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An integration between Cognitive Map and Bayesian Belief Network for conflicts analysis in drought management

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Abstract: In the real world, environmental decision-making takes place in a highly interconnected environment, in which neither the decisional ramifications of a management action, nor the complexity of its impact, can be neglected. This contribution focuses on drought management. Due to the high complexity of drought impacts and the ambiguity in drought perceptions, different and often conflicting drought management strategies could be implemented by different actors. This, in turn, could have a strong negative impact on the effectiveness of drought mitigation strategies. Therefore, a deep conflict analysis and the definition of effective negotiation strategies could be really useful. In this work, a method based on the integration between Cognitive Map and Bayesian Belief Network is proposed to support the elicitation and the analysis of stakeholders perceptions of drought, and the conflicts analysis. The method was applied to support drought management in Trasimeno Lake (Umbria Region).

Keywords: Drought management, Conflicts analysis, Cognitive Map, Bayesian Belief Network, Fuzzy Logic.

1. INTRODUCTION

Drought is largely considered as one of the major and most complex natural hazard (Wilhite et al., 2007; Pereira et al., 2009). Empirical investigations emphasize the ambiguity in drought perception and definition (Noemdoe et al., 2006). There is no unique definition of the problem (Lane and Oliva 1998; Rosenhead and Mingers, 2001), but each individual has her/his own perception of drought, which is influenced by previous drought experiences (Obeidi et al., 2005; Slegers, 2008) and the mental models used to analyse these experiences (Kolkman et al., 2005).

The way a phenomenon is defined influences a stakeholder's expectation of future occurrence, and leads stakeholders to adopt different behaviours and to act or react in different ways (Checkland, 2001; Slegers, 2008), according to different system of values and objectives (Bana e Costa et al., 2001). The potential interference between decision-makers – i.e. when the goals' attainment of at least one party is or could be undermined by others – should be taken into account. This actually describes a conflicting situation (Obeidi et al., 2005). In this condition, the perspective of the single decision-maker, who is able to significantly contribute to reduce drought impacts with his/her own actions, has to be overcome.

Drought management requires methods and tools to support the detection, analysis and reduction of conflicts between the different decision-makers.

In this work, an integration between Cognitive Map (CM) and Bayesian Belief Network (BBN) is proposed to structure stakeholders' perception of drought, and to analyze the potential conflicts due to interference between the different drought management strategies. The methodology was experimentally implemented to analyze drought perception in Lake Trasimeno, situated in the Umbria region (Central Italy).

2. CONFLICT ANALYSIS AND REDUCTION: AN INTRODUCTION TO THE LITERATURE REVIEW.

One challenge facing researchers and practitioners in negotiation and conflicts resolution is the detection of conflicts (Obeidi et al., 2005). Conflicts is driven by the perceived incompatibility of something of relevance, at least for one party. This thing could be different goals, interests, belief. The more substantive this thing is to individual the more complex and ingrained the conflict becomes, and the harder is to resolve (Obeidi et al., 2005; Obeidi et al., 2009).

Many methods have been developed to analyze conflicts. All these methods treats conflict as an interactive decision problem between two or more decision-makers, with their own systems of values and objectives (Bana e Costa, 2001; Obeidi et al., 2005; Obeidi et al., 2009). Conflict is a process triggered by an event or stimulus and evolving through a series of sequential stages (Obeidi et al., 2009).

Most of conflict resolution approaches and methods are process-oriented, trying to minimize the disagreement on the outcomes of the negotiation process by managing during it all the sources of potential inter-actors conflict (Susskind and Cruikshank, 1987). The process of conflict resolution aims to support the debate among the different decision-makers, in order to make their opinions as close as possible (Herrera et al., 1996). Many authors suggested to use a measure of conflict to support the debate and to assess the effectiveness of the negotiation process (Herrera et al., 2001; Fedrizzi et al., 1999; Giordano et al., 2007).

Other approaches are outcome-oriented rather process-oriented. These approaches, also called pre-negotiation, aim to dissolve the conflict in an enlarged frame rather than try to resolve it within the set of existing alternatives (Bana e Costa et al., 2001). This approach is based on the invention of a new solution that would reconcile as much as possible the main sources of conflict a priori detected. This new solution is also called the prominent alternative, whose absence is the main cause of the conflict (Zeleny, 2008). These approaches assume that a conflict resolution via compromise is only a temporary solution. Sooner or later the suppressed perceptions and values will allow the conflict to re-emerge. The only way to reduce the intensity of conflict is to generate alternatives that are closer to the prominent alternative (Zeleny, 2008).

