8-1-2014

Holistic Flood Risk Assessment In Coastal Areas - The PEARL Approach

Zoran Vojinović

Yared Abebe

Arlex Sanchez-Torres

Neiler Medina

Igor Nikolic

See next page for additional authors

Authors
Zoran Vojinović, Yared Abebe, Arlex Sanchez-Torres, Neiler Medina, Igor Nikolic, Natasa Manojlovic, Christos Makropoulos, and Mark Pelling

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

HOLISTIC FLOOD RISK ASSESSMENT IN COASTAL AREAS - THE PEARL APPROACH

ZORAN VOJINOVIC (1); YARED ABEBE (1); ARLEX SANCHEZ (1); NEILER MEDINA PENA (1); IGOR NIKOLIC (2); NATASA MANOJLOVIC (3); CHRISTOS MAKROPOULOS (4); MARK PELLING (5); MICHAEL ABBOTT (6)

(1): UNESCO-IHE, Institute for Water Education, Delft, Netherlands
(2): TU Delft, Netherlands
(3): TUHH Hamburg, Germany
(4): National Technical University of Athens, Greece
(5): King's College London, UK
(6): Knowledge Engineering BVBA, EIIL, Brussels, Belgium

Coastal floods are one of the most dangerous and harmful natural hazards affecting urban areas adjacent to shorelines. The present paper discusses the FP7-ENV-2013 EU funded PEARL (Preparing for Extreme And Rare events in coastaL regions) project which brings together world leading expertise in both the domain of hydro-engineering and risk reduction and management services to pool knowledge and practical experience in order to develop more sustainable risk management solutions for coastal communities focusing on present and projected extreme hydro-meteorological events. The PEARL approach draws upon the complexity theory and the use of complex adaptive system (CAS) models as tools to identify root causes of vulnerabilities and their multi-stressors and to analyze risk and the behavior of key actors.

INTRODUCTION

Record disasters such as earthquakes, hurricanes (or typhoons), tsunamis, widespread flooding and pollution, droughts, extremes of snowfalls and temperatures ─ all of which are associated with devastating losses and suffering ─ occur almost daily. Out of all natural disasters, floods in coastal regions are regarded as one of the most dangerous and harmful, see for example IPCC [1]. According to the International Disaster Database (EM-DAT) such floods have shown the fastest rate of increase relative to other types of disasters (see also CRED [2]). However, most of these events, although commonly referred to as natural disasters, are not in fact the results of nature-related processes alone. They are to an ever increasing extent directly attributable to various social, economic, historical, political and even cultural issues. Rapid urbanisation in coastal areas combined with climate change and poor governance can lead to a significant increase in the risk of local surface flooding (pluvial) coinciding with high water levels in rivers (fluvial) and high tide or storm surges from the sea (coastal) posing a greater risk of devastation in coastal communities, Djordjevic et al., [3]. Furthermore, the perception of flood impact on life and daily activities can be significantly different amongst the population and the level of knowledge and understanding of flood risk in a given area is directly related to people's decisions to either adjust their living to such a risk or simply to ignore it. The 2009 and 2011 UNISDR Global Assessment Reports on Disaster Risk Reduction, both strongly emphasise governance as a critical element in flood risk mitigation. In Europe, the Flood Directive [4] stresses the importance of assessing and mapping flood risk (Article 6). Some national initiatives e.g. the UK Pitt, 2008, argue for the need to identify flood risk in a broad, multidisciplinary and comprehensive manner. The EC Directive 2008/114/EC emphasises the need to improve protection of European critical infrastructures by gaining understanding of multiple interactions between their governance processes. These Directives together with corresponding international legislation recognise and explicitly require risk analysis to be utilised as a primary tool for management of natural hazards/floods, addressing the complexity of all aspects of the process to improve understanding of risk in order to develop best practices to minimise impacts on the public and environment. The above observations confirm that disasters that can be triggered by hydro-meteorological events (e.g. extreme winds, storm surges, coastal and estuarine floods) are interconnected and interrelated with both human activities and natural processes (Figure 1). They therefore require holistic approaches to help us understand their complexity in order to design and develop adaptive risk management approaches that minimise social and economic losses and environmental impacts and increase resilience to such events.

