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Bayesian Belief Network to support conflict analysis for groundwater protection: The case of the Apulia region

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ABSTRACT

Water resource management is often characterized by conflicts, as a result of the heterogeneity of interests associated with a shared resource. Many water conflicts arise on a global scale and, in particular, an increasing level of conflicts can be observed in the Mediterranean basin, characterized by water scarcity. In the present work, in order to assist the conflict analysis process, and thus outline a proper groundwater management, stakeholders were involved in the process and suitable tools were used in a Mediterranean area (the Apulia region, in Italy). In particular, this paper seeks to elicit and structure farmers' mental models influencing their decision over the main water source for irrigation. The more crucial groundwater is for farmers' objectives, the more controversial is the groundwater protection strategy. Bayesian Belief Networks were developed to simulate farmers' behavior with regard to groundwater management and to assess the impacts of protection strategy. These results have been used to calculate the conflict degree in the study area, derived from the introduction of policies for the reduction of groundwater exploitation for irrigation purposes. The less acceptable the policy is, the more likely it is that conflict will develop between farmers and the Regional Authority. The results of conflict analysis were also used to contribute to the debate concerning potential conflict mitigation measures. The approach adopted in this work has been discussed with a number of experts in groundwater management policies and irrigation management, and its main strengths and weaknesses have been identified. Increasing awareness of the existence of potential conflicts and the need to deal with them can be seen as an interesting initial shift in the Apulia region's water management regime, which is still grounded in merely technical approaches.

1. Introduction

Water resource management is a complex problem, as a result of various interests associated with a shared resource (Ostrom, 2005), and as such it often introduces a conflict. There has been a considerable increase in the number of reported water conflicts on a global scale (United Nations, 1988; Unesco, 2002; Mimi and Sawalhi, 2003; Mbonile, 2005; Sneddon and Fox, 2006).

An increasing level of conflict between different water users and uses is also observed in water management in the Mediterranean basin, which is facing a twofold problem. On the one hand, the spread of intensively irrigated agricultural areas is leading to a dramatic increase in water demand. On the other hand, the Mediterranean Region is characterized by water scarcity problems as a result of its climatic conditions (Iglesias et al., 2007). Increasing imbalance between water demand and water availability is leading to an explosion in the level of conflict.

Therefore, water resource management requires methods and tools to support the detection, analysis and reduction of conflicts among different users and uses.

A conflict condition arises whenever two or more groups with decision-making power and different interests, values and objectives interact with each other (Bana e Costa et al., 2001; Malta et al., 2005; Obeidi et al., 2005, 2009). Conflict is driven by perceived incompatibility – at least for one part – with regard to one of these significant aspects. The more significant this aspect is perceived to be, the more complex and ingrained the conflict becomes, and the harder it is to resolve (Obeidi et al., 2005, 2009). A conflict resolution process can be defined as a dynamic and iterative group discussion process which aims to bring agents' opinions as closely

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into line with each other as possible (Fedrizzi et al., 1999; Herrera et al., 2001, 1996; Herrera et al., 2002).

A conflict analysis is an information-gathering exercise, the overall objective of which is to identify actors involved in the conflicting situation and what issues are at the center of the conflict (Susskind and Thomas-Larmer, 1999). These issues should avoid judgments and interpretations; they should reflect what the people want to talk about (Mason and Muller, 2007). Many authors consider the definition of a measurement of conflict as crucial to supporting the conflict analysis (Fedrizzi et al., 1999; Bana e Costa et al., 2001; Herrera et al., 2001). Most of these approaches measure conflict by analyzing differences and similarities among participants' opinions about goals to be attained and the actions to be implemented (Szmidt and Kacprzyk, 2003; Giordano et al., 2007; Munda, 2009).

Zeleny (2008) and Obeidi et al. (2005) suggest that a conflict is driven by a belief that the parties' current aspirations cannot be achieved simultaneously. This leads to the definition of "interference" among decision makers, which happens when at least one party is unable to attain its goal independently. The interference could be either due to the opposition of another decision makers – i.e. the achievement of the goal is undermined by others – or due to the lack of cooperation among decision makers, which result is an increase of the costs associated to the goal achievement.

This work describes the development of a tool for conflict analysis in groundwater resources management. The tool aims to model conflicting situations and to provide answers to the main questions, i.e. where does the conflict lie? What agents are involved in the conflict? What are the main reasons for the conflict?

