannot provide the information on trends over time (Danielsen et al., 2005). This is particularly true in countries characterized by limited financial and human resources.

To deal with these issues, the design of monitoring program should include and integrate various kinds of knowledge. In this work an approach based on the integration between scientific and local environmental knowledge is proposed to support environmental monitoring for AM. 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). Our work lies on the hypothesis that 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).

Thus, in this work the potentialities of the integration between science and local knowledge to address the issues of monitoring for AM are investigated in detail. Starting from these premises, a methodology to facilitate the integration between these two kinds of knowledge has been developed and experimentally implemented to support both the integrated soil and water resources management and the wetland restoration management in the Amudarya river basin (Uzbekistan).

This contribution is organized as following: section 2 is a literature review about the use of local knowledge for environmental monitoring; section 3 describes the adopted methodological approach and how the different issues have been addressed; section 4 is devoted to the description of the results of the experimental implementation in the Amudarya river basin concerning the two issues; in section 5 the GIS-based tool able to deal with local knowledge is described.

2 The use of local knowledge for environmental monitoring: potentialities and shortcomings

Local knowledge is increasingly recognized as an important source of information for environmental resources monitoring and management. It could fill important information and data gaps, particularly in data-poor region, contributing to built a full picture (Ball, 2002). Different terms have been used to name monitoring approaches based on the use of local knowledge, i.e. "participatory monitoring", community-based monitoring", etc. All of these approaches have in common that the monitoring activities are carried out at local scale by individuals with little formal education, and that local people or local government staff are directly involved in data collection and analysis (Danielsen et al., 2005).

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. The results of the literature review are described in D 1.6.3.

The analysis of the literature review highlights several benefits related to the involvement of local communities in environmental resources monitoring for both the communities and the environmental management agencies. From the community side, the benefits obtainable through the public involvement are mainly 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. Moreover, monitoring based on local knowledge tends to focus on management issues of greatest concerns to stakeholders, and is thereby likely to have advantages over scientific monitoring to empower and enhance capacity among stakeholders.

On the other side, the environmental management agencies could increase the available information without increasing the costs of information collection, enhancing the sustainability over time of the monitoring programme (Danielsen et al., 2005); they could base their strategies on a more integrated knowledge, and on information on management effects at local level, which are often omitted by scientific monitoring. 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 of cultural understanding (Ball, 2002). Compared to scientists, local people are often best placed to assess local ecological changes and contribute relevant information and actions to solve environmental problems (Hambly, 1996). The diachronic nature of local knowledge can provide robust temporal perspectives and baseline information. Moreover it provides observation about occasionally extreme events, whereas scientific monitoring may miss these events because of short sampling duration (Moller et al., 2004).

Monitoring based on local knowledge has the potential to generate environmental data sustainably and at low costs. But due to several shortcomings, its use to support environmental resources management is still limited. Among them: (1) the credibility of data collected by local communities is of outmost importance; (2) local knowledge is not subjected to a peer-review process of validation, nourishing the scepticism of both scientists and policy makers; (3) particularly, scientists remain concerned about its ability, compared to professional monitoring methods to detect true environmental resources trends, which are important for AM.

According to the scientific literature, the scepticism of scientist and decision makers is due to limited accuracy and precision of the monitoring information based on local knowledge. The accuracy can be biased by lack of measurement experience, potential conflict of interests, a tendency to reflect long term perceptions more than current trends, the potential for spatial and temporal coverage of monitoring to be unrepresentative of the entire system of interests. The low precision leads to high variance around the estimated true value of the attribute of interest. Possible sources are small sample size, overly thin or patchy temporal or spatial deployment of sampling effort; the physical loss of data; and the inconsistent application of methods, either through time or across observers (Danielsen et al., 2005).

Moreover, the local knowledge is qualitatively and unstructured, based on experiences and stories, and therefore not easily and comprehensible for the decision makers and immediately functional for the decision process. The spatial scale of local knowledge is another important issue, because it tends to focus on information in small areas. This influences also the effectiveness of decisions based on locally-based monitoring, which generally have no impacts beyond the local scale.

To overcome these shortcomings a methodology based on the integration among scientific and locally-based monitoring is proposed in our work. The hypothesis here is that scientific knowledge and local knowledge should be considered as different areas of expertise that complement rather than contradict each other (Moller et al., 2004). Therefore, in our approach the integration does not mean to invite members of local community to carry out monitoring with scientific methods, which are often too complicated and distant from the daily life of local community. 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 environmental knowledge, which differs from simply collecting data, and it can play a fundamental role in facilitating long term participation in environmental resources monitoring and management.

In the next sections we provide a description of how the most important issues concerning local knowledge for environmental monitoring have been addressed in our work.

3 Integrating local and scientific knowledge to support soil monitoring

During the Soviet time it was planned to make Uzbekistan the largest centre of cotton production. Due to the arid climatic conditions this aim could be achieved only by the construction of large irrigation systems (UNDP, 2007). In the early 1990s, Uzbekistan accounted for about 20 percent of world trade and thus was the third largest cotton producer in the world (ERS, 2006). The inefficiency of the irrigation network, inadequate drainage systems, and intensive agricultural production were leading to severe soil degradation (salinisation). 55% of the land in the Khorezm oblast (the study area) is medium to severe salinised (UNDP, 2007). In order to reduce the degree of salinity and to increase the agricultural productivity the soils are leached before the vegetation period requiring large amounts of (not always available) water. Based on a forecast of water availability for the oncoming vegetation period, carried out by a national authority, certain amounts of water allowed to be used for leaching and irrigation are defined at the regional scale. The regional branches of the Ministry of Agriculture and Water are responsible to allocate the available water among the Water User Associations (WUA) leading to a competitive situation between WUA. Each WUA claims for water required for agricultural management according to the degree of salinisation. Hence, an adequate soil salinity monitoring system is required for a reasonable allocation of the available water resources.

Currently, the monitoring network is based on soil sampling stations where one station represents an area of about 50 ha. The monitoring network is managed by the Hydromeliorative Expedition (HE) that is a branch of the Amelioration Expedition, a governmental agency. Soil samples are collected each year before the harvesting time and are analyzed in the HE laboratories in order to assess soil salinity. The data are used to develop a regional map of soil salinity, which plays a fundamental role in the definition of water allocation strategies in the Khorezm oblast.