The first step to support the creative process to invent or discovery the prominent alternative is to address a fundamental question "where does the conflict lay?" (Bana e Costa et al., 2001), that is, to detect the main reasons behind the conflicts.

The aim of this work is to develop and test a methodology able to investigate the differences between stakeholders' drought perceptions, to identify and analyse the conflict and, thus, to support the identification of the prominent solution for drought management.

3. DESCRIPTION OF THE CASE STUDY

The methodology developed was applied to elicit and analyse drought perceptions in the area of Lake Trasimeno, located in the Umbria region (Central Italy).

The Trasimeno Lake covers a surface area of 128 km². The lake has unusual hydromorphological conditions, characterized by the absence of substantial inlet and outlet rivers. The tributary catchment of the lake covers a limited area. Moreover, the depth of the lake is around 4 m, with a maximum of 6 m. These conditions make the lake particularly vulnerable to drought phenomena.

Drought increases the effects of already adverse climatic conditions. Drought is quite recursive in this area. The last strong drought phenomenon initiated in 2002 and finished in 2006. During this period, the drought had a strong negative impact on the local socio – economic conditions. In fact, most of the economic activities were strongly influenced by the state of the lake. Farmers used to withdraw water for irrigation directly from the lake. Therefore, the reduction of the level significantly decreased the water available for irrigation. Moreover, the reduction in the level of the lake had a strong negative impact on the tourist industry in the area.

The stakeholders analysis allowed the authors to identify the main actors to be involved in this study: 1) the Umbria Regional Authority; 2) the Local Irrigation System Management (EIUT); 3) the local Municipalities; 4) the Local Development Support Association (GAL); 5) the local Farmers Association; 6) the Regional Environmental Protection Authority (ARPA); 7) the local Tourist Industry Association.

4. CONFLICT ANALYSIS FOR DROUGHT MANAGEMENT

A methodology based on the integration between Cognitive Map (CM) and Bayesian Belief Network (BBN) was developed to structure drought perceptions and to analyse conflicts. For a detailed description of the CM methodology, a reader could refer to (Axelrod, 1976; Eden, 2004; Eden and Ackerman, 2001; Marchant, 1999; Montibeller et al., 2001). Interesting experiences concerning the implementation of BBN to support environmental management could be found in (Bromley et al., 2005; Castelletti and Soncini-Sessa, 2007; Henriksen and Barlebo, 2008)

A significant strength of CM is that the modelling is closed to natural language. CM captures causal knowledge of stakeholders in a more comprehensive and less-time consuming manner than other methods (Nadkarni and Shenoy, 2004), and the results are easily comprehensible for participants. Nevertheless, CM permit only limited forms of causal inference, and they are not able to take into account the uncertainty due to limited knowledge of the system.

BBN showed great potentialities to deal with uncertainty caused by imperfect knowledge of the state of the domains and partial understanding of the mechanisms governing the behaviour of the domains (Bromley et al., 2005). This makes BBN suited to structure the stakeholders' understandings of the drought phenomenon and its impacts on the system, and to define the mental models influencing their behaviours to cope with drought.

The potentialities of CM and BBN integration and the main issues to be addressed are described in (Nadkarni and Shenoy, 2004).

The main steps of the methodology are: elicitation of stakeholders' mental models concerning drought perceptions (knowledge collection; development of CM; development of BBN from CM); conflicts analysis.

4.1. Elicitation of drought perception

A round of semi-structured interviews was carried out involving the main stakeholders. Following Slegers (2008), the interviews were aimed at collecting stakeholders' experiences about both direct and indirect drought impacts. Moreover, the stakeholders were required to specify elements which can either increase or decrease the impacts of a drought.

The collected narratives were analysed and coded in CM. To this aim, causal statements were identified (Nadkarni and Shenoy, 2004). The causal statements were transformed in causal links in the CM. Using the results of the interviews, a polarity and a weight were assigned to each link (Marchant, 1999). The weight of each link was described using linguistic statements, i.e. “high”, “medium”, “low”.

Figure 1 shows the CM developed using the interview to farmers association.