The tool described in this work is able to measure the level of conflict by analyzing the strength of interference among decision makers, that is, the obstacle that the implementation of a decision maker's actions will create against the achievement of another's objectives.

The tool was experimentally applied to support conflict analysis in groundwater management in the Apulia region, located in the south-eastern part of Italy.

The Apulia region has a Mediterranean climate with low precipitation, mild winters and warm, dry summers. It is mainly dominated by agriculture, with more than 70% of the total area occupied by cropland. There is not enough surface water to satisfy the demand entirely and for this reason significant amounts of water are withdrawn from groundwater by farmers. Irrigated agriculture is the unique user of groundwater in the Apulia region (Giordano et al., 2010a). The use of groundwater for irrigation should be kept sustainable by balancing abstractions against the recharge of the aquifer. There is a risk of overexploitation of systems, leading to a dramatic fall in the aquifer level and sea water intrusion, as observed in most of the coastal zones in the region. To deal with this issue, a Regional Water Resource Protection Plan (Regione Puglia, 2009) was developed by the Regional Authority. The plan provided for more severe constraints on groundwater exploitation according to the state of the resource.

During the implementation of the plan, a large number of conflicts between Regional Authority and farmers affected by the plan arose, hampering its effectiveness. Due to the heterogeneity of interests and concerns of the stakeholders involved, conflicts regarding groundwater protection were extremely severe and complex. The tool described in this work allowed to identify the main reasons of conflict and to start the conflict resolution process.

A sequential implementation of Cognitive Maps and Bayesian Belief Networks made it possible to elicit and structure the mental models of the different actors involved in the conflict, and to assess the impacts of groundwater protection strategy. CMs demonstrated their potential to contribute to debate with local stakeholders, as the modeling was close to the natural language and the results of CM were easily comprehensible by participants. Although the adoption of BBN for the integration of different sources of knowledge to support environmental management is not new (e.g., Henriksen et al., 2007; Henriksen and Barlebo, 2008; Molina et al., 2010; Castelletti and Soncini-Sessa, 2007), in this work BBN was innovatively applied to simulate the interferences amongst decision-makers. To this aim, BBNs showed several advantages compared to other modeling tools. Firstly, BBNs permit the integration of objective and subjective (expert) knowledge. This allowed to simulate actors' behavior by easily and in a mathematically coherent manner incorporate the variables assessed using quantitative methods with the qualitative variables, for which no data exists. Secondly, compared to qualitative methods such as Fuzzy Cognitive Map, BBNs allowed a more accurate assessment of the main actors' objectives after the implementation of the protection strategies and, thus, a more accurate evaluation of the level of conflict. Thirdly, the Bayesian distribution of probabilities allowed to assess the interference among different actors taking into account the imperfect understanding and/or incomplete knowledge that each actor had of the system.

Beside the conflict analysis, the work also aims at dealing with three important research questions concerning the use of cognitive modeling to facilitate the use of stakeholders knowledge for environmental management, i.e. to which extent CM and BBN are capable to represent something implicit such as mental models? Do CM and BBN facilitate or hinder the debate between technicians and farmers? What is the impact of cognitive modeling on stakeholders knowledge reliability for decision-makers?

This work is organized as follows. Section 2 is devoted to the description of the methodology used to analyze conflicts for groundwater protection. Results from the case study are described and discussed in Section 3. Concluding remarks are then provided in Sections 4 and 5.

2. Materials and methods

The methodology for the analysis of conflicts due to the implementation of groundwater protection strategy was based on a multi-step approach:

1. elicitation of actors' mental models influencing their decisions about groundwater management and development of actors' Cognitive Map (CM);
2. development of a Bayesian Belief Network (BBN) to support conflict analysis and resolution;
3. measurement of conflict level.

Each step is described in detail in the following paragraphs.

2.1. Eliciting of actors' mental models and developing Cognitive Maps

Several definition of mental models can be found in the scientific literature (e.g. Doyle and Ford, 1998). In this work, we mainly referred to Sterman (1994, p.294) definition, which stresses the implicit "beliefs about the network of causes and effects that describe how a system operates, the boundary of the model (the exogenous variables) and the time horizon we consider relevant – our framing or articulation of a problem". CM, as defined by Axelrod (1976), was applied to elicit mental models, making them explicit and "external" (Schaffernicht, 2006).

A CM can be defined as a qualitative model of the decision-making environment (see for example, Kosko, 1986; Ozesmi and Ozesmi, 2004), in which the nodes represent variables and the