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The integration of Expert and Stakeholder Cognitive Models to support Environmental Monitoring

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Abstract: 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 adaptive approach, monitoring becomes the primary tool for learning about the system and assessing the management strategies. Nevertheless, professional monitoring faces several important challenges, especially in countries where financial and human resources are limited. In our work, the usability of local knowledge to support environmental monitoring has been investigated. Several shortcomings are hampering the use of local knowledge. The data credibility is among the most important ones. To address this issue, we propose a methodology based on the integration between stakeholders knowledge and expert knowledge. Cognitive modelling has been used to disclose individual perceptions and understanding of the system. The integrated cognitive model is used as basis for the development of an expert system able to assess the reliability of local knowledge. The methodology is under experimental implementation to support soil salinity monitoring in the Amudarya River Basin using local knowledge for a qualitative assessment. The preliminary results of the experimentation are described in this contribution.

***Keywords**:* Adaptive management; Monitoring system; Local knowledge; Cognitive modelling; Expert system.

1. INTRODUCTION

The increasing awareness of complexity and uncertainty of the real world is posing new challenges to environmental resources management, and, consequently to the production of information to support decision making.

One approach, based on learning process, developed to face complexity and uncertainty is Adaptive Management (AM) (Holling 1978). AM approaches explicitly recognise the existence of uncertainty, and create an experimental management framework based on flexibility to test and refine a range of management approaches over time, based on a careful comparison of results. Using intervention as experiments, managers can learn-by-doing in a structured process. Learning in AM leads to a focus on the role of feedback from the implemented actions to stimulate a better understanding about the environmental system and its responses. Such feedback-base learning models stress the need for monitoring the discrepancies between intentions and actual outcomes (Fazey et al., 2005). Monitoring becomes the primary tool for learning about the system and assessing management strategies.

Thus, a monitoring system for AM has to be able to support the identification of changes in system behaviour. To this aim, the collection of information on trends plays a fundamental role. In fact, the availability of time series data of different variables allows the definition of the behaviour of the system variables and the trajectory of the system. The detection of trends facilitate the identification of system thresholds, i.e. breakpoints between two states of a system.

An important issue need to be dealt with, i.e. the cost of environmental monitoring. On one hand, the detection of trends in system dynamics requires the collection of long time series of data. On the other hand, in order to take into account the complexity and the strong interaction between different spatial and temporal scale, AM often results in a demand to monitor a broad set of variables, with prohibitive costs if the monitoring is done using only traditional methods of measurement, impeding the economic sustainability over time of the monitoring system.

The issue of monitoring cost is crucial in countries where, due to limited financial and human resources, monitoring may cover only small part of the territory, or the number of monitored factors is incomplete, or data gathering process may be too costly to allow collection of long data series for trend detection.

Therefore, developing an affordable monitoring system for AM requires substantial innovations in methods and approaches (Walters, 1997). In this contribution, the usability of local knowledge to support environmental monitoring is investigated.

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).

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. 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. Interesting experiences demonstrate the capability of local communities to monitor soil degradation using their knowledge about plants species (Hambly, 1996). In several cases, local knowledge has been used to monitor the biodiversity at local level (Danielsen et al., 2000).

According to the scientific literature, several benefits related to the involvement of local communities in environmental monitoring for both the communities and the environmental management agencies. 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 environmental management agencies could increase the available information reducing the cost of information collection; they could base their strategies on a more integrated knowledge; the implementation phase could be facilitated since the conflicts could be reduced.

Nevertheless the use of local knowledge in environmental resources monitoring is still limited because of several shortcomings. Among them, the credibility of data collected by local communities is of outmost importance. Local knowledge is not subjected to a peer – review process of validation, nourishing the scepticism of both scientists and policy makers. Moreover, the local knowledge is qualitatively and unstructured, based on experiences and stories, and therefore not easily comprehensible for the decision makers and functional for the decision process.

To overcome these shortcomings and enhance the usability of local knowledge for environmental monitoring two important phases have to be considered, i.e. the validation and structuring of the local knowledge.

In this contribution the integration between experts and local communities cognitive models is proposed as a methodology to deal with these two issues.

The paper is organized as following. Section two describes the potentialities of cognitive modelling for local knowledge structuring and validation. In section three the preliminary results of the implementation of the methodology for soil salinity assessment are described.

2. COGNITIVE MODELLING FOR KNOWLEDGE STRUCTURING AND KNOWLEDGE VALIDATION

As reported in previous section, the structuring of the local knowledge is a fundamental step in order to enhance its usability to support environmental monitoring. To this aim, the potentialities of cognitive modelling to disclose individuals' understandings of the environmental system and its main properties are particularly interesting.

