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INTEGRATING PROBLEM STRUCTURING METHODS AND AGENT-BASED MODELLING TO DEAL WITH AMBIGUITY: THE CASE OF THE GLINŠČICA RIVER

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Integrating Problem Structuring Methods and System Dynamic Model to deal with ambiguity: the case of the Glinščica river

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Abstract: Evidence demonstrate that the effectiveness of flood risk management measures depends on human decisions, actions and interactions. Action choices are not neutral, but commensurate with the perspectives and frames held by the actors making the decisions. The problem is that when these frames do not overlap or are incompatible, they potentially lead to a situation of conflict, hampering the effectiveness of risk management measures. In this work, we argue that making the decision actors aware of the existence of ambiguous problem framings and of the impacts of ambiguity on the measures' effectiveness is the key to deal with conflicts in risk management. To this aim, a multi-step methodology based on the integration between Problem Structuring Methods (PSM)and Ambiguity Analysis has been developed and experimentally tested in the Glinščica river basin (Slovenia). PSM, and specifically Fuzzy Cognitive Mapping (FCM) were used to elicit individual risk perception and to structure the decision model for each decision actor. Moreover, they were used to analyze the behavior of complex systems (environmental and social) in flood management. Specifically, the hybrid model allowed to capture both the dynamic evolution of the interactions among the actors during the different phases of the risk management process, to simulate different management scenarios accounting for the actors' reactions, and to improve the implementation of Nature Based Solution (NBS) to reduce the flood risk in the Ljubljana catchment.

***Keywords**:*Ambiguity analysis, Fuzzy Cognitive Maps, Flood Risk management, Nature-Based Solutions

1. Introduction

The increasing growth of flood damages in Europe (e.g. IPCC, 2013; Di Baldassarre et al., 2013; Domeneghetti et al., 2015) has raised the public and policy makers' awareness for the need to manage risks in order to mitigate their causes or consequences (e.g. de Moel et al., 2012; Alfieri et al., 2015).The EU Flood Directive 2007/60 (EU-FD) offers general guidelines to develop risk management strategies but it does not detail methods or approaches that can be applied to reduce flood risk (Albano et al., 2017).
According a literature review, Flood Risk Management practices claim the need of including social perception in risk analysis (Ho et al., 2008), since the reality perceived affects stakeholders' decisions making process and could lead to fail protecting themselves(Savadori, 2004; Bickerstaff, 2004; Flynn et al., 1999; Harclerode et al., 2016 ;Vandermoere, 2008; Weber et al., 2001).Stakeholders' perception and understanding of natural disasters is socially constructed and depends on interests, values, background, previous experiences and societal position among the actors (Boholm,

2003).These factors are constantly reinforced, modified, amplified or attenuated by interaction processes (Morgan et al., 2001).This difference between risk reality percived lead a situation of ambiguity (Brugnach and Ingram, 2012). Ambiguity refers to the degree of confusion that exists among actors in a group for attributing different meaning to a problem that is of concern to all (Weick 1995). Evidences demonstrate that making the decision actors aware of the existence of ambiguous problem framing is the key to enable creative and collaborative decision-making processes (e.g. Giordano, Brugnach, and Pluchinotta, 2017).
Indeed, enhancing the comprehension of interaction among different decision-makers is a relevant step in flood risk management for mitigating the conflicting interpretation of information due to differences in knowledge, values, belief, and assumptions (Wolbers and Boersma, 2013; Giordano et al., 2017), in order to involve different actors, institutions and community members (Hardy and Comfort, 2015; Seppanen et al.,2013) and to increase stakeholders' awareness about solutions promoting the long-term health of the associated ecosystems, societies and economies (Sayers et al., 2013).
In response to these challenges, the paper presents a multi-step methodology based on Fuzzy Cognitive Mapping (FCM), experimentally tested in the Glinščica river basin (Slovenia). Specifically, the results of the AA leading to a better comprehension of the problem formulation through FCM building. At first, individual FCMs have been used to detect and analyze the main differences between stakeholders' flood risk perception. In order to improve the accuracy of the ambiguity analysis and obtain a reliable representation of knowledge from several stakeholders, individual FCMs have been commuted in aggregated FCM. The aggregate FCM was, hence, used to simulate different risk management scenarios and to detect potential reasons capable of hampering green policy implementation. To this aim, individual FCM were used to evaluate potential trade-off among the different decision actors due to the implementation of NBS for flood risk management.