Several people working in the management of the monitoring system, water managers, and chiefs of the WUAs were interviewed about the current monitoring system. According to their opinions, the soil salinity map developed using traditional monitoring information is reliable only at the regional scale, while at the local scale the information provided are often not correct. This means that the water allocation among farmers could be wrong. These errors are due to the grid of the monitoring network, which is not dense enough.

The objective of our work is to support water allocation strategies by improving the current soil salinity assessment and monitoring at the local scale. Therefore, knowledge of local experienced farmers is used. To this aim, the issues described previously have been addressed as reported in the following.

Issue 1: Assure the involvement of members of local community

One of the most important issues to be addressed when establishing a locally-based monitoring programme concerns the involvement of local community in monitoring activities. This objective cannot be achieved involving local community's members in complicated monitoring methods. They do not possess science capacity to carry out scientific monitoring, and they are likely to be too busy to divert time in complicated monitoring activities (Moller et al., 2004). For locally-based monitoring to become sustainable the key is to keep it as simple and locally appropriate as possible. Moreover, during the field work we learnt that the involvement in monitoring is easier if the monitoring activities are incorporated in the community's members daily activities.

To this aim we worked with experienced farmers to describe traditional methods used by local community members to assess the soil salinity during their normal activities. This phase aims to collect and structure the local knowledge about soil salinity. In a preliminary phase, semi-structured interviews have been carried out to acquire information about when the farmers do salinity assessment, which factors are taken into account, and which decisions are based on this assessment. As a result of this phase, a cognitive map has been developed considering the inputs from farmers.

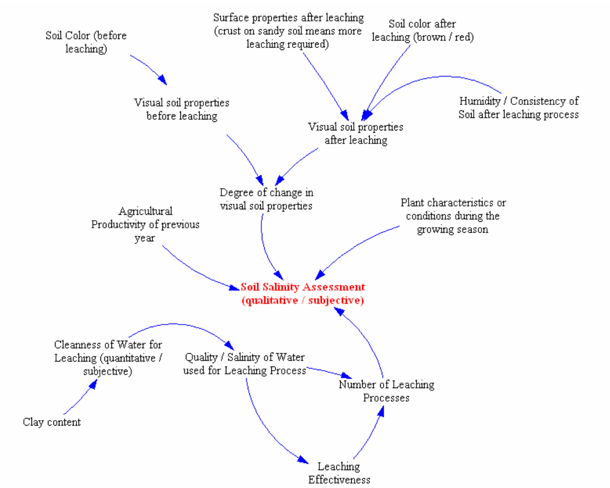

Fig. 1: Cognitive model of qualitative soil salinity assessments

This cognitive map has been developed superimposing and augmenting the individual cognitive naps. The number of interviews to be made was determined considering the number of new concepts included in the model after each interview (Ozesmi and Ozesmi, 2004). The cognitive map was concluded when no new variables emerged after a number of interviews. The farmers' cognitive map represents the farmers' understanding of soil salinity phenomena, and it includes the concepts forming the tacit knowledge of experienced farmers. This tacit knowledge allows farmers to assess the degree of soil salinity qualitatively.

Furthermore, a debate session was organized with all interviewed farmers in order to validate the cognitive map and to complete the local knowledge elicitation. At the end of the process, a clear idea about the traditional method for soil salinity assessment was settled. Farmers assess soil salinity two times in the year, i.e. at the beginning of the season, and after leaching. The first assessment is used to evaluate qualitatively the amount of water needed to leach the salt and to prepare the soil for seeding. At the end of leaching, the assessment allows farmers to decide whether the number of performed leaching is enough or more water is required.

During the first assessment, farmers consider the colour of the soil (the more white is the soil the more salty it is), and the decrease of production of the previous year. For the second assessment, farmers consider the soil colour and the actual number of performed leaching.

In order to keep the monitoring program as simple as possible for farmers, a step of the local knowledge acquisition process was focused on the terminology used by them to describe these factors. Several interviews have been carried out to define the terms used by local community to describe the soil state and the meaning of each term. This information has been used to define the data collection protocol, as described in section 4.

As stated by Danielsen et al. (2005), the long term involvement of local community's members in monitoring can be problematic when the benefits they derive from monitoring are less than the costs. In our approach, in order to reduce the monitoring costs for local people, the developed monitoring program is entirely integrated in the farmers' daily activities. Thus, it does not require added efforts from farmers. This was an explicit requirement made by farmers. During the debate we showed to experienced farmers and WUA chairmen, with practical examples, the potential benefits related to the improved water allocation strategies due to the enhanced information availability.

Issue 2: Acceptability of the locally-based monitoring from decision makers

In order to ensure the sustainability of the monitoring programme and the usability of this information to support decision making, efforts have been made to build the locally-based monitoring on existing traditional institutions and other management structures as much as possible. Thus, in a first phase of our work a deep investigation of the current monitoring system has been carried out, in order to verify whether the locally-based monitoring and the traditional one can be integrated.

The traditional monitoring system is based on soil sampling. Due to limited economical and human resources, HE cannot increase the number of soil samples in order to enhance the reliability of soil salinity map. Therefore, a preliminary phase is carried out by HE aiming to define homogenous areas. The samples are taken and analyzed from each of the homogeneous areas and the obtained degree of salinity is then extended to these areas. The definition of homogeneous areas is accomplished on the basis of one parameter only – the visual assessment of plant growth characteristics during the growing season. The weak point in this approach is that plant growth is influenced by a variety of factors such as seed quality, agricultural management practices, climatic conditions, to name a few only. Thus, the errors in soil salinity assessment are due to the wrong definition of homogeneous areas. This leads to an not always adequate water allocation strategies among farmers

The definition of the homogeneous areas has been used as the integration point between traditional monitoring and locally-based monitoring. That is, the information collected from experienced farmers is used to support the definition of homogeneous areas, enhancing the reliability of the sampling programme, and, thus, of the soil salinity map. In this way, the locally-based monitoring does not intend to substitute the traditional one, but it is integrated in it. This increases its acceptability from decision makers.