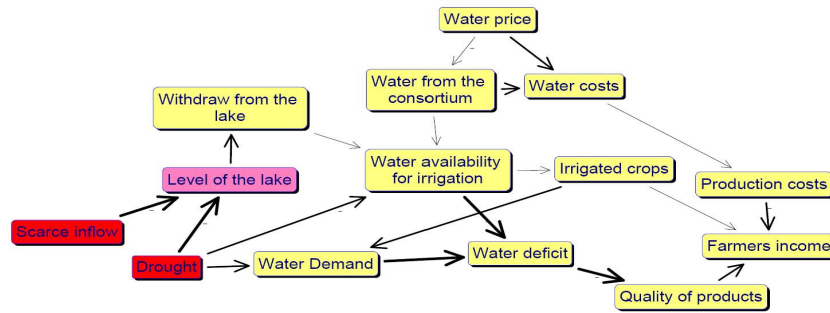


Figure 1: CM obtained analysing the results of farmers' association interview. The links are represented with different thickness according to strength of the relationships. The “-” is used for the negative links.

CM analysis supported the identification of the most important elements in drought perceptions for each stakeholder. The importance degree was assessed considering their centrality in the CM. The weighted extended domain analysis was applied (Eden, 2004). Drought perception depends on the severity of drought impacts. Therefore the analysis of drought perceptions was completed by assessing and comparing the impacts of drought on the elements in the stakeholders' mental models. To this aim, BBN were derived starting from the CM. To construct the BBN starting from the CM requires the definition of the state space of each variable and the derivation of the conditional probabilities associated with the variables in the map. In our work, the definition of the state space were carried out interacting with stakeholders. The conditional probabilities associated with the variables were derived using the weight and the polarity of the links in the CM. At the end of this step the BBNs representing the stakeholders' understanding of the drought phenomenon were derived. The BBNs were used to assess the main drought impacts according to stakeholders' mental models. The comparison between the values in rainy conditions and during a drought period allowed us to assess the drought impacts (figure 2 a and b).

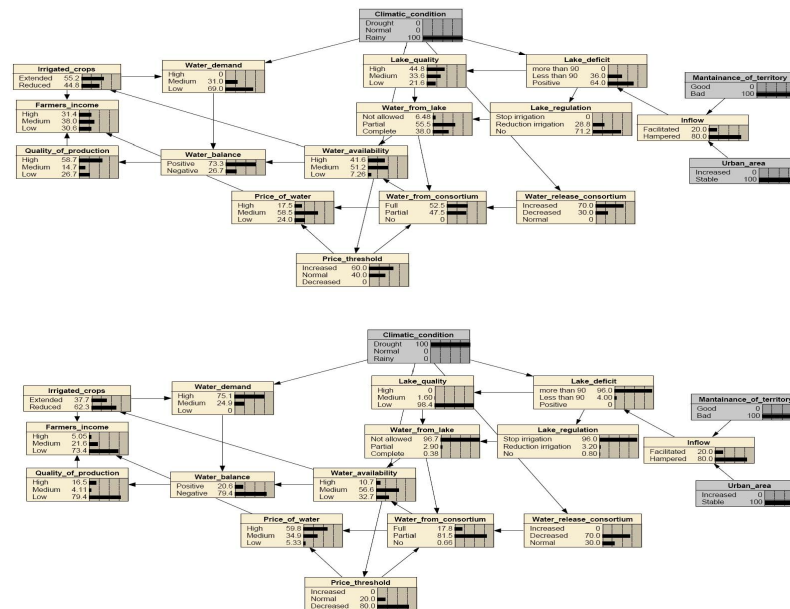


Figure 2a: Farmers' association BBN in rainy conditions. **Figure 2b:** Farmers' association BBN in drought conditions.

Figure 3 shows the comparison between the values of the variable “Water balance”. The

change between the two states was calculated as distance between the centroids of the two graphs.

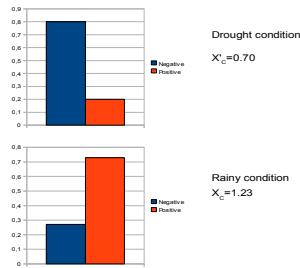


Figure 3: Comparison between the value of “Water balance” during a drought phenomenon and in a rainy period. X_c and X'_c represent the centroids of the two graphs.

The change was assessed according to the following formula:

$$C = X'_c - X_c$$

[1]

Therefore, $C = -0,53$. In order to simulate the approximate reasoning of the stakeholders, a fuzzy linguistic function was defined to describe the impact degree (figure 4).