2. Methodology

The developed methodology consists in three main phases: i) Problem Structuring Method tools, specifically FCM building throught semi-structured interviews in order to elicit and structure available stakeholders' knowledge, investigating stakeholders' role, objectives, interdependencies, and network of interaction between individuals, groups and organizations who are affected by or can affect those parts of the phenomenon (STEP 1). The implementation of the PSM in this work aims at assessing to what extent divergences in problem framing could also lead to barriers hampering the adoption of risk management measures, and specifically Nature-Based Solutions (NBS).; ii) Risk Perception and AA of the stakeholders' decision making through the development of FCMs analysis (STEP 2); iii) aggregated FCM in order to simulate different scenarios, describing the system behavior and NBS implementation, accounting for the stakeholders' risk perception (STEP 3).

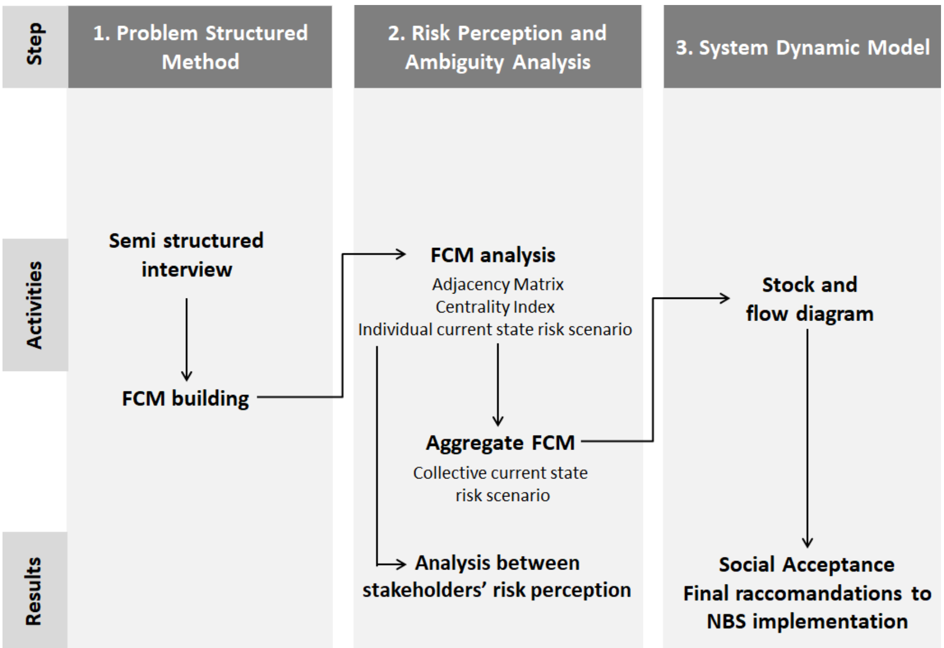

Figure 1- Methodology steps

The information deriving from semi-structured have been organized in the form of individual FCMs foreach group of stakeholders involved. In order to maximize the stakeholders' involvement a top-down stakeholder identification practice, which is referred as ”snowballing” or ”referral sampling”, has been implemented (Prell et al., 2008; Reed et al., 2009). The selection process started with the institutional actors. The preliminary interviews carried out with their allowed us to widen the set of stakeholders to be involved.
Thesecond phase aimed at analyzing ambiguity in risk perception and to assess to what extent ambiguity could represent a barrier to the actual implementation of risk management strategies, considered as collective action. According to Ozesmi and Ozesmi (2004), FCMs are useful for representing stakeholders' mental models. Graphically, a FCM is represented as an oriented graph with feedback, consisting of nodes (C_i) rapresenting the concept and weighted arcs(W_i) (figure 2) representing the causal relationships that between the concepts. (Papageorgiou, Kontogianni, 2012).
The developed FCMs were transformed into adjacency matrices$A_{ik}$where the variables were listed on the vertical and horizontal axis to form a symmetric matrix and allows to formally understand the influence of one variable on the others (Harary et al. 1965).
The connection of each individual concept is revealed through the centrality index (CI). (Ozesmi, 2004). It is represented through the nodes size and measures the cumulative strength of the connections (Papageorgiou and Kontogianni, 2012). The summation of indegree (in-arrows) and outdegree (out-arrows) values build the CI (Harary et al., 1965; Eden et al., 1992).