An agreement has been reached with decision makers about the institutional framework in which the locally-based monitoring is integrated. Therefore, after some rounds of interviews and debate with local decision makers, a detailed plan for data collection, analysis and use has been developed. In this plan, all the actors to be involved in monitoring activities, and the different roles have been clearly defined: i.e. who collects data from farmers, the protocol for data collection, who stores and analyze the data, the rules for the analysis of data. The agreement has been achieved finding a compromise between the requirements of decision makers concerning the data accuracy, frequency and the data format, and the capabilities of data providers.

According to the agreement, the data will be collected from farmers by WUA technicians using a pre-defined questionnaire. This questionnaire contains all the elements used by farmers to qualitatively assess soil salinity. It has been developed during the local knowledge elicitation process, and validated by experienced farmers. To facilitate the data collection process, the local terminology has been used in the questionnaire. The data are inputted in the GIS-based system, which works as an interface between farmers and decision makers. This system, using fuzzification and defuzzification process, is able to use the qualitative knowledge of farmers as input, and to provide to decision makers information at the required level of reliability. The functionalities of the GIS-based system are described in section 4.

Issue 3: Reliability of monitoring information

The local knowledge is vulnerable to several pitfalls which cause a reduction of both accuracy and precision of monitoring data. This nourishes the scepticism of scientists and decision makers. To overcome this drawback, an integration between local knowledge and scientific knowledge is proposed in this work. In fact, as many decision makers said during the interviews, the reliability of local knowledge can be enhanced through a validation phase carried out by experts. Particularly important is the validation of the causation (Moller et al., 2004) between the parameters used by farmers for the salinity assessment (e.g. soil colour) and the actual salinity degree. In other terms, the reliability of the monitored information could be enhanced if it would be possible to confirm that differences in soil colour and productivity are actually related to differences in soil salinity.

To this aim, the knowledge of local scientists and experts have been collected and structured. For seek of concision, they are called “experts” in the rest of the text.

The experts have been involved in a cognitive mapping exercise which aims to collect and structure their understanding about the considered environmental problem. From now onward, this map is called expert cognitive map. Similarly to the previous step, the expert cognitive map is developed by semi-structured interviews and group discussion. In this case, the interviews are not focused to the factors used by expert to assess the state of environmental resources, but to the factors that, according to their opinion, can influence the state of the soil. Therefore, the cognitive map developed at the end of this phase aims to structure experts’ understanding about the risk that the soil salinity happens (figure 2).

The experts seem to associate the soil salinity risk to two main factors, i.e. natural vulnerability (groundwater level and salinity, soil type, surface characteristics, etc.), and agricultural management (choice of plants, quality of drainage system, irrigation and leaching practices, etc.). The combination of these elements allows them to assess different degree of soil salinity risk.

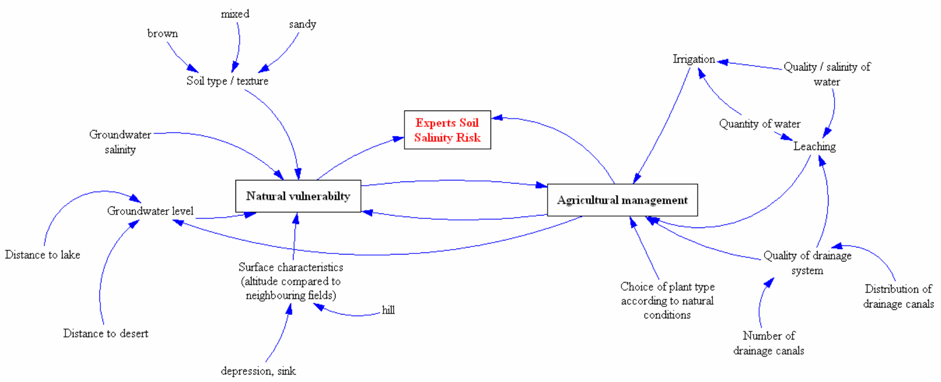

Fig. 2: Experts cognitive map for soil salinity risk assessment

Experienced farmers and experts were required to identify possible links between the two cognitive maps. The results of the discussion allowed us to develop the integrated cognitive map (see figure 3).

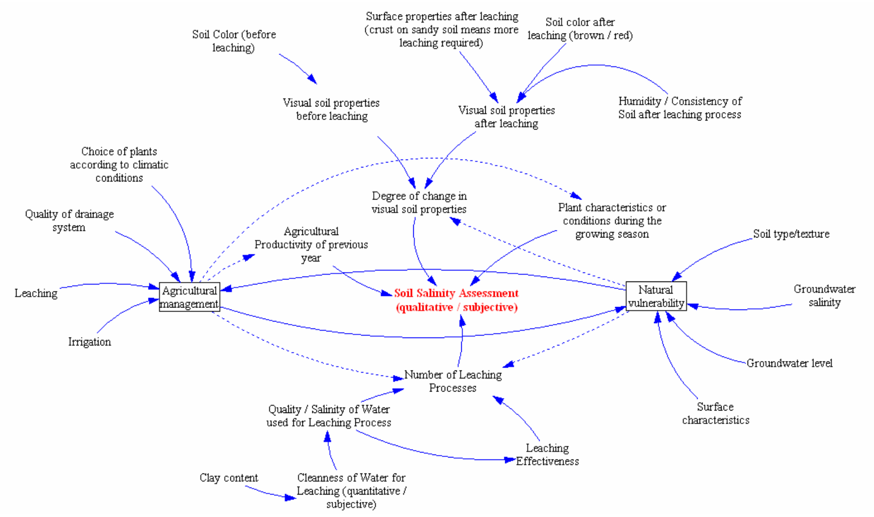

Fig. 3: Integrated cognitive map

The integrated cognitive map has been used as basis for the definition of the integrated monitoring system, in which the soil salinity value is assessed combining farmers' factors and experts' factors. This combination allows a strengthening of the causal links between the actual soil salinity and the changes visually assessed by farmers.

As stated by Moller et al. (2004), "*see, touch and feel monitoring*" may be not considered as enough for environmental monitoring, but in combination with other methods has the potential to support adaptive and integrate management.

4 Integrated monitoring system for soil salinity assessment

The issues described in the previous sections have been used to define the monitoring system able to support the integration of experts and farmers knowledge for soil salinity assessment. The conceptual architecture is shown in figure 4 below.