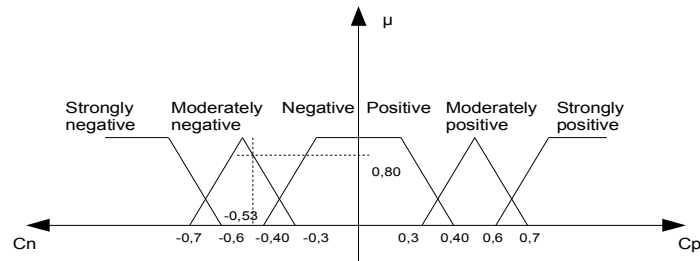


Figure 4: Fuzzy function to describe the degree of change due to drought initiation. The distance between the centroids was reported on the x-axis.

where C_n represents negative changes due to drought. A negative change can occur either when a negative element (e.g. price of water) increases or when a positive element (e.g. farmers income) decreases. C_p represents positive impacts. μ represents the membership degree to the fuzzy sets “Strongly Negative”, “Moderately negative”, “Negative”, “Positive”, “Moderately positive”, “Strongly positive”.

C was reported as crisp value on the x-axis. Thus, the drought had a “moderately negative” impact on “water balance”, with a membership equal to 0.80.

The same calculation was done for the other elements in farmers' BBN. The aggregation of the importance degree and the impact degree allowed us to derive the influence of each variable on drought perception. The fuzzy AND operator (Zimmermann, 1991) was adopted as aggregation operator. The following table summarizes the results of the analysis for the farmers' BBN.

Tab.1: the main elements influencing the drought perception.

Variables	Importance degree	Impact degree	Influence on drought perception
Farmers Income	Highly important	Strongly negative	Highly impacting
Water balance	Highly important	Moderately negative	Moderately impacting
Water availability	Highly important	Moderately Negative	Moderately impacting
Quality of production	Highly important	Strongly negative	Highly impacting
Price of water	Important	Negative	Impacting
Lake deficit	Important	Strongly negative	Impacting

Therefore, farmers' perception of drought was influenced mostly by the income, the water balance, the water availability and the quality of production.

The same analysis was carried out for the other stakeholders' BBN. The results of this analysis were used as basis for the conflicts analysis in drought management, as described in the following section.

4.2. Conflict analysis

The only way to dissolve conflict is to cope with it in creative way, increasing the set of possible alternatives in order to identify the prominent solution (Zeleny, 2008; Bana e Costa et al., 2001). To support this creative approach to conflict dissolution, the identification of the main causes of conflict is crucial.

To this aim, the impacts of the current drought management strategies on the stakeholders objectives were analysed. Table 2 summarizes the current strategies to cope with drought and the actors involved.

Tab.2: Actions to cope with drought

Actors	Action to cope with drought
Umbria Regional Authority	1. To reduce the amount of water exploitable from the lake 2. To stop the withdraw from the lake
Local Irrigation System Management	1. To reduce the amount of water available for irrigation; 2. To increase the price of water for irrigation (price threshold).

The impacts of these actions on the values systems of the different stakeholders were simulated using the BBNs. For seek of brevity this contribution is focused on farmers' drought perception. This is justified further in the text. Figure 5 shows the impacts on farmers' BBN.

Due to the implementation of the drought management strategies, the state of the variables "Price threshold" "Water released from consortium" and "Lake regulation" were changed. Moreover, farmers are forced to reduce the water demand by reducing the irrigated areas and the cultivated areas (figure 5).

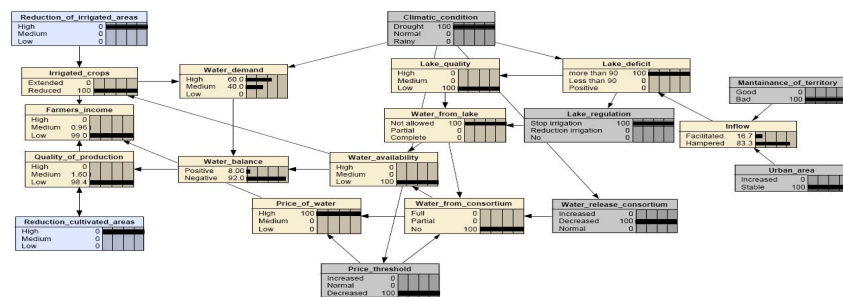


Figure 5: State of the variables of the farmers' BBN due to the implementation of other stakeholders' strategy.