$$CI = od(v_i) + id(v_i)$$

Subsequently, for each group of stakeholder, an *Individual Current State Risk Scenario* have been developed. Scenario building present perceptions of context risk in which decisions and actions might be played out (Brightman et al., 1999), an individual or organisation lives or operates may develop, given certain future events, trends or developments (Goodier et al. 2010).
The individual FCM were, then, aggregated into *Aggregate FCM* (Kosko, 1986b, 1992a). Each adjacency matrix of individual FCM $A_{ik}$is augmented by including all distinct variables from all individual FCMs. Then all augmented matrices are added together to form a combined or collective FCM matrix W:

$$W = \sum_{i=1}^{N} W_i$$

Where W is the aggregated FCM, N is the number of augmented FCMs, andW_i is the augmented matrix FCM. The *Aggregate FCM* was implemented to simulate different management scenarios. As explained further in the text, the Aggregated FCM was used to assess the impacts of the risk management measures on the different decision actors' behavior. To this aim, the values of the most important variables in the individual FCM were calculated and compared with the desirable values. The higher the difference between these two values and the higher is the risk of conflict.

3. Ljubljana Case

3.1 Study area

The described multi-step methodology has been applied to the Ljubljana municipality case study (figure 3). The Glinščica catchment area (Slovenia) is situated within the borders of the municipality of Ljubljana that spans roughly 275 km^2 and has a population of 284,000 in habitants (SI-STAT). The site covers 7.01% of Ljubljana's surface area includes 5 of its districts (Dravlje, Šiška, Rožnik, Vič, Šentvid) and accounts for 8.17% of its population(23,200 in habitants). Originating at 409 m.a.s.l., the head waters in the steep hills lopes of Toško Čelo give the Glinščica stream a torrential character which, together with climate change (e.g. less frequent, but high intensity rainfall) and hard regulations, results in regular flood in the Vičand Rožnad districts of Ljubljana.In order to analysis the current knowledge and perceptions regarding flood risk and response actions, this study recruited participants from all levels of risk management in the Ljubljana municipality case study. Within the case of study, twelve groups of stakeholders have been identified: 1) Civil initiative for flood protection, 2) Slovenian water agency - sector for development and planning, 3) Ministry for agriculture, forestry and food of the Republic of Slovenia, 4) Municipality of Ljubljana, department for nature conservation, 5) Municipality of Ljubljana - department for civil protection and disaster relief, 6) Municipality of Ljubljana - department for spatial planning, 7)Ministry of environment and spatial planning- water and investments directorate, sector for natural disaster rehabilitation, 8)Ministry for environment and spatial planning - sector for nature protection, 9) Fishing Club Dolomiti, 10) Administration for civil protection and disaster relief, 11) Institute of the Republic of Slovenia for nature conservation, 12) Fisheries research institute of Slovenia.

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3.2 Problem Structuring Method

The semi structured interviews were supported by 17 questions on three main topics: i) stakeholders' previous flood experience; ii) stakeholders' knowledge regarding strategies used for dealing with hazard impacts; iii) stakeholders' awareness on the NBS use for reducing flood risk. For each class of stakeholder, the analysis of the interviews allowed to develop individual FCMs.

3.3 Risk Perception and Ambiguity Analysis

3.3.1 Fuzzy Cognitive Maps

In order to elicit stakeholders' risk perceptions on flood risk and NBS implementation, twelve FCMs have been built thanks to the information collected during semi-structured interviews. For exemplifying purposes, in this sub-section the methodology applied for developing the FCMs, is illustrated for only one group of stakeholders. Specifically, figure 2 shows the elicited concepts and connections strength related to flood risk as perceived by Slovenian water agency - sector for development and planning (DRSV). In DRSV's FCM 18 variable have been considered.