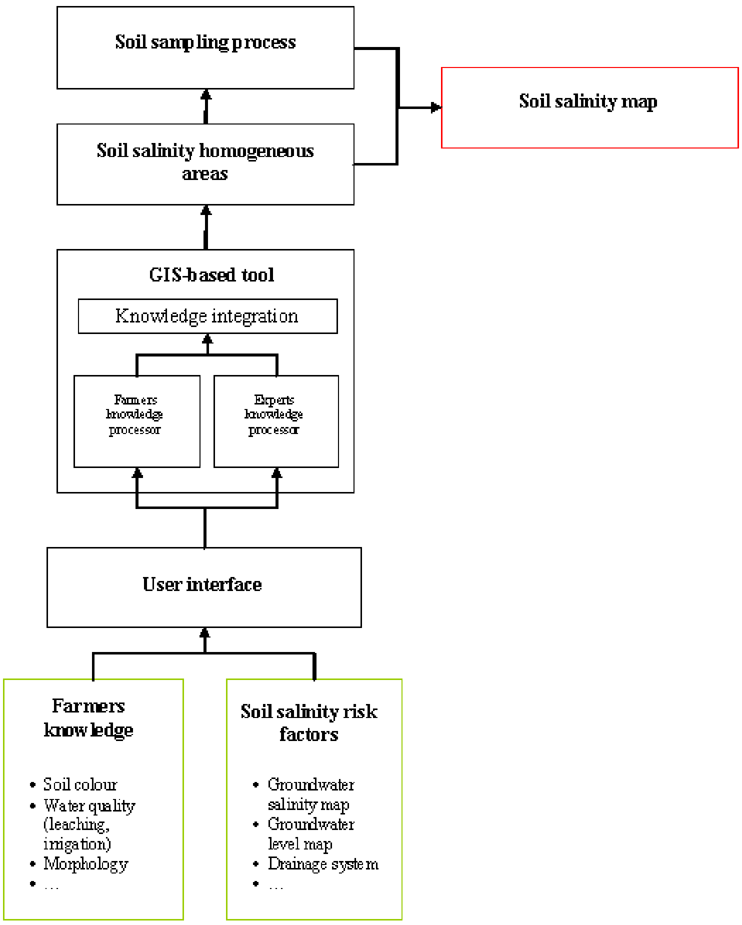

Fig. 4: Conceptual architecture of the integrated monitoring system

As shown in the architecture, there are two kinds of data inputs for the monitoring, that is the farmers knowledge and the factors mentioned by experts. Farmer's knowledge is collected through questionnaire, developed taking into account the results of knowledge elicitation process (see section 3). Moreover, as stated previously, efforts have been to support the integration of the local-based monitoring system in the current institutional system. Therefore, the data collection will be performed by WUA technicians during their daily activities. This will enhance the sustainability in long terms of the monitoring system.

In order to fill in the questionnaires, the WUA technicians will interview farmers and collect their assessments. Following farmers' traditional knowledge, the collection of data is done once per year, i.e. after harvesting time. This makes the information collected by farmers useful for the definition of the homogeneous areas.

The data are then collected and input by technicians of HE. In order to facilitate the input of farmer's knowledge, a user interface has been designed, as illustrated in figure 5.

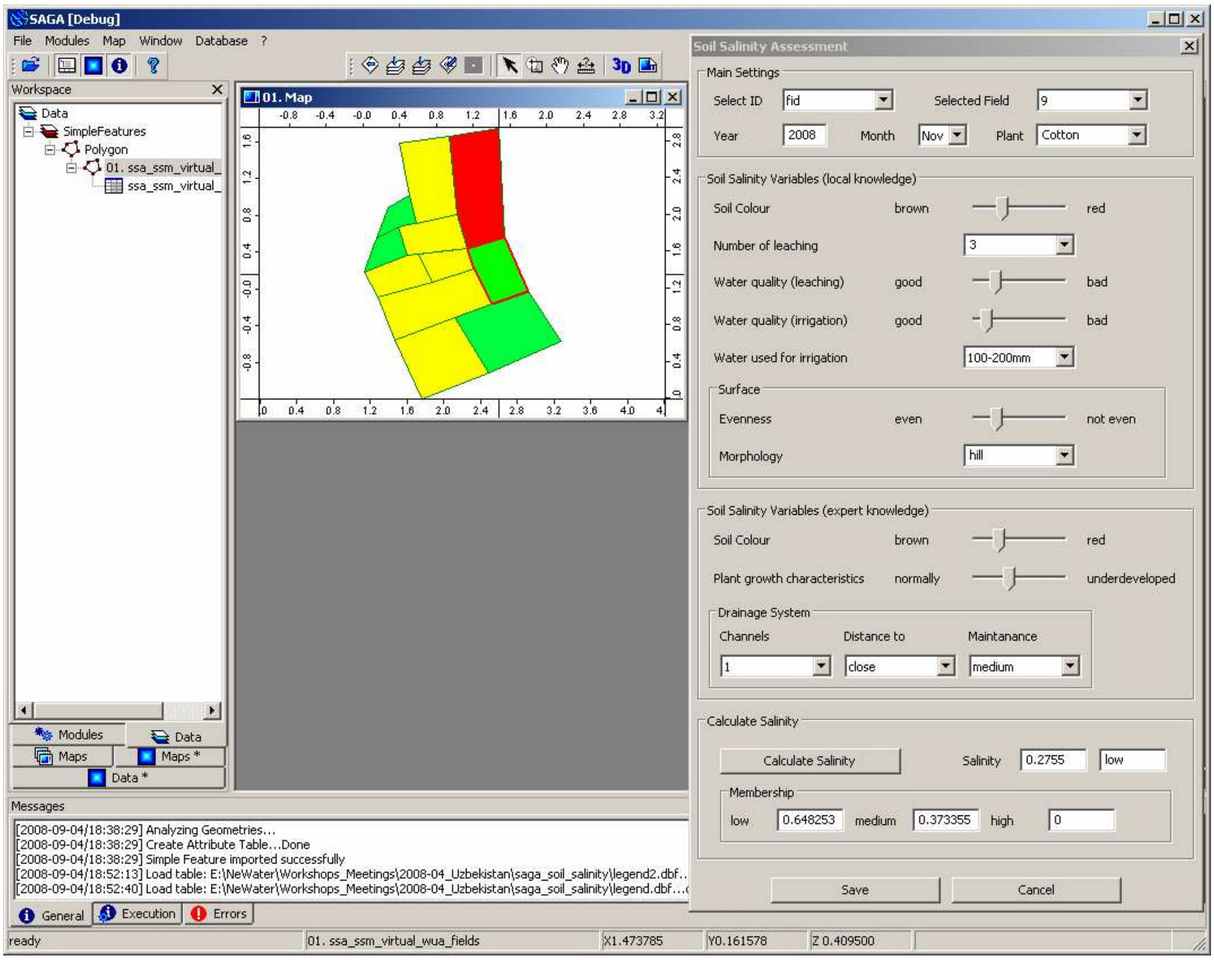

Fig. 5: GIS interface for data input.

