

INTEGRATED SET OF PHYSICAL AND SOCIO-ECONOMIC INDICATORS FOR DROUGHT IMPACTS MONITORING

Raffaele GIORDANO¹, Adele CELINO², Emanuele ROMANO³ & Elisabetta PREZIOSI³

- (1) Water Research Institute, National Research Council, UOS Bari, Italy, email: raffaele.giordano@cnr.it
(2) Dept. of Architecture and Urban Planning, Polytechnic of Bari, email: a.celino@poliba.it
(3) Water Research Institute, National Research Council, UOS Rome, Italy, email: preziosi@irsa.cnr.it; romano@irsa.cnr.it

ABSTRACT

Drought is largely considered as one of the major and most complex natural hazard. Empirical investigations emphasize the ambiguity in drought perception and definition. There is no unique definition of the problem, but each individual has her/his own perception of drought, which is influenced by previous drought experiences and by the mental models used to analyse these experiences. Defining drought simply as departure from the average rainfall considers only one aspect of the problem, i.e. the meteorological drought. This work describes an attempt to develop an integrated set of indicators to observe drought phenomenon and its environmental and socio-economic impacts, which usually develop later, by taking the local stakeholders' perception of drought into account. The activities were carried out in the Lake Trasimeno district (Central Italy). This work describes the results of the comparison among indicators in the case study area. Some interesting, although preliminary, conclusions about the usability of local knowledge for drought monitoring are drawn.

1 INTRODUCTION

Drought is considered as one of the most complex and relevant natural hazard due to the complexity of both direct and indirect impacts (Pereira et al. 2009). Defining drought simply as the departure from the average precipitation value describes only one dimension of the complex problem (Noemdoe et al., 2006). A wider definition requires to take the drought impacts at different level into account (Wilhite e Glantz 1987).

Empirical investigations emphasize the ambiguity in drought perception and definition (Noemdoe et al., 2006). There is no unique definition of the problem (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 ambiguity in drought definition could reduce the effectiveness of drought risk

management strategies due to the emergence of conflicts. 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). This actually describes a potential conflicting situation (Obeidi et al., 2005). The more ingrained is the conflict between stakeholders and authorities, the stronger is the opposition to the drought management strategy and the less effective are the mitigation measures.

The aim of this work is to develop a comprehensive definition of drought, based on the integration between the scientific and local knowledge. To this aim, a methodology able to elicit and analyze stakeholders' perception of drought impacts, and to integrate the local knowledge with meteo-hydrological information was developed and implemented in the Lake Trasimeno (Central Italy).

The methodology was applied to develop an integrated set of drought indicators to be used to analyze the phenomenon and to support the definition of risk management strategies (fig.1). Some interesting, although preliminary, conclusions about the usability of local knowledge for drought monitoring are drawn.

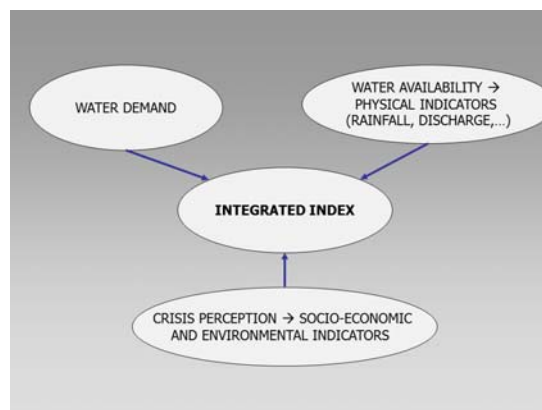


Figure 1. Integration of different sources of information.

2 INTEGRATION OF SCIENTIFIC AND LOCAL KNOWLEDGE: AN INTRODUCTION TO THE LITERATURE

The integration of different sources of knowledge and information is widely considered as crucial to cope with complexity and uncertainty of environmental problems (Raymond et al., 2010). Many different forms of knowledge are discussed in the environmental management literature. These range from the tacit, personal knowledge to a coded knowledge generated through more formalized processes. Categories have been created to simplify the discussion. According to these categories, 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). Scientific knowledge usually refers to the often explicit

knowledge that has been derived from applying formal methods. Raymond et al. (2010) also refers to the hybrid knowledge as the result of the integration of different type of knowledge, e.g. local and scientific. This innovative concept is based on the increasing awareness that local and scientific knowledge should be considered as different areas of expertise that complement rather than contradict each other (Moller et al., 2004).