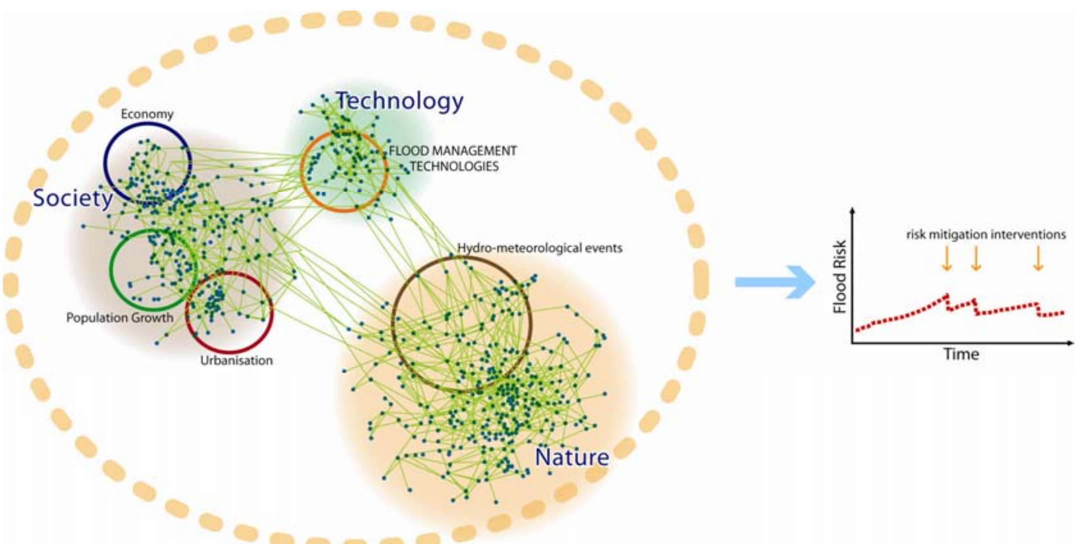

Figure 1: Formation and propagation of risk is a result from the coevolutionary nonlinear process between the ever changing social, technical and natural processes. Dots represent sub-processes and activities and lines represent their interactions (Source: Vojinovic [5]).

The present paper discusses the FP7-ENV-2013 EU funded PEARL (Preparing for Extreme And Rare events in coastaL regions) project which brings together world leading expertise in both the domain of hydro-engineering and risk reduction and management services to pool knowledge and practical experience in order to develop more sustainable risk management solutions for coastal communities focusing on present and projected extreme hydro-meteorological events. The PEARL approach draws upon the complexity theory and the use of complex adaptive system (CAS) models as tools to identify root causes of vulnerabilities and their multi-stressors and to analyze risk and the behavior of key actors. The PEARL framework also addresses risk and root cause assessment through enhanced FORIN methodology, event prediction, forecast and warning, identification of adaptive structural and non-structural strategies and development of cost-effective risk-reduction plans. The project combines 24 partners and it aims to demonstrate its methodologies, tools and techniques on several case study sites.

PEARL FRAMEWORK

The main goal of PEARL is to develop adaptive, sociotechnical risk management measures and strategies for coastal communities against extreme hydro-meteorological events minimising social, economic and environmental impacts and increasing the resilience of Coastal Regions in Europe. PEARL adopts a holistic risk management approach, based on the following three premises:

- First, risk management is a sociotechnical process, which cannot be studied by separating social and technical processes (i.e., parts) and designing them in isolation.
- Second, the relationships between the parts are mutual, emergent, dynamic and nonlinear and are guided by the self-organising capacities of each part and the (unpredictable) dynamics of their coevolution.
- Third, the process of strengthening any kind of flood risk mitigation measure (such as forecasting, prediction and early warning capabilities) should be understood and studied within the context of the larger flood management process which depends on interactions with other sub-processes at different levels.

At the flood management process level, we can identify a number of sub-processes, objects and actors which interact with each other. Figure 2 gives an example of a causal loop diagram depicting complexities and interdependencies/interactions within the flood management process and that the overall phenomena that emerges (i.e., the risk) is shaped by a myriad of sub-processes, objects and actors with none of them being in a position to control the whole process (i.e., the level of risk). This implies that the effective strengthening of forecasting, prediction and early warning capabilities must be approached from a much larger perspective. It is here that step changes in risk management will be gained. As seen in Figure 2 the main elements of flood risk management continuously interact between them creating nested loops of cause and effects. This realisation is crucial to the PEARL project. This perspective however may raise the following question: If everything is connected to everything else, how can we ever hope to understand anything? Our response draws from the understandings brought by complexity theory. Individual elements are "nested" within the interacting whole, they coevolve together – both in development and application. This recognition opens analysis beyond the direct objects or actors of concern (risk forecasting, early warning, land-use planning and technology for example), and into the relationships between them. Some have considered this in terms of the intensity of interactions between the most dominant processes and their associated actors. This builds on a fast growing literature on sociotechnical problems, (see for example, Callon [6]; Byrn [7]; Latour [8]; Boelens [9]; Boelens [10]; Vojinovic and Abbott [11]; Vojinovic [5]; van Dam [12]). It goes beyond the traditional integrated view which examines input-output to emphasise the importance of relationships, interactions and interdependences lying between different processes and actors (which may relate to nature, society and technology).

