The PEARL-toolbox: supporting the decision making process in selecting flood resilience strategies

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Abstract

Dilemmas of a what/if nature is a common challenge affecting decision makers that are responsible for managing socio-technical systems of increased complexity. In order for the scientific community to answer questions about the effects of decisions, it has to address issues of defining levels of acceptable risk and safety under uncertainty. And even when the scientific community has answers regarding the outcome of the decisions, transferring this knowledge is challenging requiring a lot of effort and resources in order to support the decision makers, in a simple and yet informative way. This research is focused on the work carried out for assisting decision makers involved in flood risk management. In this regard, a methodology supported by a toolbox was developed guiding the decision makers along the selection of suitable flood resilience strategies and measures. The toolbox includes a library of optimisation and multi-criteria decision analysis algorithms that identify optimal flood mitigation strategies, as well as an agent based model that allows the exploration of the response of the system, under different extreme flood event scenarios, socio-economic conditions and flood resilience strategies. In this work, the toolbox and its user friendly online interface are presented, developed to allow decision makers to use the proposed tools thus transferring actual scientific knowledge to the involved parties.

Keywords: decision support system, agent based modelling, flood resilience strategies, optimisation and MCDA algorithms, science-policy interface

1. Introduction

Decision makers that are responsible for managing systems of increased complexity are facing dilemmas of a what/if nature. For example, responsible authorities for flood management planning need to investigate different scenarios of flood events that have a high level of uncertainty in respect to the event's actual social, technical, economic and environmental impacts. In order for the scientific community to answer the decision maker's questions about the effects of their decisions, it requires to address challenging issues of what is safe and how risk is defined which include a significant level of uncertainty (von Winterfeldt, 2013). This paper presents research work included within the activities of the EU funded PEARL project (www.pearl-fp7.eu), to be completed by the end of 2017. The project aims to develop adaptive risk management strategies for coastal communities against extreme hydro-meteorological events. The main objective of this work is to support decision makers in selecting flood resilience strategies by providing them with a collection of methods and tools, implemented among others in the PEARL project's Rethymno case study. In this work, a web application named PEARL Toolbox (Figure 1) is presented which includes a combination of different methods and tools that were identified, proposed and even developed for the creation of an integrated methodology that will assist decision-making processes. Part of the PEARL Toolbox is a newly designed and developed Agent Based Model for the simulation of the decision-making process of authorities responsible for a city's flood protection and preparation. The PEARL Toolbox is complimentary to the PEARL Knowledge Base (www.kb-pear-fp7.eu), which has been developed and designed so as to assist to the selection of resilience strategies based on the specific characteristics and hazards affecting the case study areas (Karavokiros *et al.*, 2016). Furthermore, the PEARL project proposes involving the stakeholders in the process of identifying the most appropriate resilience strategies for a specific area, and thus promotes the establishment of Learning and Action Alliances for flood risk management (Gourgoura *et al.*, 2015, Makropoulos *et al.*, 2015). For identifying the most appropriate flood resilience measures and strategies, the PEARL Toolbox supports a methodology, which is divided in the following discrete stages:

1. Flood resilience measures: Use of the PEARL Knowledge Base to select a list of flood resilience measures that fit the flood risk problem and the specifics of the area.

2. Algorithms: Use of optimisation and multi-criteria decision analysis algorithms (see, Reed *et al.*, 2013; Maier *et al.*, 2014 for recent reviews) to define specific attributes of the selected resilience strategies (from the PEARL KB) that offer a minimised cost and a maximised protection from extreme events.

3. Agent based modelling: Use of a new agent based model to simulate the authorities' decision making process for the selection of resilient strategies and assess the performance

of the case study area under different socio-economic and flood events scenarios.

The main aim of the proposed methodology is to be able to transfer scientific knowledge to decision makers by exploring the response of the city to the flood management decisions under different flood event scenarios and socio-economic conditions. In the following paragraphs, the tools and methods proposed and included within the PEARL Toolbox, are presented.

2. PEARL Toolbox methodology

2.1. Selection of resilience measures and strategies

Based on the research activities of the PEARL project, the need for knowledge management and sharing, regarding flood resilience measures and strategies has been addressed by creating an interactive intelligent Knowledge Base (The PEARL KB) (Karavokiros *et al.*, 2016). Within this context, the PEARL KB of resilience strategies provides an environment that allows end-users to begin with their observed problem and be guided using an intuitive interactive interface, through a process of selecting the specifics of the problem and of the area, to select possible options and interventions (Karavokiros *et al.*, 2016).