The impacts of the drought management strategies on farmers was assessed by comparing the states of the main variables in farmers' BBN. Figure 6 shows the comparison concerning the value of the variable "water balance".

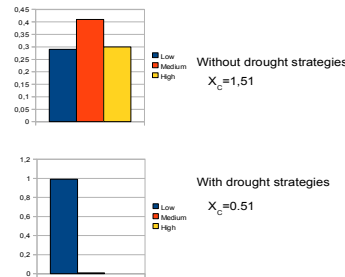


Figure 6: Comparison between the value of “farmers' income”.

According to [1], $C = -1$. Therefore the impact of drought management strategies on water balance was strongly negative. The degree of impact was calculated for each of the most important elements in farmers' drought perception. The overall impact was assessed by aggregating the impacts. The Linear Geometric Weighted Averaging operator (LGWA) (Xu 2004) was used for the aggregation. This operator made it possible to aggregate linguistic values for elements that are not equally important and, thus, were characterised by different weights (Herrera et al. 2001). In this work, the weights were defined considering the influence on stakeholders' drought perceptions (tab.1). Before applying the LGWA operator, the weights were modified to comply with the rule $\sum \omega_i = 1$. As reported in Xu (2004), the term set should be structured in such a way that $S_i \geq S_j$ if $i \geq j$. In this work, the term set was $S = \{S_1 = \text{Strongly positive impact}, S_2 = \text{Moderately positive impact}, S_3 = \text{Positive impact}, S_4 = \text{Negative impact}, S_5 = \text{Moderately negative impact}, S_6 = \text{Strongly negative impact}\}$.

The aggregated value is assessed according to the following formula (Xu 2004):

$$LGWA = (S_1)^{\omega_1} \otimes \dots \otimes (S_n)^{\omega_n} = (S_{(1^{\omega_1})}) \otimes \dots \otimes (S_{(n^{\omega_n})}) \quad [2]$$

The impacts of irrigation system management strategy on the main variables of farmer's BBN are reported in table 3.

Tab.3: impacts of drought management strategy on farmers' BBN variables

Variables	Impact	Weight ($\sum \omega_i = 1$)
Farmers Income	Strongly negative	0,2
Water balance	Moderately negative	0,21
Water availability	Strongly negative	0,15
Quality of production	Strongly negative	0,22
Price of water	Negative	0,11
Lake deficit	Moderately negative	0,11

According to [2], $LGWA = S_{5,37}$. Taking into account the definition of the vector S , the drought management strategy had a negative impact on farmers' drought perception. Considering that the more negative the impact the stronger the conflict, there was a strong conflict between farmers and irrigation system managers. This table allows to identify the main reasons of the strong conflict between farmers and the two actors devoted to drought management. The usefulness of this information is discussed in the next session.

The same analysis was carried out with the other stakeholders. The results are not discussed here since the assessed degree of conflict was rather low.

5. DISCUSSION AND CONCLUSIONS

The adopted approach was discussed with the involved stakeholders in order to identify benefits and weaknesses.

One of the positive results of the adopted methodology is its ability to make explicit the differences in drought perceptions. The results of the CM and BBN analysis about the influences on perceptions were discussed with the involved stakeholders. Thus, they became aware about the interests and concerns of the other participants about drought impacts and drought management. This information allowed them to reflect about divergences and similarities of problem perceptions. E.g. regional authority became aware that tourist operators and GAL perceived farmers as the main responsible of the lake quality.

From the decision makers point of view, the main benefits are related to the capability to simulate the impacts of drought management strategies on stakeholders' objectives and to identify the main reasons of conflicts. This information can be used by them to increase the set of potential alternatives in order to define actions as close as possible to the prominent ones. During the experimentation, the results of conflict analysis were discussed with decision-makers. Once they became aware of the main farmers' concerns, they started to discuss about the possibility to make the irrigation system independent from the lake level. In the meantime, a more effective drought early warning system was proposed, in order to support farmers in the selection of the most suitable crops according to the foreseen climatic conditions.

One of the drawbacks highlighted during the analysis of the results concerns the qualitative nature of the results of BBN simulation. This represented a weakness of the system according to the decision-makers, who are familiar with quantitative assessments. Thus, for the decision-makers, qualitative results were considered as not completely reliable. An important improvement in the system could be made by coupling the BBN with some quantitative models in order to increase the reliability of the results for the decision-makers.

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