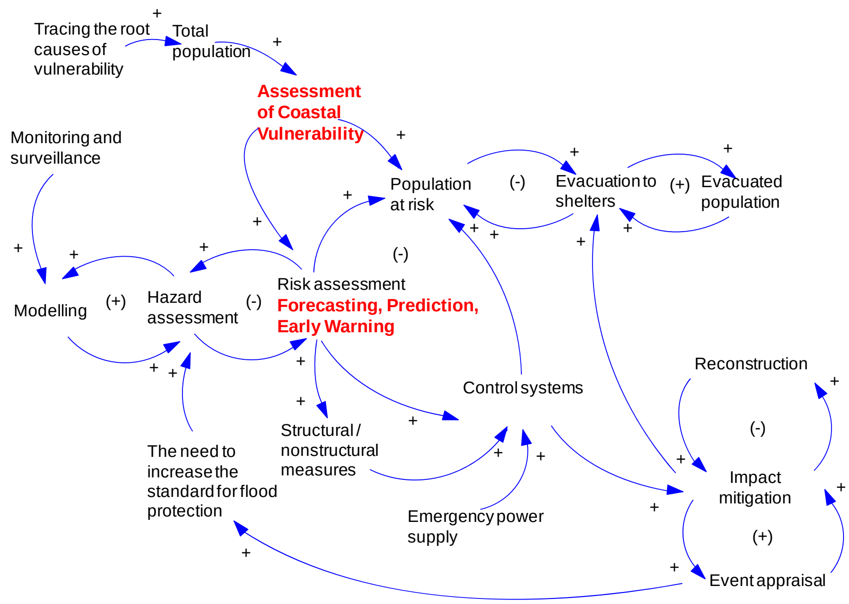

Figure 2: Illustration of the complexity of the coastal flood risk management process and interdependences of various sub-processes (or parts) within the larger process. The functioning of the flood risk management process depends on interactions (with positive and negative feedbacks) with other sub-processes from within and outside of its boundaries - which can be referred to as nesting (Source: Vojinovic [5]);

Work packages

To achieve its objectives, PEARL has been structured around eight work packages over a period of four years (2014 - 2018). Forming the basis of the work are seven European case studies covering different coastal regions and several International case studies. WP1 forms the project's starting point, and it aims to develop an understanding of formation of vulnerabilities and risk in coastal regions by applying the extended FORIN methodology as described in IRDR [13] and developing the vulnerability assessment framework. It will look into all possible root causes and their interdependencies and it will develop a framework for the holistic risk assessment work. Extreme events scenarios will be analysed and developed in WP2. WP3 will develop methods for the holistic risk assessment due to individual and coinciding (or multiple) hazardous events. WP4 will deal specifically with advancements in early warning systems, methodologies and tools. It will also address different sources of uncertainties and the ways of how to approach uncertainty analysis. WP5 will identify resilient strategies (i.e., protection, short- and-long term adaptation and mitigation strategies) and develop a knowledge base of existing and novel strategies and measures and the associated tools for their evaluation and assessment. It will then focus on decision support for policy development and work on science-policy interfacing with an emphasis on risk governance. All developments (including concepts, methodologies and tools) will be tested and demonstrated on case studies which is the focus of WP6. WP6 will also explore efficient ways concerning data storage and management. It will consider the existing EU initiatives and Directives for management of data infrastructure (e.g. 2007/2/EC- INSPIRE) as well as the experience and data infrastructure developed within previous projects, in particular the German national project KLIMZUG- Nord, where OGS standards complied data services and data management have been developed. WP7 will focus on dissemination and outreach, supporting an international knowledge and practice community, while fostering clustering activities with other projects. WP8 will deal with project management and coordination aspects, with direct input from a selected team of high profile international collaborators and advisors.

Case studies

PEARL draw***s*** on seven EU case study areas: Greve (DK), Liverpool (UK), Hamburg (DE), Charente-Maritime/Xynthia (FR), Liguria (IT), Marbella (ES) and Rethymno (GR). These have been carefully chosen to reflect a wide range of conditions as given in Table 1.