The integration of these two forms of knowledge could have several benefits for the environmental monitoring and management. On one side, local knowledge can be used to corroborate scientific data and to fill in gaps in scientifically generated data (Scholz et al. 2004). On the other side, scientific knowledge complements local knowledge by testing causation (Moller et al., 2004). Moreover, while local knowledge tends to focus on long time series of information concerning small areas, science is good at collecting short time series over a large area (Moller et al., 2004).

Despite the numerous advantages and the increasing number of successful experiences (e.g. US EPA 2000) of integrating local and scientific knowledge in environmental monitoring and management, three main research questions have to be dealt with, i.e. how to guarantee the long term involvement of local communities in monitoring activities? How to integrate locally-based information in the decision-making process? How to increase the reliability of locally-based information? (Giordano et al., 2010).

Ovuka & Lindqvist (2000) and West et al. (2008) investigated how to integrate local and scientific knowledge to support the monitoring and analysis of climatic phenomenon. Although these works found the local communities' perceptions as coherent with the climatic data analyzed by experts, some important issues concerning the nature of the communities' perceptions should be addressed:

Normally, the members of local communities are more interested in the impacts of one variable over the other rather than in the evolution of one single variable (Nichols et al., 2004);

The perceptions refer often to aggregated variables (e.g. temperature and precipitation generically considered as "climatic conditions"), which could result in misleading perceptions of the cause-effect chains;

The perception of drought impacts could be influenced by external phenomena.

Starting from these premises, this work aims to collect and analyze the drought perception of local communities in Lake Trasimeno in order to:

verify the coherence between local and scientific knowledge;

assess the reliability of local knowledge to describe the drought's impacts at local level;

verify whether the stakeholders' drought perception is characterized by the weaknesses of local knowledge described above (i.e. not clear understanding of the cause-effect chains, the underestimation of external influences, and the aggregation of variables).

To this aim, the physical analysis of the phenomena and the analysis of the perception have been carried out contemporarily in the case study. The former aimed to assess the variation of the water resources availability due to the variation of the rainfall. The analysis of the drought perception aimed to identify the most important elements used by local communities to assess the severity of drought's impacts. The results of the two analysis are described in the following sections.

3 DROUGHT IMPACTS MONITORING IN THE LAKE TRASIMENO

The Trasimeno Lake covers a surface area of 128 km². The lake has unusual hydromorphological conditions, characterized by the absence of significant tributaries and emissaries. 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.

Figure 2 shows the hydrological balance of Lake Trasimeno according to the hypothesis developed by Dragoni and Evangelista (1999). Since then the consumptive use of the resource is being progressively stopped in order to protect the ecosystem.

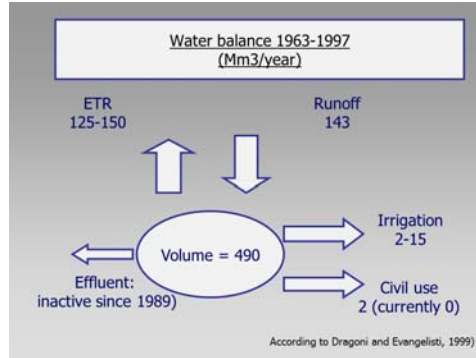


Figure 2. Hydrological balance of Lake Trasimeno according to Dragoni and Evangelista (1999).