The developed AMIS can be considered as a software tool that provides different methods to deal with spatial and temporal data. Furthermore, the system was extended by specific tools tailored for the requirements of soil salinity and wetland monitoring based on local knowledge.

The AMIS consists of various software components: (1) the GIS SAGA (http://sourceforge.net/projects/saga-gis/); (2) the object-relational database management system PostgreSQL (www.postgresql.org); (3) a GIS-database interface; (4) and graphical user interfaces and functions developed for specific requirements. In order to ensure sustainability from a technical point of view, freely available and open source software was used in all of this. Hence, it is possible to adapt the system to future requirements.

The system is based on a fuzzy logic module, able to deal with linguistic assessments made by farmers. In fact, to facilitate the task of both farmers and data collectors, the numerical inputs have been reduced as much as possible.

Two different kinds of input are considered in the system, i.e. the farmers' input and the "cartographic" input. The first one refer to data collected by interviewing the farmers. These data are associated to each field in the map. The "cartographic" data are collected using official maps, such as groundwater level, groundwater salinity, etc. These data are analyzed directly by the GIS module. A preliminary step is, therefore, the digitalization of the existing information. Beside the proposed new approach in soil salinity monitoring we also try to establish the usage of GIS technology.

Once in a year, after harvest, soil salinity data will be collected from farmers. This information will be entered into the user dialog and assigned to each agricultural field. The GIS component of the AMIS acts here as user interface to enter and to visualize data.

The dialog provides controls to enter the information according to the parameters characteristics. In order to avoid the usage of numbers we implemented slide bars to enter qualitative information, such as the soil colour, the evenness of the field etc. The terminology used to describe the minimum and maximum values of the slide bars are the terms used by the local community. To input discrete information, such as the number of leaching performed, the morphology of the field, etc., drop-down controls are used to select the designated value from a list.

Finally, by pressing button *Calculate Salinity*, the settings of the controls are converted to numbers, and the degree of salinity is calculated and displayed in the text field *Salinity*. This value is assessed integrating the farmers' information with the soil salinity risk factors. Additionally, the degree of membership of the salinity value to the classifications *low*, *medium*, and *high* is shown in the membership fields. By pressing button *Save*, all values of the corresponding agricultural field are stored in the database. The process needs to be repeated for each field, of course.

The assessed soil salinity degree is then used to define the homogeneous areas, which are the basis for the soil sampling process. The AMIS provides a methodology to support the current monitoring practice by integrating local knowledge into the scientific approach. Thus, it helps to partly overcome the problems related to data gaps without increasing monitoring costs.

5 Integrating local and scientific knowledge for wetland monitoring

As stated previously, AMIS implementation in the Amudarya river basin focuses on two important environmental issues, i.e. the soil salinity monitoring (as described in the previous section), and the monitoring of the wetland ecosystems.

Concerning the latter, the research activities have been mainly focused on the deltaic region of the Amudarya. This area is characterized by the presence of a system of lakes which supports commercially valuable fish and muskrat populations, other game species (wild boar, water fowl, etc.) as well as reed production (Schlüter et al., 2007). The wetland ecosystems in the delta of the Amudarya river represent a single hydrographic net of major irrigation canals, lakes and lake systems on the territory of the Autonomous Republic of Karakalpakstan and the Khorezm province of Uzbekistan and the Tashauz region of Turkmenistan associated with a single source of water supply, that is the Amudarya river (Schlüter et al., 2007).

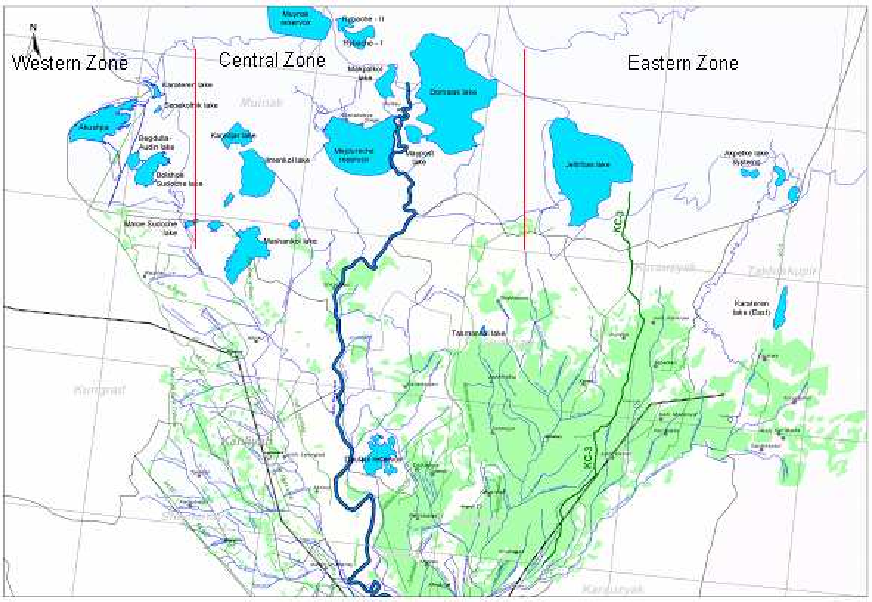

Fig. 6: Amudarya deltaic region with the wetland system.