A cognitive model can be defined as a representation of thought process for how something works in the real world. Most of the techniques for cognitive modelling may be viewed as composed by three main phases: identify concepts, refine concepts and identify links. A common characteristic of these approaches is a focus on obtaining the views of people in the problem environment.

Starting from these premises, a methodology has been define to develop a cognitive model to be used as a basis for the design of a monitoring system able to integrate local knowledge as a source of information. The methodology is composed by three main steps, i.e. the structuring of local knowledge, the structuring of expert knowledge, and the integration among conceptual models.

The first step aims to disclose the perceptions of local communities about the system to be investigated and the environmental problem to be monitored. This step is based on the premises that, due to their knowledge and experiences, local communities are able to evaluate the state of environmental resources and to detect possible changes. Moreover, in our approach 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. The basic idea is to involve local communities in a process of co-producing environmental information. Furthermore, to facilitate a long term engagement of local communities in monitoring, it's important to integrate the monitoring activities within the daily activities of the community. Thus, it becomes fundamental to start the design of the monitoring system defining the mental model used by the members of the communities to make a judgement of the state of the environmental resources. This mental model is structured in the local community conceptual model.

The definition of this conceptual model is based on two phases. In the first phase, semi-structured interviews are conducted involving members of the local communities in order to obtain preliminary ideas about the factors used by local people to assess the state of the environmental resources and causal links among them. The number of interviews to be made is determined considering the number of new concepts included in the model after each interview (Ozesmi and Ozesmi, 2004). The cognitive model is concluded when no new variables emerged after a number of interviews. As a result, a preliminary local community conceptual model is defined, which provides a preliminary list of factors to be monitored and their degree of importance. To this aim, the analysis of CM can provided information about the relative importance of the different variables, by analysing the complexity of the causal chain. Those nodes whose immediate domain is most complex are taken to be those most central and, thus, the most important according to the perception of the local communities. The members of the local communities are then involved in a group model session, in which the results of the interviews are used as basis for the debate. During the debate, the cognitive model and the importance degree for each factor are discussed until a consensus is achieved among the participants.

At the end of this phase, the local communities conceptual model is defined. This model allows to structure the local knowledge, making it easily understandable for the decision makers. The conceptual model is used as basis for the definition of the protocol for data collection. This protocol takes into account the factors highlighted by local communities and the terms used by them to describe their possible states.

The usability of local knowledge to support the decision making requires a validation phase.

In our work, the validation is based on the integration among local communities knowledge and experts knowledge. To this aim, local experts can be involved in a cognitive modelling exercise which aims to collect and structure their understanding about the considered environmental problem. Similarly to the previous step, the expert cognitive model 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

environmental resources. Therefore, the conceptual model developed at the end of this phase aims to structure experts' understanding about the risk that the environmental problem happens.
The next step is to integrate the two cognitive models trying to define the possible impacts of "experts" factors on "farmers" factors. In our approach, an impact means that there is a relationship between the experts' concept and the farmers' concepts. Therefore a relationship could be found between the values assumed by experts and farmers concepts. The links have been defined according to the results of experts' interviews. These relationships can be used in the validation phase.
Therefore, the validation is based on the comparison between the assessment made by local communities and the assessment made considering the factors defined by the experts. To this aim, data from local community are collected according to the protocol. Using these data and the local community conceptual model, the state of environmental resources can be assessed. To be validated, this assessment has to be compared with the risk that a certain state of the environmental resources occurs. This risk is assessed considering the experts conceptual model.
Then, the experts' assessment and the farmers' assessment can be compared in order to define a degree of congruence. The congruence degree is assessed using the fuzzy semantic distances. Therefore, the formula (1) is applied.

$$S_d(1,2,x_i) = \left|\mu_1(x_i) - \mu_2(x_i)\right| \quad (1)$$

Where S_d (1, 2, xi) represents the semantic distance of the values of the element x_i in experts' assessment and local community's assessment; $\mu_1(x_i)$ represents the value of experts' assessment and $\mu_2(x_i)$ represents the value of local community's assessment. The congruence degree is, then calculated according to the formula (2).

$$CD(x_i) = 1 - S_d(1,2,x_i) \quad (2)$$

The congruence degree (CD) provides information about the reliability of the assessment made by local community, supporting the validation of local knowledge, as requested to enhance its usability in environmental monitoring. Therefore, if the value assigned by local community is highly congruent with the value defined using experts conceptual model, then the value can be considered as reliable. Otherwise, a suggestion to deepen the investigation is provided to the monitoring system managers.
In the next section, the preliminary results of an experimental implementation of the methodology to support soil salinity monitoring are described.

3. LOCAL AND EXPERT KNOWLEDGE FOR SOIL SALINITY MONITORING IN THE AMUDARYA RIVER BASIN

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 is representing 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.