3.1 Physical analysis of the drought phenomenon in the Lake Trasimeno

The available data of precipitation in the whole Tiber river basin (reference period: 1922-2007) have been analyzed at annual scale by means of a standardized index similar to SPI (McKee et al., 1993) assuming a gaussian distribution of data: $SPI_j^i = (P_j^i - \bar{P}_j) / \sigma_j$ where P_j^i is the value of the annual cumulated precipitation for the year i at the j station, $\bar{P}_j$ is the long-term mean annual cumulated precipitation at the j station and σ_j is the correspondent standard deviation. A similar index have been computed for the mean annual values of Tiber river discharge (reference period: 1922-2007). Rainfall gauge stations with at least 30 years of data (hydrologic year, September to August), although not consecutive, have been retained, totalling 88 stations. A precipitation index at basin scale was obtained by means of a weighted average, where

the weights are given by the areas of the Thiessen's polygons associated to each rainfall gauging station and normalized with respect to the total area. At the same time, discharge data at Ripetta site have been analysed. In order to verify the Gaussian hypothesis, the Lilliefors test [2] has been applied to each time series: most of the precipitation time series (approximately 84%) and all of the discharge time series follow a Gaussian distribution, justifying the adopted standardization procedure. In fig. 3 the 5-years moving average of the precipitation index P_{ann} has been compared to the flow annual index of the Tiber at Ripetta (SQI).

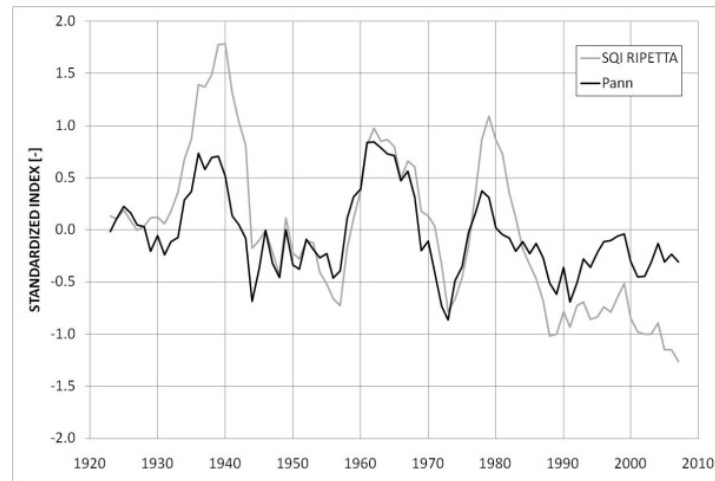


Figure 3 – 5-years moving average of the annual discharge index SQI at Ripetta station (Tiber) and of P_{ann}

The 5 years moving average enhance the existence of a cyclic behavior with relatively humid periods (whose peaks fall in 1924; 1938; 1961; 1978 and 1998) and dry periods (around 1931; 1944; 1956; 1973; 1991; 2002). The periods between each maximum results equal to 14, 23, 17 and 20 years respectively.

There is good correlation ($R^2 = 0.58$) between Tiber SQI and P_{ann} . The cyclic behavior of precipitation can be clearly seen also on the river discharge regimen. Moreover the index related to the number of rainy days (not shown here for sake of shortness) appear to be strongly related to the precipitation index at basin scale, while the mean intensity and maximum precipitation indices appear to be approximately stationary in the reference period.

For the analysis of the lake level, both annual data from Umbria Region (1912-2008) and data gathered at San Savino station (1968-2009) have been considered). The lake Trasimeno level standardized index, computed for the hydrologic year (September to August) has been compared to P_{ann} index (fig. 4). The 5-years moving average points out a clear decreasing of the level lake index from 1980 onward. The relation between P_{ann} and the lake level is not always clear: i.e. in the period 1980-1988 the lake level is approximately constant even if the precipitation decreases: it is likely that other variables than precipitation affect the lake level (the effluent functioning, the widening of the basin, the consumptive use of the resource, ...).