In this region the availability of information on the state of the wetland ecosystem is of outmost importance given that the people's quality of life strongly depends on the stability of the ecosystem, particularly on the status of the lakes, which, in turn, is mainly connected to water quality and the water level in the lakes. If enough water is provided by the river and the water quality is good, the wetlands provide enough resources for the community to survive. However, due to intensive agricultural water consumption in upstream areas, in some years, the river provides not enough water and the lakes are drying out. Thus, monitoring information is crucial for both: (1) to support the definition of robust management strategies; (2) and to assess their effectiveness suggesting possible adaptation.

Although the state of the wetlands strongly influences the life of the local population, monitoring system able to systematically collect data on the state of the deltaic ecosystem of the Amudarya is basically not existent. Thus, long time series of data are not available, making not possible the detection of system trends, which is one of the most important issues in system monitoring. The detection of trends, in fact, allows the identification of possible system's trajectories, facilitating the identification of actions to "correct" this trajectory and, therefore, avoid undesirable system states.

In the deltaic region, there are few snapshots of the ecological conditions related to some projects activities. This information is not sufficient to establish relationships between the different variables of the system, such as the river flow and the ecosystem states. Innovations in monitoring activities are needed in order to enlarge the set of monitored variables (integrated approach) and to collect data in long time period, without increasing the costs of the monitoring activities.

Similarly to the monitoring of soil salinity, the scarcity of human and ecological resources impedes the introduction of innovation in monitoring based on the adoption of new and expensive technologies for data collection, storage and/or analysis. A strong involvement of local communities in environmental monitoring is considered by many parties as an interesting approach to increase the information availability for the assessment of the health of the aquatic and floodplain ecosystem in the delta area (Schlüter et al., 2007).

Thus, the main aim of the research activities carried out in the delta area is to support the involvement of local communities in the monitoring of the state of their ecosystem. The collected information will be used to support the adaptive environmental management of the deltaic lakes system.

The issues to be addressed to achieve this aim are the some of those described previously, but the adopted approach is different, as explained in the following.

Issue 1: Assure the involvement of members of local community

As stated for the soil salinity case, in order to guarantee the long terms involvement of local communities in environmental monitoring, keeping it as simple as possible is crucial. This means that the involvement of local communities should start from the design phase of monitoring program implementation. Local communities cannot be involved in complex scientific monitoring program to populate indicators, which are incomprehensible for them, with monitoring methods settled somewhere else. Contrarily, most traditional monitoring methods used by indigenous cultures are rapid, low cost and easily comprehensible for local community members (Moller et al., 2004).

Therefore, the first phase of our work intended to gather knowledge about the indigenous methods used by fishermen to assess the state of lake ecosystems. During individual interviews and group discussions done in local communities, we learnt that the qualitative assessment of the lake's state is one of the fundamental fishermen's activities. Thus, in this phase of our research we worked on the elicitation of the tacit knowledge allowing local population to assess the state of the system, although they have no access to official data. Main questions of this phase are "How do you assess the state of the system?", "Which kind of elements do you take into account?", "How do you consider these elements?".

The results of this phase are a conceptual model to structure the tacit knowledge of local population. In this model the links between easily monitored elements (e.g. the presence of aquatic plants) and system variables (e.g. water salinity) are investigated (see figure 7).

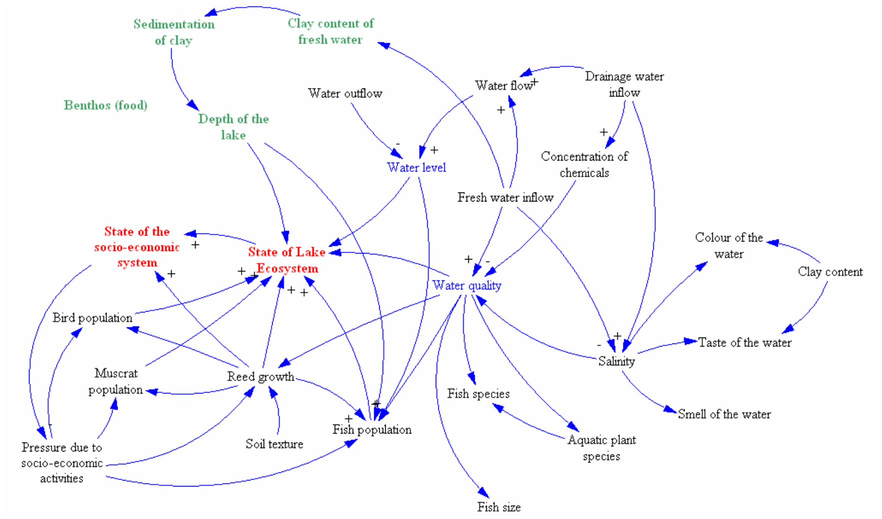

Fig. 7: Conceptual model concerning the local knowledge for the assessment of wetland ecosystem's health

The conceptual model has been used to structure the tacit knowledge. The conceptual mode in figure 7 is the results of the integration between the individuals' models.

The developed model has been used as basis for the definition of the monitoring plan. Starting from this model, the elements which are considered by local communities to assess the state of the environment have been clearly identified:

- Fish population (number of elements, number and kind of species, size, health);
- Aquatic plants species (diffusion in the lakes and health)
- Water quality (smell, colour, taste);
- Muskrat population (number of elements and health);
- Birds population (number of elements and species)
- Depth of the lakes;
- Area covered by water.

In the next step local community's members have been involved in the definition of the indicators to be monitored, the terms to be used to describe the value of the indicators (which have to belong to the local "natural" language), the data collection methods (which have to be easily implemented by local people) and plan. The indicators selected by fishermen are reported between brackets. As we will describe later, the set of the indicators proposed by fishermen have been discussed with scientists in order to validate it.

The possible values of the indicators have been defined together with the fishermen, because it's important to use a terminology closed to their local language. Therefore, for example, the possible values of the indicator "kind of fish species" are expressed in the local language such as *sudak*, *som*, *zmeygolova*, *tolstolobyk*, etc.

This step aims to make the monitoring system as close as possible to the habits of local community, in order to facilitate its integration in daily activities. This information has been used as basis for the definition of the questionnaire for data collection.

An important issue to be addressed in this case concerns the definition of the protocol for data collection. Particularly, it was important to identify who has to be in charge of the collection of data from fishermen. In the wetland area there are no “official” monitoring institutions which can be considered as the responsible for this task, as HE for the soil salinity monitoring.