Given the scarcity of financial resources of the HE, the sampling is not carried out using a well-structured monitoring network. Moreover, in order to reduce the number of required soil samples, 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 etc., to name a few only. During our fieldwork, 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 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. According to the interviewees' opinions, these errors are due to the wrong definition of homogeneous areas.

Therefore, the aim of our work is to support soil salinity monitoring at the local scale using local knowledge for a qualitative assessment of soil salinity. This qualitative assessment can be used as basis for the definition of the homogenous areas. In fact, as several water managers said during the interviews, farmers are able to assess the soil salinity in a qualitative way using their tacit knowledge. The methodology described in previous section was applied to collect and structure this knowledge making it usable to support environment monitoring. The experimentation is focused on the Khorezm oblast, in the delta region of the Amudarya.

Therefore, we tried to capture the cognitive models of experienced farmers during several interviews. A preliminary cognitive model about factors that are considered in the qualitative soil salinity assessment was developed by augmenting and superimposing the individual cognitive models. The farmers' cognitive model is shown in figure 1. In this model, the concepts forming the tacit knowledge of experienced farmers are included. This tacit knowledge allows farmers to assess qualitatively the degree of soil salinity.

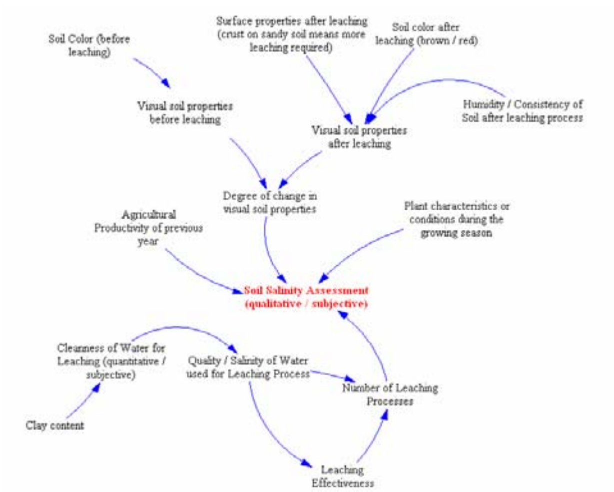

Figure 1. Cognitive model of qualitative soil salinity assessments.

Furthermore, a debate session was organized with all interviewed farmers in order to validate the cognitive model and the importance degree of the factors. At the end of this section, an agreement was reached about the definitive list of factors to be considered. Therefore, the soil salinity degree based on farmers' knowledge is assessed using the formula (3).

$$FA(x_i) = \sum_j f_j \times w_j \qquad (3)$$

Where, $FA(x_i)$ is the soil salinity value for the element x_i, f_j represents the value of the j-th factor, w_j represents the importance degree of j-th factor according to the farmers conceptual model.

As reported in previous section, the conceptual model is fundamental to define the protocol for data collection. Therefore, a questionnaire was developed considering the factors highlight by experienced farmers and their possible states. The questionnaire was developed together with farmers in order to make it easily understandable. The collection of data from farmers is going to be started in next months, after the harvesting time. At the current state of the experimental implementation the process for data collection was discussed during the debate session with farmers. WUAs technicians are involved in collecting data from farmers during their normal activities. The data collection uses the field as spatial basis. Therefore, using (3), a map of farmers soil salinity assessment can be developed. A fuzzy linguistic variables "soil salinity" is defined. This variable can assume four different values, i.e. highly salinised, salinised, relatively salinised and not salinised. The values to be assigned to the variable are similar to the linguistic terms used by the farmers.

To validate the local knowledge, several local experts working on water and soil management were interviewed. The interviews aimed to collect and structure the understanding of the experts concerning the definition of soil salinity risk. A cognitive model was developed using the results of the interviews (figure 2).

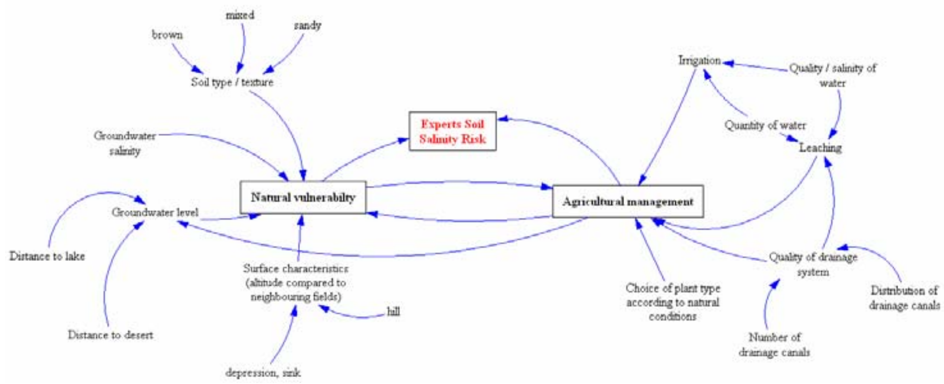

Figure 2. Cognitive model for soil salinity risk assessment

In this model, all the factors taken into account by experts to assess the soil salinity risk have been described. The importance degree of the factors was defined and validate by participants. Therefore the soil risk can be assessed using experts' knowledge according to the formula (4).