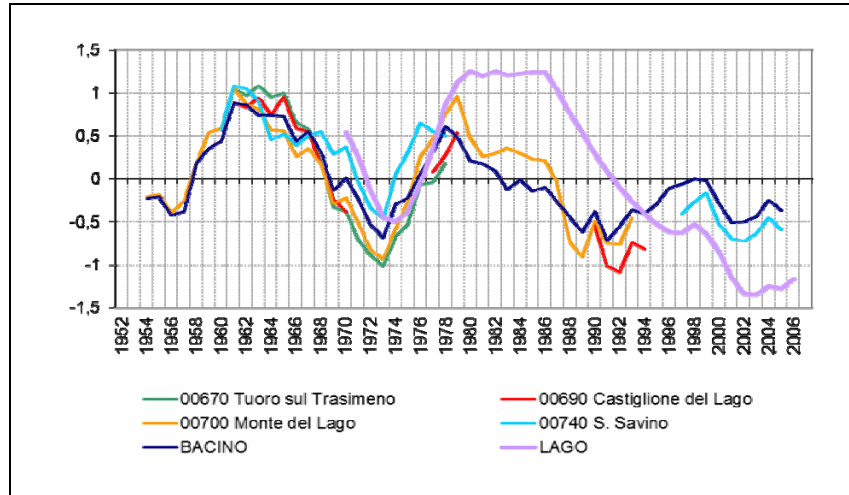


Figure 4 – 5-years moving average of Trasimeno lake level (LAGO), of P_{amm} (BACINO) and standardized precipitation at 4 sites in the Trasimeno area (1952-2007).

3.2 Analysis of drought perception

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.

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.

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 5 shows the CM developed using the interview to farmers association.

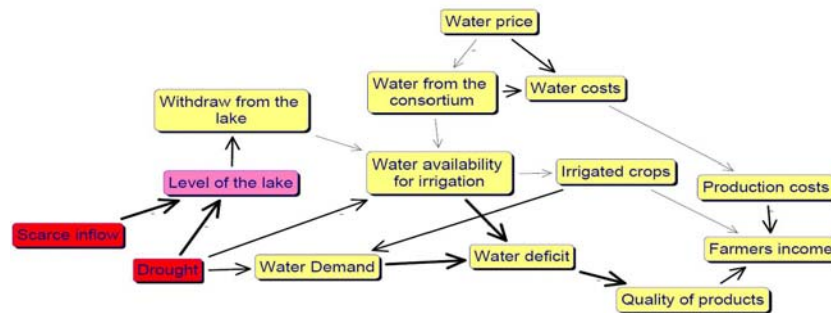


Figure 5: CM obtained analysing the results of farmers' association interview. The links are represented with different thickness according to strength of the relationships. The “-” is used for the negative links.

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 6 a and b).