The basic idea was to select some local actor, which has familiarities with fishermen and which meets frequently them during his/her normal activities. After some rounds of interviews with members of local community, we learnt that most of the fishermen (more 70% of them) attend a monthly village meeting in the city council to discuss the problems of the village. Therefore, we organized a meeting with the chief of the city council in the village of Muynak to explain him the aim of our activity and to discuss with him the protocol for data collection. At the end of the meeting we got his availability to carry on the collection of information.

Therefore, the chief of the city council collects the information directly from fishermen. Then, scientists from Nukus input the data in the GIS-based system able to deal with qualitative information (see further in the text).

Issue 2: Acceptability of the locally-based monitoring from decision makers

As stated previously, the acceptability of locally-based monitoring for decision makers depends on the possibility to integrate this monitoring within the “official” monitoring framework.

In the case of wetland monitoring, the requested integration is done integrating the locally-based monitoring within to the protocol for data collection used by scientist to define the state of the wetland ecosystem. In fact, as reported by Shlüeter et al. (2007), local scientists sporadically – mainly during research projects - perform investigations in the lakes system. Therefore, several rounds of interviews have been carried out involving local scientists in order to define the protocol of data collection they normally use and to verify if the local knowledge can be integrated in him. The integration has been done trough a strong interaction with local scientists.

As a result, the following schema for wetland ecosystem assessment has been defined:

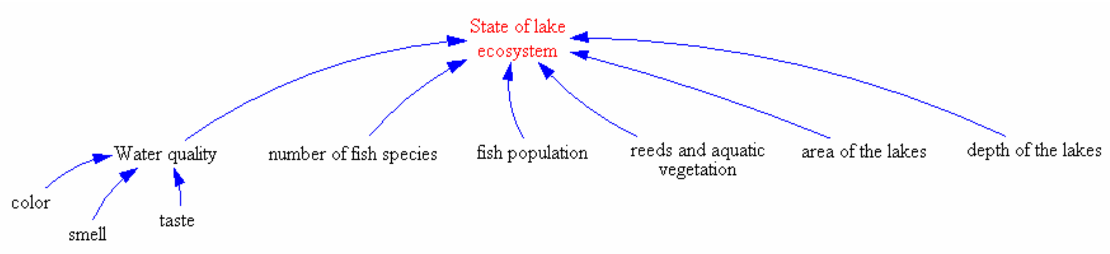

Fig. 8: Indicators of the locally-based monitoring for wetland ecosystems

As it is clear in the figure, the information needed for the assessment of the lake ecosystem can be easily collected by fishermen and integrated in the official monitoring system.

Issue 3: Reliability of monitoring information

Several interviews have been made with scientists and water managers in order to get their opinions about how to increase the reliability of the locally-based information. As a result, we learnt that the information can be considered reliable is if a validation phase is performed before using the information in the decision process.

To this aim, the integration of the locally-based monitoring within the “official” monitoring framework performed by scientists plays a fundamental role. In fact, fishermen and scientist consider the same set of indicators for the assessment of wetland ecosystem. This facilitates the control of the collected information by scientists.

The validation phase is done in two steps. The first step is what we call validation “on-time”. In fact, as stated previously, local scientists are involved in data collection. Therefore, a preliminary assessment of data reliability is done by scientists before inputting them in the GIS-based system. In this phase they will use their expert knowledge.

The second step of validation is done through a comparison between the data collected with traditional monitoring system and the locally-based data. In fact, scientific methods for wetland monitoring are applied sporadically. Therefore, besides the on-time validation, the data collected by local people will be compared with official data, in order to identify discrepancies. Also for this case, the integration between locally-based monitoring and the traditional one is useful for the validation phase. This kind of validation will be done frequently in the early stage of the monitoring plan development, in order to increase the trustiness towards this approach by decision makers.

Once the data are assessed as reliable, they are inputted in the system, using an interface similar to the one described in previous section. The interface is linked to a GIS – based system, able to deal with linguistic – qualitative information.

6 Integrated monitoring system for wetland ecosystem assessment

The issues described previously have been used as basis for the definition of the conceptual architecture of the GIS – based system able to support the assessment of wetland ecosystem, using the information collected by a locally-based monitoring system.

The system is composed by three modules, i.e. the data collection module, the validation module and the GIS-base module. The conceptual architecture of the system is showed in figure 9.

The data collection module is composed by two main inputs: local data that is the data collected using fishermen knowledge, and scientific data. The latter refers to the wetland monitoring performed sporadically by local scientists. Therefore, the conceptual architecture is based on the premise that local knowledge and scientific knowledge are not mutually exclusive, but they can complement each other. More in detail, scientific knowledge can be useful to test cause-effects relationships between the natural phenomena observed by community members and their causes. In the case study, scientific information can support the test of the causal link between visual monitoring (e.g. colour of the water), and the real state of the lake (e.g. water quality).

The validation through scientific knowledge is done in two different ways, i.e. collecting data according to scientific monitoring methods, providing scientific (theoretical) knowledge. This theoretical knowledge is used for the on-time validation. Moreover, the integration among science and traditional knowledge can support the learning process leading to a better assessment of water salinity.

To this aim, the diachronic – synchronic integration, as described in Moller et al. (2004) can be useful. In fact, traditional knowledge can collect data frequently and for long time. On the other side, scientific methods can be applied to have snapshot of the environmental conditions, to be compared with the local community assessment.