Table 1: Criteria for selection of PEARL case studies.

Criteria for selection	**Motivation**
Geographic spread across Europe	To derive a more generic outcomes
Major flood events occurred in the past (e.g. Xynthia, Liguria flash floods, dike breaches)	To emphasise the relevance of the research
The extent of the present and anticipated future socio economic impacts of extreme events	To cover a wide range of conditions
Data availability and previous experience of partners	To have a good understanding of case studies and to minimise data collection activities
Established networks with the local stakeholders	To improve the uptake of the project results and enable wide dissemination within the area
Different types of hazards (single and in combination) i.e. coastal, estuarine, pluvial, fluvial	To cover all relevant types of flooding including multi hazards

Through the international/associated partners, PEARL will also draw upon international experience of extreme events including, 2011 Thailand Floods - particularly in the area of Ayutthaya region, 2011 Great East Japan Tsunami, 2007 Cyclone Krosa and 2009 Cyclone Morakot, 2012 Hurricane Sandy, and some major Hurricanes from the Caribbean Island States (St Maarten, BVI and St Lucia) such as Leni, Lewis and Omar (Figure 3).

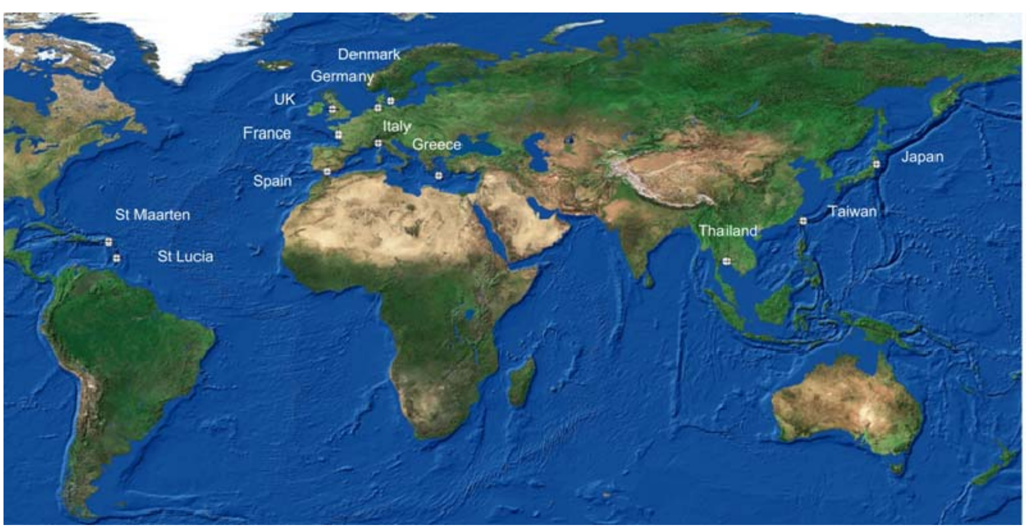

Figure 3: PEARL case studies;

HOLISTIC AND MULTIPLE RISK ASSESSMENT (Work Package 3)

The work package 3 (Holistic and Multiple Risk Assessment) aims to identify those interconnected processes in which the failure of a part (or a process) can trigger the failure of successive parts (i.e. risk cascading) and to address uncertainties that may propagate throughout this process. The latest knowledge from complex system theory and agent-based models developed by PEARL partners will be used to undertake this challenge (e.g. van Dam et. al [12] and Nikolic et. al. [14]). Work Package 3 also aims to address the causal chain of relations between perceptions, attitudes, decisions, risk and mitigation strategies through the extended FORIN approach and explore the use of agent-based models for strategic planning purposes. The focus of these models is on interacting agents and how their interaction can lead to emergent phenomena. Emergence is a phenomenon whereby the collective behaviour of agents arises from their localised, individual behaviour. Agent-based (AB) models are represented as systems of interacting agents embedded in a form of behavioural rules, Figure 4.