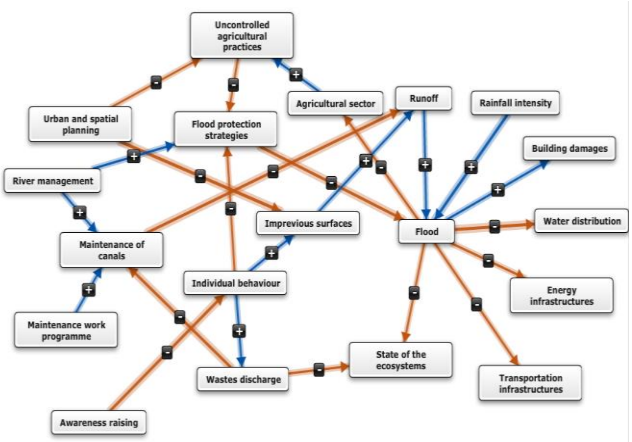

Figure 2 - FCM Risk variables perceived by DRSV

3.3.2 Adjacency Matrix and CI

In order to understand the different flood risk perceptions between stakeholders, the most important elements, clusterized into expected impacts and variables of vulnerabilities, have been detected by aggregating the FCM centrality degree, as shown in the table 1. The centrality degree measure has been implemented in order to identify the key elements in the stakeholders' problem understanding. These elements represent the most important vertices within a graph, accounting for the complexity of its network of connection have been built, according to the stakeholders' risk perception.

EXPECTED IMPACTS	**CI**
Decrease agricultural sector productivity	1,56
Increase building damages	0,81
Decrease transportation infrastructures effectiveness	0,72
Decrease energy infrastructures effectiveness	0,78
Decrease Water distribution efficiency	0,86
Decrease state of the ecosystem	1,56
VARIABLES OF VULNERABILITIES	**CI**
Decrease citizien awarness	1

Table 1- List of variable and corresponding CI

3.3.3 Individual current state risk scenario

The Individual Current State Risk Scenario has been developed using the DRSV's FCM. It represents the current state of percived flood risk and has been built considering the maximum value of the state vector "rainfall intensity"[+1], with all variables set to 0.

Figure 3 shows, the number of interactions between variables (ascites) are related with the value of FCM's variables (ordinates).

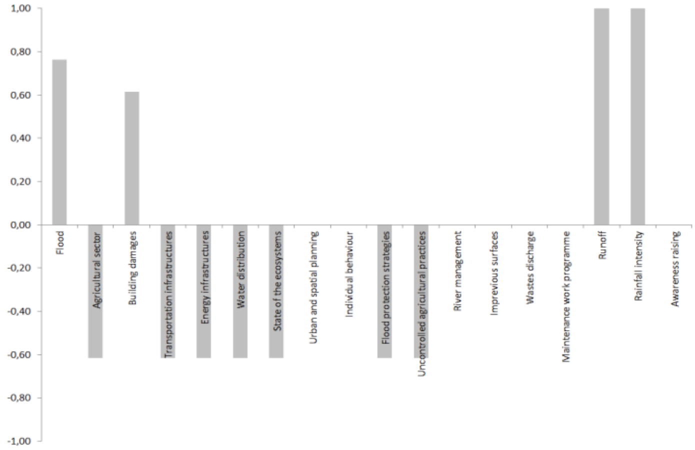

Figure 3 - DRSV's Current State Risk Scenario

Accounting for the cause-effect chains perceived by DRSV, fig. 5 shows the expected change in the state of the system variables in case of flood as the decreasing of on agricultural sector productivity, transport infrastructure efficiency, energy infrastructure, water distribution and on the state of the ecosystem. The aggregation between the centrality degree and individual FCM simulation were used to identify the key elements in the actors' risk perception and to analyze differences and similarities. Some examples in the following table:

Decision actor	Variable	Centrality degree	Impacts degree	Importance
Civil initiative for flood protection of SW part of Ljubljana	Lack of funding	Medium	Weakly negative	Medium
	Infrastructure effectiveness	Medium	Negative	High
	Urbanization of flood plain	Medium	Weakly positive	Medium
	People awareness	Low	Weakly positive	Low
	Building damages	High	Highly negative	High
	Economic losses	Medium	Negative	High
Slovenian water Agency Sector for development and planning	Lack of spatial planning	Medium	Weakly negative	Medium
	People awareness	High	Negative	High
	Agricultural productivity	Medium	Weakly negative	Medium
	Building damages	Low	Negative	Medium
	State of the ecosystem	Medium	Negative	High
	Social vulnerability	Low	Weakly negative	Low
	Water distribution	Low	Weakly negative	Low

Table 2 - Variables' analysis

3.3.4 Collective FCM building

Figure 4 shows a graphical representation of the collective FCM obtained from the aggregation of the 12 stakeholders groups' FCMs. The *Aggregate Matrix* is composed by 41 variables and 94 connections.

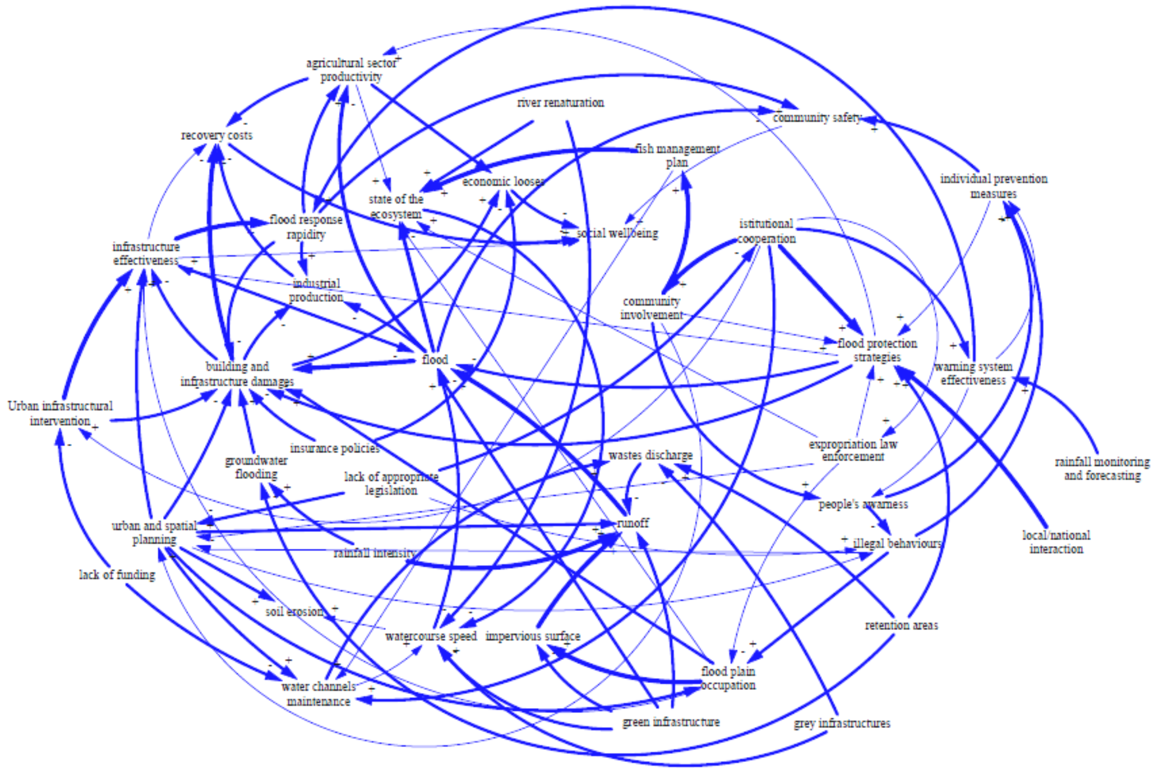

Figure 4 -Collective FCM derived from the aggregate adjacency matrix

Similarly to the individual FCM, a *Collective Current State Risk Scenario* has been built increasing the value of the 'rainfall intensity' variable (figure 5).