$$EA(x_i) = \sum_j e_j \times w_j \qquad (3)$$

Where, $EA(x_i)$ is the soil risk for the element x_i, e_j represents the value of the j-th factor contained in the experts cognitive model, w_j represents the importance degree of j-th factor. All the factors contained in the expert cognitive model can be assessed considering "traditional" environmental data, such as groundwater level, groundwater salinity, soil type, drainage system, etc. Therefore, a map for soil salinity risk can be develop using this information. This map shows for each field the value of soil salinity risk. A fuzzy linguistic variable "soil salinity risk" is defined. At the current stage of experimental implementation, the collection of data for the factors contained in the experts cognitive model is started. The soil risk map will be ready before the initial phase of collection of data by farmers. This map will be stored in HE office and it will be used by them to validate the farmers' information, following the procedure described in previous section.

The integration between farmers' and experts' cognitive model is represented in fig. 3.

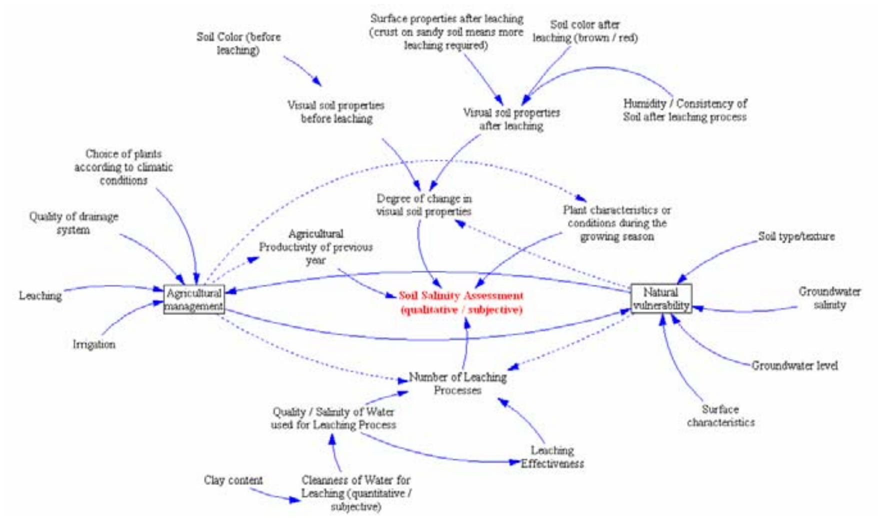

Figure 3. Integrated cognitive model

The validation of farmers' knowledge is made comparing, for each field, the value in farmers soil salinity map and the value in soil risk map. The comparison is done by HE using a prototype of a software developed by us able to produce the two maps and to evaluate the congruence degree for each field. At the current stage of the experimentation, the prototype has been developed and presented to HE to collect feedback. In next months the prototype will be installed in HE office in Urgench (Khorezm).

As reported in previous section, the congruence degree (CD) provides information about the reliability of farmers' salinity assessment, supporting the validation of local knowledge, as requested by the water managers and people working in the monitoring system management. Therefore, if the value assigned to the field x_i in the farmers' map is highly congruent with the value in the soil risk map, then the value can be considered as valid. Otherwise, a suggestion to deepen the investigation is provided to the monitoring system managers.

At the end of this process, the validated farmers soil salinity map is used to define the homogenous areas, and, following the current monitoring practices, samples will be taken in each area in order to create the soil salinity map.

4. CONCLUSIONS

The development of an affordable monitoring program to support Adaptive Management involves substantial, scientific innovation in both method and approach. Particularly interesting are methods and tools able to facilitate the integration of different sources of information. In this contribution, local knowledge is proposed as an interesting alternative source of information to support environmental monitoring. Nevertheless, local knowledge cannot be used by decision makers as it is proposed. A structuring and validation phase is needed.

The potentialities of cognitive modelling as a tool to support the structuring of local knowledge, which is tacit and not easily understandable for decision makers, are investigated in this work. The methodology is applied for the monitoring of soil salinity in the Amudarya river basin. A farmers cognitive model have been defined which highlight the factors used by members of the local community to make a qualitative assessment of soil salinity, i.e. the basis of their tacit knowledge. The design of the protocol for data collection has been designed considering these factors.

To facilitate the validation of the local knowledge, an expert system for the assessment of soil salinity risk has been defined using the knowledge of local experts. The integration among farmers and experts cognitive models and the comparison between the two assessments facilitate the local knowledge validation.

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