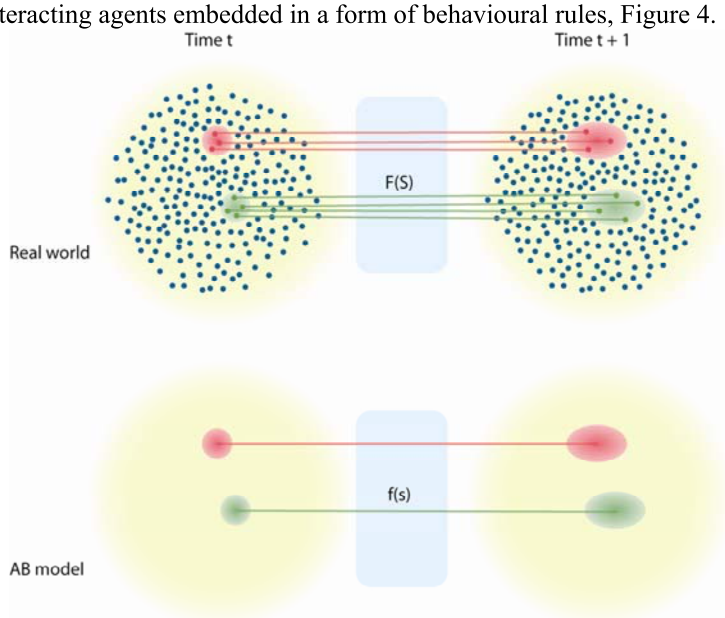

Figure 4: Modelling complex systems with AB models. The behaviour of actors at one point in time in the real world (Time t: upper panel) will lead to a new state at another point in time (Time t + 1: upper panel) through the unknown function F(S). This may be captured with an agent-based model (lower panel) through transition model function f(s) (Source: Vojinovic [5]).

The process under consideration, i.e., the macroscopic state $X(t)$, can be given by the set of microscopic states of the n agents: $X(t) = (xi(t))i=0,...,n$. The state transitions for all of the agents' internal states together yield the Dynamical System's transition function $X(t+1)=F(X(t),\phi(t))$. In other words, the transition function is a combination of all of the agents' rules $(R\ j\ )\ j=0,...,m$. Therefore $F=R\ i\ 1\ \circ R\ i\ 2\ \circ ...$ where the order $i\ 1\ ,i\ 2\ ,...$ is specified by the second argument $\phi(t)$. A random order $\phi(t)$ results in a stochastic ABM, and the corresponding mathematical formalism is that of a Markov Chain. In this case one refers to the probability of finding the system in a particular state $Pr[X(t)=x]$. This probability is built on the micro-states and the transition function F made up by the rules.

The above explained agent-based modelling framework has been developed and the preliminary results are being evaluated on one of PEARL's case studies (St Maarten).

Preliminary results

The preliminary work has been carried out using the data from St Maarten case study. The following Figures 5 and 6 depict some of the preliminary agent-based model results.

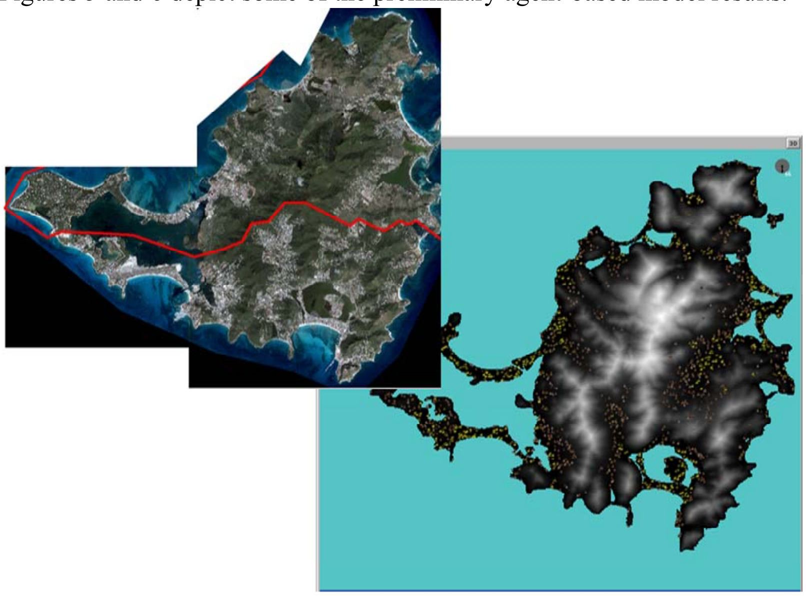

Figure 5: Modelling urban growth processes with agent-based models (the case of St Maarten). Arial image (left) and agent-based model result (right). The results obtained from an agent-based model shows good agreement with the aerial image (i.e., reality). The rules are based on local land use development policy, see also Vojinovic [5].