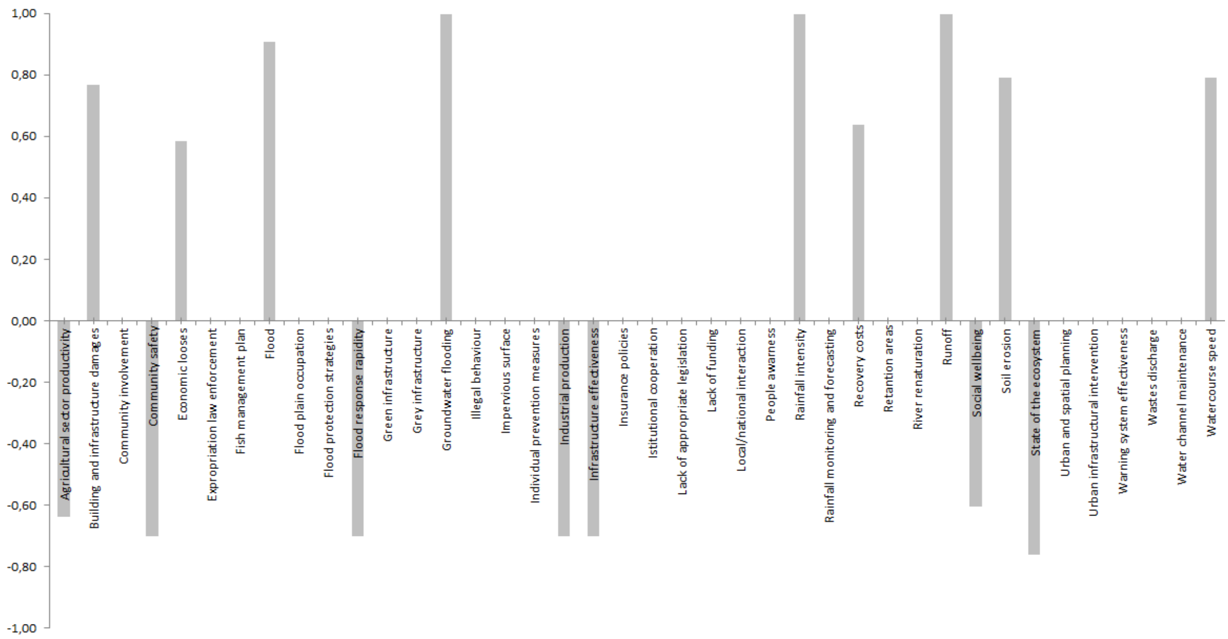

Figure 5 - Collective Current State Risk Scenario derived from the aggregate adjacency matrix

The *Collective Current State Risk Scenario*, describes the current state in the case of rainfall intensity. The impacts deriving from the flood risk can be subdivided into three categories: i) economic losses, represented by the decrease in agricultural and industrial productivity with consequent recovery costs for the restoration of the activities; ii) physical damage, related to soil erosion, buildings and infrastructures; iii) social damage, affecting the security of citizenship and the effectiveness of safety and prevention measures. These variables' categories are interconnected by the visible relationships in the collective FCM in figure 4. From stakeholders' risk perceptions, the management measures variables (table 3) have been used to build a *Collective Management Scenario* (Figure 6), i.e. considering the maximum value of the state vector "rainfall intensity" [+1], with management measures variables set to 1.