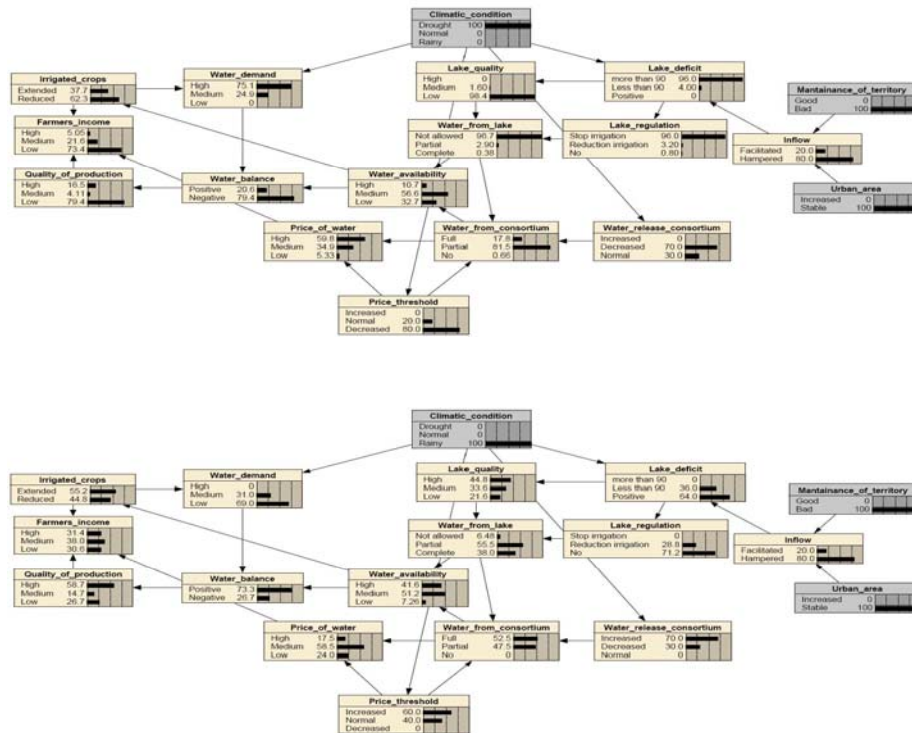


Figure 6a: Farmers' association BBN in rainy conditions. **Figure 6b:** Farmers' association BBN in drought conditions.

The fuzzy linguistic variable “Drought impact” was developed to describe the degree of change of the BBN variables due to drought initiation. The impacts can be either positive or negative. 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. The linguistic fuzzy sets to describe the drought impacts are “Strongly Negative”, “Moderately negative”, “Negative”, “Positive”, “Moderately positive”, “Strongly positive”. The degree of impact has been calculated for each variable in the stakeholders’ 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. At the end of this phase, the set of the most important elements in the stakeholders’ drought perception was developed. These elements were used as basis for the discussion with the involved stakeholders, aiming to validate the results of BBN analysis and to develop a set of drought indicators taking the stakeholders’ perceptions into account.

Table 1 shows the results of the debate and the list of the indicators for the most important elements of drought perception.

Table 1: drought indicators based on stakeholders' understanding.

Drought perception element	Indicator
Lake level	Level below the hydrometric 0
Farmers income	Per capita income Productivity/ha Quality of production
Ecosystem quality	Varioation of reed extension Quality of the reed Water transparency Water temperature
Tourism income	Yearly number of tourists Avarege stay duration
Fishing income	Fishing association income Quantity of fishing Presence of fish species vulnerable to stress conditions Quality of fishing

The data concerning some of these indicators were collected and compared with those concerning the physical analysis of the phenomenon. The results of the comparison are described in the following section.

4 COMPARISON BETWEEN DROUGHT PHYSICAL INDICATORS AND DROUGHT PERCEPTION INDICATORS

The data collected for both the physical and perception indicators allowed us to compare the trends of some of the most important indicators, to verify the reliability of stakeholders perceptions of drought and to verify whether an integrated drought indicator can be developed or not.

As stated previously, the reliability of drought perception is negatively impacted by the limited understanding of the complex cause-effects chains. Some phenomenon are often considered as the results of drought impacts, whereas other causes can originated them (Slegers, 2008). The comparison between physical and perception indicators allowed us to infer some conclusions.

For what concerns the touristic sectors, figure 7 shows the comparison between the number of tourists, and average stay duration and the level of lake.

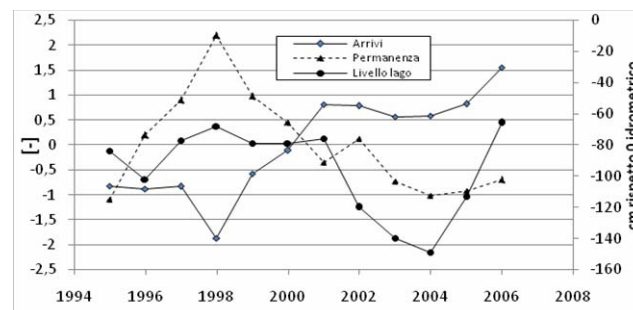


Figure 7. Comparison between the data concerning the touristic sector and the level of the lake

The comparison does not allow to infer that there is a strong correlation between the level of the lake and the data concerning the touristic sector. In the period 2003 – 2005, characterized by a strong reduction of the lake level due to a severe drought phenomenon, the graphs seem to have a similar trend. This means that in this period the decrease of the number of tourist can be associated with the severe drought.

Moreover, we should mention that the strong decrease of the tourists in the 1998 could be the result of the disastrous 1997 earthquake effects in the area rather than of the decrease of the lake level. Therefore, the stakeholders ignored the existence of other causes for the observed phenomena.