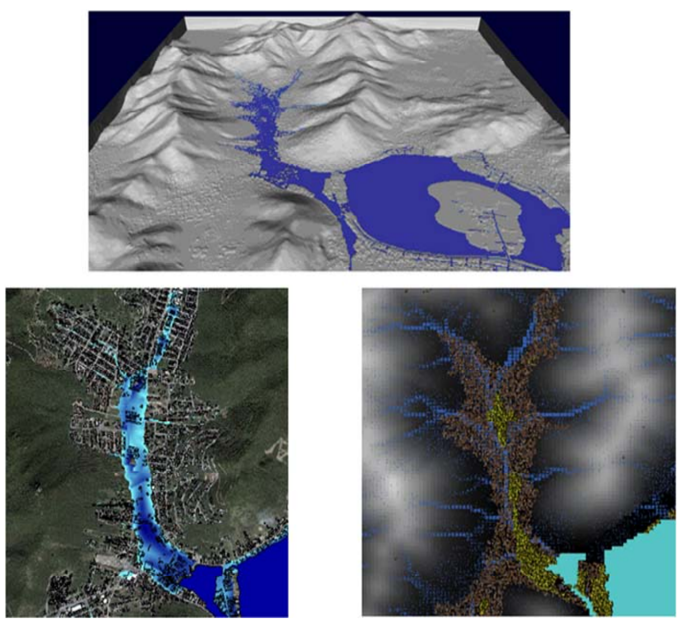

Figure 6: Modelling urban growth and flooding processes (the case of St Maarten). The hydrodynamic model results (up and left below) and agent-based model result (right below). The flood pattern obtained from an agent-based model shows good agreement with the hydrodynamic model results. In this simulation, apart from urban growth processes, the rainfall runoff process was represented as an agent, see also Vojinovic [5].

Further work

Our further work will expand into other aspects of flood risk and vulnerability assessment and it will demonstrate the usefulness of the agent-based approach on a variety of case studies.

Acknowledgments

The research work presented here has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under Grant agreement n° 603663 for the research project PEARL (Preparing for Extreme And Rare events in coastaL regions). The research and its conclusions reflect only the views of the authors and the European Union is not liable for any use that may be made of the information contained herein.

REFERENCES

[1] IPCC [Intergovernmental Panel on Climate Change] (2012): *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Eds.)]. Cambridge University Press.

[2] CRED (Center for Research in Epidemiology of Disasters), 2011, 2010 Disasters in Numbers. Available at: http://cred.be/sites/default/files/PressConference2010.pdf [Accessed 12 October 2013]

[3] Djordjević, S., Butler D., Gourbesville P., Mark, O. and Pasche E†., (2011), New Policies to Deal with Climate Change and Other Drivers Impacting on Resilience to Flooding in Urban Areas: the CORFU Approach, *Environmental Science & Policy*, 14(7): 864-873

[4] Flood Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks.

[5] Vojinovic Z (2013). *Flood Risk: The Holistic Perspective, From Integrated to Interactive Planning for Flood Resilience*, IWA Publishing.

[6] Callon, Michel. (1986). *The Sociology of an Actor-Network: The Case of the Electric Vehicle*, In Callon, Law & Rip (eds.) Mapping the Dynamics of Science and Technology: Sociology of Science in the real World. London: MacMillan Press.

[7] Byrne D. (1998). *Complexity theory and the social sciences: An introduction*, Routledge.

[8] Latour B. (2005). *Reassembling the Social*, New York: Oxford University Press.

[9] Boelens, L. (2009) *The Urban Connection: An actor relational approach to urban planning, Rotterdam*, O10 publishers (352 pages)

[10] Boelens, L. (2009) Theorizing practice and practicing theory: Outlines for an actorrelational approach in planning, *Planning Theory* 1109.

[11] Vojinovic Z and Abbott M (2012). *Flood Risk and Social Justice: From Quantitative to Qualitative Flood Risk Assessment and Mitigation*, IWA Publishing.

[12] Van Dam, K.H., Nikolic, I., and Lukszo, Z. (eds.). (2013) *Agent-Based Modelling of Socio-Technical Systems. Agent-Based Social Systems*, Springer, 2013.

[13] Integrated Research on Disaster Risk (IRDR), (2011), *Forensic Investigations of Disasters: The FORIN Project* (IRDR FORIN Publication No. 1). Beijing: Integrated Research on Disaster Risk

[14] Nikolic, I., C. B. Davis, E. J. L. Chappin, and G. P. J. Dijkema (2010), On the development of agent-based models for infrastructure evolution, *Journal of Critical Infrastructures*, vol. 6, no. 2, pp. 148 - 167.