EXPECTED IMPACT IN CASE OF FLOOD RISK	CI	MANAGEMENT MEASURES TO REDUCE IMPACTS DERIVED FROM STAKEHOLDERS' PERCEPTION
Decrease industrial sector productivity	7,40	Increase flood protection measures
Decrease community safety	4,00	Increase citizen awareness
		Increase individual and collective preventive measures
Decrease state of the ecosystem	3,40	Increase river renaturation
Increase building and infrastructural damages	2,30	Increase individual and collective preventive measures
Decrease agricultural sector productivity	1,90	Increase flood protection measures

Table 3 – Expected impact: Management measures derived from the aggregate adjacency matrix

Figure 6- Collective Management Scenario derived from the aggregate adjacency matrix

The aggregated FCM was used to simulate different management scenarios and to assess the impacts of the risk management measures on the individuals' risk perception. For instance, the *DRSV's Management Scenario* (figure 7) evaluates the impact on the individual risk perception of the implementation of the management measures derived from the aggregated stakeholders' perception. Specifically, the implementation of risk management measures increases the productivity of the agricultural sector, the effectiveness of infrastructure, the state of ecosystem and the people's awareness about flood risk.

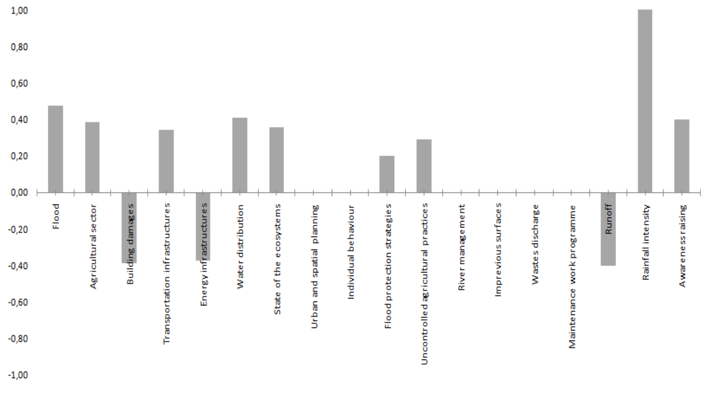

Figure 7- DRSV's Management Scenario derived from the aggregate adjacency matrix

4. Conclusion

The expectation that flood damages may escalate over time has increased the policy-makers' awareness for the need of changes in risk management strategies. Studying differences in stakeholders' risk perceptions could help environmental policy-makers and practitioners to enhance the effectiveness of relevant strategies in multi-stakeholders context where the presence of differences and ambiguity is unavoidable. Furthermore, this paper showed the potentialities of the Ambiguity Analysis for eliciting and structuring stakeholders' perceptions on flood risk within the Ljubljana (Slovenia) case study. In conclusion, the importance of this study lies in the fact that a deep understanding of stakeholders' knowledge and their risk perceptions is acritical concern for behavioral adjustment, risk communication, and efficient risk mitigation policies. These elements are aimed at creating resilient communities facilitating the generation, acquisition and diffusion of different types of knowledge and information and to promote an implementation of innovating tools as NBSs. Research efforts should be oriented toward future modelling activities that help to reduce the distance between risk perceptions.

5. References

Alfieri L., Burek P., Feyen L., Forzieri G., 2015, 'Global warming increases the frequency of river floods in Europe', Hydrology and Earth System Sciences 19, pp. 2247–2260;

Boholm Å., 2003. The cultural nature of risk: can there be an anthropology of uncertainty? Ethnos 68 (2) ,159–178;

Brightman J.R., Eden C., Van der Heijden K., Langford D.A., The development of the construction alternative futures explorer, Automation in Construction 8 (1999) 613–623

Brugnach M., Ingram H., 2012. Ambiguity: the challenge of knowing and deciding together. Environmental Science and Policy, 15(1), 60-71;

De Moel H., Asselman N.E.M., Aerts J.C.J.H., 2012. Uncertainty and sensitivity analysis of coastal flood damage estimates in the west of the Netherlands. Nat. Hazards Earth Syst. Sci. 12, 1045–1058;

Di Baldassarre, G., Kooy, M., Kemerink, J.S., Brandimarte, L., 2013. Towards under- standing the dynamic behaviour of floodplains as human–water systems. Hydrol. Earth Syst. Sci. 17, 3235–3244;

Domeneghetti A., Carisi F., Castellarin A., Brath A., 2015. Evolution of flood risk over large areas: quantitative assessment for the Po river. J. Hydrol. 527, 809–823;

Durance P., Godet M., 2010. Scenario building: Uses and abuses, Technological Forecasting & Social Change 77, 1488–1492.