During the knowledge collection phase, the stakeholders highlighted the impacts of drought on the quality and quantity of fishing. In order to verify this causal connection, the data concerning different fish species, both autochthonous and allochthonous, were collected and analyzed and compared with the variation of lake level (figure 8).

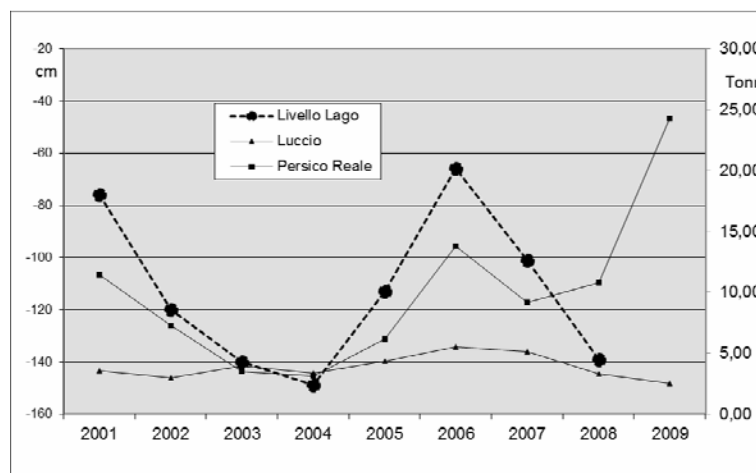


Figure 8. Comparison between the lake level and some fish species

The Pearson correlation index has been calculated for the different species and the lake level. In some cases, the correlation index is notably positive. This means that there is a positive correlation between the quantity of fish and the level of lake. This correlation does not exist for all the species.

Therefore, we can deduce that the stakeholders perception is distorted by the not complete understanding of the complex dynamics in the lake ecosystem. In other terms, the reduction of the population of some fish species could be due to other reason. Nevertheless, the stakeholders seemed to consider the lake level variation as the unique cause, and neglect e.g. the impact of the fishermen behaviours and of the fish market variation.

The stakeholders consider the reduction of agricultural productivity as one of the most important drought impacts. To verify this perception, the data concerning the productivity per hectar of local crops and the average farmers income were collected and compared with the data concerning the rainfall. The standardized precipitation index for the whole basin (SPI) has been used in this study (figure 9).

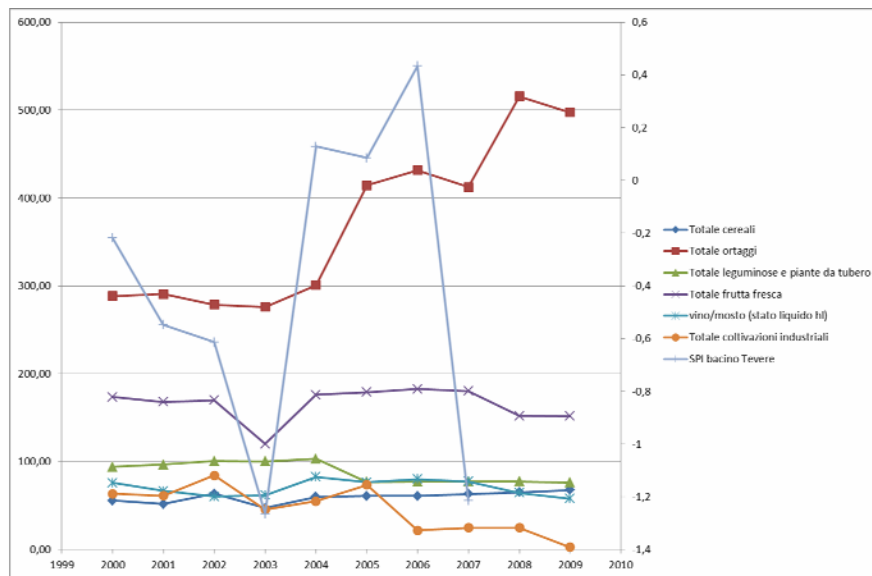


Figure 9. Comparison between the SPI and the productivity per ha of local crops.