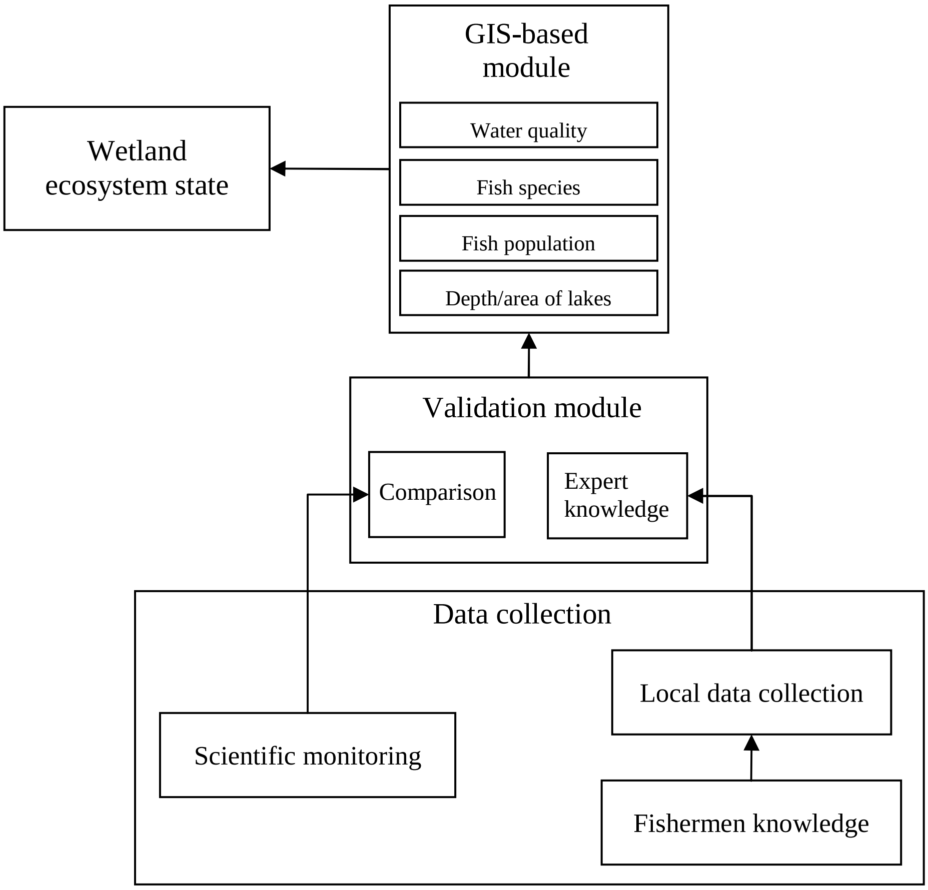

Fig. 9: Conceptual architecture of the AMIS implementation for wetland monitoring

The collection of data from fishermen is performed by the chief of the city council during the monthly meeting with the community. To keep data collection phase as simple as possible, a questionnaire is defined according to the fishermen's conceptual model. Moreover, the local terminology is used.

The input of data is performed by local scientists, which have also the responsibility of the on-time validation using their knowledge. This is the first step of the validation. The validated data are inputted in the system using the user interface (see figure 10).

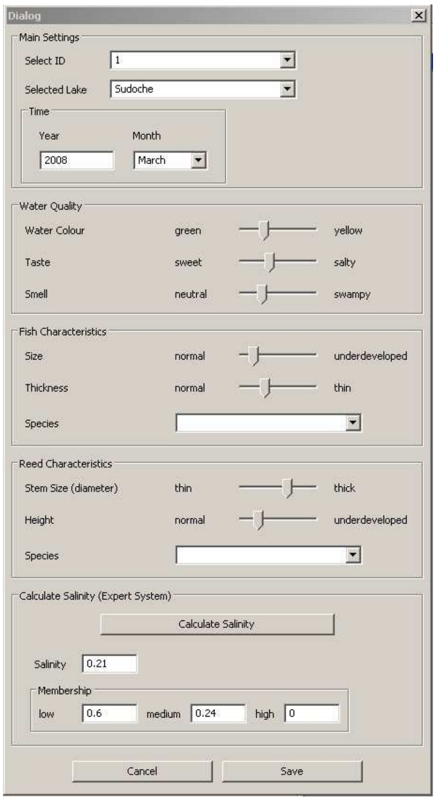

Fig. 10: Interface for local data entry

The GIS-based module is able to integrate all this qualitative information using a fuzzy logic approach. At the end of the process, the state of the wetland ecosystem is assessed. Given the uncertainty associated with the use of qualitative information, the state is not provided as an "exact" number, but the degree of membership to the three possible states (low, medium and high) is calculated.

The second step of validation is done by scientists through a comparison between the results of locally-based monitoring and the assessment made by scientific monitoring. The validated results are then stored in a database of the wetland ecosystem state. The information contained in the database will be used to define the trend of the wetland ecosystem and to assess the effectiveness of management actions.

7 Conclusions

The cost of environmental monitoring is an issue of outmost importance to support AM. In fact, the adoption of multi-scale and integrated approaches often results in the necessity to monitor a broad set of variables, with an unsustainable increase of the monitoring costs. Moreover, the monitoring system has to be sustainable over time, in order to allow the collection of long series of data to detect trends in system dynamics, and to define the system's trajectory and possible thresholds.

Innovations in both monitoring design and data collection methods are needed to increase the availability of information, without increasing the costs of monitoring. This issue is particularly important in regions where, due to the scarcity of human and economical resources, it is not possible to enhance the monitoring system adopting complex and expensive technical innovations.

The need to integrate different sources of knowledge to support AM was emphasized from the beginning of WP 1.6 research activities. Among them, local knowledge seems particularly interesting to support environmental monitoring.

A deep literature review has been carried out concerning the usability of local knowledge, in order to identify benefits for both the communities and the environmental managers, and the possible shortcomings. The results of this review have been described in D1.6.3. Nevertheless, the implementation of AMIS in the Amudarya river basin emphasized new and important practical issues to be addressed, i.e. how to guarantee the long terms involvement of local community in monitoring activities; how to increase the acceptability of locally-based information for the decision makers; how to increase the reliability of locally-based information.

These three issues have been used to lead the narrative about the experiences done in the Amudarya to facilitate the involvement of local communities in environmental monitoring. The work done in this basin is based on a fundamental premise: scientific and local knowledge may be considered as different areas of expertise that complement rather than contradict each other. Therefore, the combination of scientific monitoring data and local community observations provide optimal monitoring information to manage the resource.

Starting from this premise, monitoring plans involving water management institutions, local scientists and local communities have been defined to support monitoring of both soil salinity and wetland ecosystem. Based on this monitoring plan, a GIS-based system able to deal with qualitative information has been designed.

The prototype of the system has been discussed with people working in the "official" monitoring system, which represent the users of the system. The collected feedback have been used to improve the prototype and to make it closer to the users' needs, in order to enhance its acceptability.

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