EC: Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks, Official Journal of the European Communities, Brussels, available at:

Eden C; Ackermann F, & Cropper S (1992). The analysis of cause maps. Journal of Management Studies vol. 29, pp. 309–324;

Eden, C., Ackerman, F., Cropper, S., 1992. The analysis of cause maps. J. Manage. Stud. 29, 309–323.

Giordano R., Brugnach M., Pluchinotta I., 2017. Ambiguity in problem framing as a barrier to collective actions: some hints from groundwater protection policy in the Apulia Region, Group Decision and Negotiat., 26(5), 911-932;

Goodier C.I, Austin S.A., Soetanto R., Dainty A.R., Guthrie W., 2010. Looking to the future – scenarios for construction, book, in writing, Blackwells Publishing, UK;

Harary, F., Norman, R.Z., Cartwright, D., 1965. Structural Models: An Introduction to the Theory of Directed Graphs. John Wiley & Sons, New York;

Harclerode M. A. Lal P.,Vedwan N., Wolde B., Miller M. E., 2016. Evaluation of the role of risk perception in stakeholder engagement to prevent lead exposure in an urban setting, Journal of Environmental Management, 184, 132-142

Hardy, K., Comfort, L.K., 2015. Dynamic decision processes in complex, high-risk operations: the Yarnell Hill Fire, June 30, 2013. Saf. Sci. 71 (Part A), 39e47;

Ho, M.C., Shaw D., Lin S. Chiu Y.C., 2008. How Do Disaster Characteristics Influence Risk Perception? Risk Analysis, Vol. 28, No. 3

IPCC, 2013. Summary for policymakers. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, United Kingdom and New York, NY, USA;

Kosko, B., 1992. Neural Networks and Fuzzy Systems: A Dynamical Systems Approach to Machine Intelligence. Prentice-Hall. New York.

Kosko, B.,1986. Fuzzy cognitive maps. International Journal on Man-Machine Studies, vol. 24, pp.65-75.

Özesmi U., Özesmi S.L., 2004. Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach, Ecological Modelling 176, 43–64.

Pagano A., Pluchinotta I., Giordano R., 2017. Drinking water supply in resilient cities: notes from L'Aquila earthquake case study", Sustainable Cities and Society 28, 435–449

Papageorgiou, E., Kontogianni, A, 2012. Using fuzzy cognitive mapping in environmental decision making and management: a methodological primer and an application. INTECH Open Access Publisher;

Prell, C., Hubacek, K., Reed, M., 2009. Stakeholder analysis and social network analysis in natural resource management. Society Nat. Resour. 22 (6), 501e518.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manage. 90 (5), 1933e1949.

Savadori L., Savio S., Nicotra E., Rumiati R., Finucane M., Slovic P., 2004. Expert and public perception of risk from biotechnology. Risk Anal. 24, 1289–1299.

Sayers P., L.i Y., Galloway G., Penning-Rowsell E., Shen F., Wen K., Chen Y., Le Quesne T., 2013.Flood Risk Management: A Strategic Approach . Paris, UNESCO.

Simonovic, S. P. (2009). A new method for spatial and temporal analysis of risk in water resources management. Journal of Hydro Informatics, 11(3-4), 320–329.

Vandermoere, F., 2008. Hazard perception, risk perception, and the need for decontamination by residents exposed to soil pollution: the role of sustain- ability and the limits of expert knowledge. Risk Anal. 2, 387e398.

Weber, O., Scholz, R.W., Bühlmann, R., Grasmück, D., 2001. Risk perception of heavy metal soil contamination and attitudes toward decontamination strategies. RiskAnal. 5, 967e967.

Weick K, 1995. Sense-making in organizations. Sage, Thousand Oaks Wolbers, J., Boersma, K., 2013. The common operational picture as collective sensemaking. J. Contin. Crisis Manag. 21 (4), 186e199.

Wolbers, J., Boersma, K., 2013. The common operational picture as collective sensemaking. J. Contin. CrisisManag. 21 (4), 186e199. http://doi.org/10.1111/ 1468-5973.12027.