The correlation index is notably positive only for some crops – i.e., grapevine and fruit – and is low or negative for the orchards. The low correlation can be explained by the implementation of an improved irrigation system, which is reducing the dependency of the agricultural sector from the level of the lake.

The impacts of drought on the crop productivity was stronger in 2003 than during the dry period in 2007. This is because of the decreased vulnerability to drought of the farming system. On one side, new irrigation infrastructure was developed in order to assure a more stable water supply, even in dry period. Moreover, the most intensively water demanding crops have been abandoned in the last years, mainly because of the market conditions and of the price of water for irrigation.

5 DISCUSSION AND CONCLUSIONS

The comparison between stakeholders' perception of drought impacts and scientific knowledge pointed out that the coherence between these two kinds of knowledge strongly depends on which impacts of drought are taken into account. As previously described, the correlation degree between perception indicators and scientific indicator is high when considering a direct impact of drought, e.g. the reduction of productivity for non-irrigated crops.

The correlation is relatively low for the touristic sector and for the fishing activities. This could be because of two main elements. On the one hand, the stakeholders tend to oversimplify the cause-effects chain and, consequently, to consider the drought as the cause of certain phenomena which, actually, are originated by other causes or by the interaction between drought and other phenomena. This is particularly true for the

impacts on fishing activities. The involved stakeholders had a limited understanding of the complexity of lake ecosystem dynamics and tended to consider any negative states as an impact of drought. Therefore, the hypothesis according to which the stakeholders perception is characterized by a vague understanding of the cause-effect chains seems to be confirmed in our study.

Moreover, the collected data shows that the stakeholders tend to aggregate the variables describing the drought impacts. E.g. the impacts of crop productivity dramatically change according to the considered crop. Whereas stakeholders perceived a general reduction of the productivity. This could lead to an erroneous definition of drought indicators. Therefore, an accurate validation of the stakeholders' perception of the cause-effect chains should be carried out before using the drought perception indicators to monitor the phenomena.

This work demonstrates also that there is an asynchrony between the stakeholders perception and the drought onset. In fact, stakeholders become aware of the drought only when they recognize the impacts on their perceived environment. Often those impacts are recognizable only when the drought is on its peak – e.g. the number of tourists decreases only when the level of the lake is significantly lower than the normal hydrometric zero.

According to the results of this work, we could conclude that the definition of an integrated indicator to monitor the evolution of the drought phenomena, obtained through the integration of local and scientific knowledge is not always possible, due to the different nature of the indicators. According to our experience, the drought perception indicators are rather suitable to identify some thresholds concerning drought severity which can support the decision makers in the definition of drought mitigation measures.

Acknowledgments. The research activities described in this work have been financially supported by the Italian Ministry of University and Research (MIUR), National Relevance Research Program 2007 (PRIN 2007) – Drought management and climatic variability (20075WFE7P).

REFERENCES

- Axelrod, R.(1976). *Structure of Decision - The Cognitive Maps of Political Elites*. Princeton University Press, Princeton, NJ, 1976.
- Bromley, J., N.A. Jackson. O.J. Clymer, A.M. Giacomello and F.V. Jensen (2005). The use of Hugin® to develop Bayesian networks as an aid to integrated water resources planning., *Environmnetal Modelling and Software*, 20, 231-242.
- Castelletti, A. and R. Soncini-Sessa (2007). Bayesian Networks and participatory modelling in water resources management, *Environmnetal Modelling and Software*, 22, 1075-1088.
- Checkland, P., *Soft System Methodology* (2001). In Rosenhead, J., Mingers J. (eds), *Rational Analysis for a Problematic World*. John Wiley and Sons, Chichester, UK.
- Dragoni, W., Evangelisti, C. (1999). Il problema del lago Trasimeno. *Spazio Ambiente*, 3, Perugia, pp. 14 – 17.
- Eden, C. (2004). Analyzing cognitive maps to help structure issues and problems, *European Journal of Operational Research*, 159, 673-686.
- Eden, C. and Ackermann F. (2001). SODA – The principles. In Rosenhead, J., Mingers J. (eds).

- Rational Analysis for a Problematic World*. John Wiley and Sons, Chichester, UK.
- Giordano, R., S. Liersch, M. Vurro and D. Hirsch (2010). Integrating local and technical knowledge to support soil salinity monitoring in the Amudarya river basin. *Journal of Environmental Management*, 91, 1718-1729.
- Lilliefors, H. (1967). On the Kolmogorov-Smirnov test for normality with mean and variance unknown. *Journal of the American Statistical Association* 1967; 62:399-402.
- Kolkman, M.J., M. Kok, and A. van der Veen (2005). Mental model mapping as a new tool to analyse the use of information in decision-making in integrated water management, *Physics and Chemistry of the Earth*, 30 (4-5), 317-332.
- Marchant, T. (1999). Cognitive maps and fuzzy implications, *European Journal of Operational Research*, 114, 626-637.
- McKee, T.B., Doesken, N.J. and Kleist K. (1993). The relationship of drought frequency and duration to time scale – In: *8th Conference on Applied Climatology*, Am. Meteor. Soc., Boston, 179-184.
- Moller, H., F. Berkes, P. O. Lyver, and M. Kislalioglu (2004). Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society* 9(3): 2. [online] URL: <http://www.ecologyandsociety.org/vol9/iss3/art2>
- Montibeller, G., F. Ackermann, V. Belton, and L. Ensslin (2001). Reasoning Maps for Decision Aid: A Method to Help Integrated Problem Structuring and Exploring of Decision Alternatives. *ORP3*, Paris, September 26-29.
- Nadkarni, S. and P.P. Shenoy (2004). A causal mapping approach to constructing Bayesian networks, *Decision Support System*, 38, 259-281.
- Nichols, T., Berkes, F., Jolly, D. and Snow, N.B. (2004). Climate change and sea ice: local observations from the Canadian Western Arctic. *Arctic* 57 (1), 68-79.
- Noemdoe, S., L. Jonker, and L.A. Swatuk (2006). Perceptions of water scarcity: The case of Genadendal and outstations. *Physics and Chemistry of the Earth*, 31, 771 – 778.
- Obeidi, A., K.W. Hipel and D.M. Kilgour (2005). The Role of Emotions in Envisioning Outcomes in Conflicts Analysis, *Group Decision and negotiation*, 14, 481-500.
- Ovuka, M., Lindqvist, S. (2000), Rainfall variability in Murang'a District, Kenya: meteorological data and farmers' perception. *Geografiska Annaler Series A Physical Geography*, 82A (1), 107-119.
- Raymond, C.M., I. Fazey, M.S. Reed, L.C. Stringer, G.M. Robinson and A.C. Evely (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management*, 1766-1777.
- Robertson, H. A. and T.H. McGee (2003). Applying local knowledge: the contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia. *Journal of Environmental Management*, 69, 275-287.
- Rosenhead, J., and J. Mingers (2001). A New Paradigm for Analysis. In Rosenhead, J., Mingers J. (eds), *Rational Analysis for a Problematic World*. John Wiley and Sons, Chichester, UK, 2001, pp. 1-19.
- Scholz, A., K. Bonzonb, R. Fujitab, N. Benjaminc, N. Woodlingd, P. Blackb and C. Steinback (2004). Participatory socioeconomic analysis: drawing on fishermen's knowledge for marine protected area planning in California. *Marine Policy* 28, 335-349.
- Slegers, M.F.W. (2008). "If only it would rain": Farmers' perceptions of rainfall and drought in semi-arid central Tanzania, *Journal of Arid Environments*, 72, 2106 – 2123.
- Wilhite D.A., Glantz M.H. (1987). Understanding the drought phenomenon: the role of definitions. In: Wilhite D.A., Easterling W.E., Wood, D.A. (Eds.) *Planning for Drought*, Westview Press, Boulder, CO, pp. 11-27.
- Zimmermann, H.J.(1991). Fuzzy Sets, Decision Making, and Expert Systems. Kluwer Academic Publisher, Dordrecht, 1987.