Additionally, the PEARL KB includes real case studies for allowing the user to extract evidence-based conclusions on the applicability and usability of the flood resilience measures and strategies under consideration. As presented in Figure 2, the end user, that wishes to explore alternative options for flood resilience measures and strategies, follows four discrete steps. First, the type of flood problem that affects the area is selected, then the type of measure that the area needs the most, and finally the spatial scale and the land use that the measures should be implemented upon and protect accordingly. The Knowledge Base presents to the user a list with all those flood resilience measures that meet the selected criteria. Apart from the typical procedure of exploring the alternative flood related interventions which can be initiated from any part of the PEARL KB, users are also

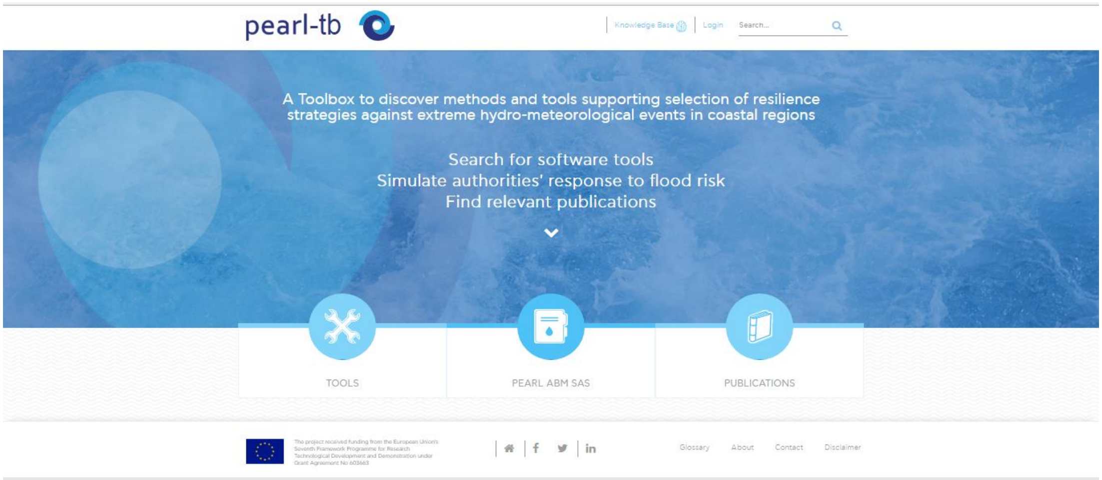

Figure 1. PEARL Toolbox online interface with access to algorithms (Tools) and agent based modelling (PEARL ABM SAS)

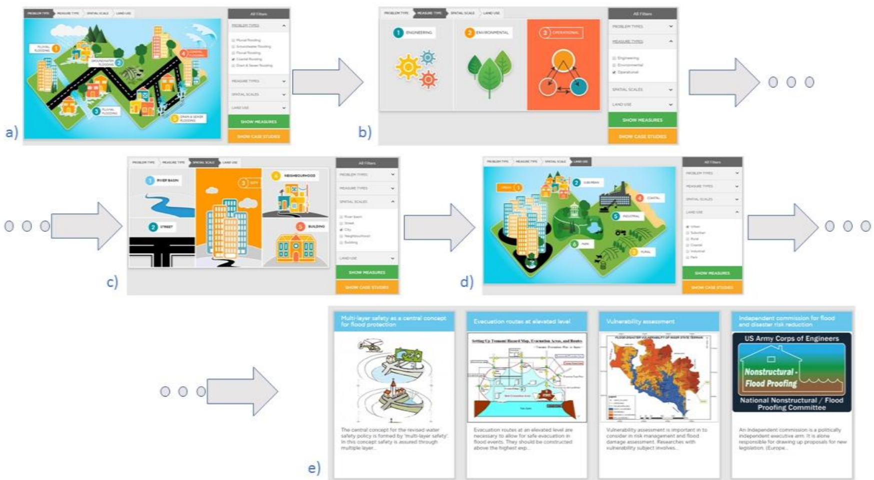

Figure 2. PEARL KB process and interface for selecting flood resilience measures and strategies based on selected criteria: a) selected flood problem, b) select type of measures c) select spatial scale, d) select land use and e) extract list of resilience measures and strategies that meet the defined criteria.

provided with enhanced searching capabilities such pivot tables, textual search, etc.

2.2. Algorithms for selecting attributes of resilience measures and strategies..

The next step for a decision maker in order to make an informed decision regarding the suitability and effectiveness of different flood resilience measures is to explore the response of the area to the selected measuresThe methodology underlying the PEARL Toolbox proposes to use optimisation and multi-criteria decision analysis algorithms The main advantage of employing such methods is their capability to identify optimal flood mitigation strategies and measures via the maximisation or minimisation of one or several criteria. The main disadvantage of these approaches, is that algorithms of optimisation and MCDA techniques require a large number of simulation model runs (i.e., computational time); which in some cases may pose a significant barrier to their application. Although, it is worth mentioning that a viable alternative that could provide a remedy for this issue is the use of surrogate based techniques (e.g., Razavi *et al*., 2012; Tsoukalas *et al*., 2016; Tsoukalas and Makropoulos, 2015) which can significantly reduce overall computational load. Under the PEARL project, a methodology was also developed to integrate flexibility and adaptation capacity including the links between landscape and ecosystem characteristics (Alves *et al*., 2016), into the selection process of strategies for the maximisation of multi-functionality (Alves *et al*., 2016). . The methodology assesses qualitatively, using among others, indicators to measure the capacity of ecosystems to provide services. The aim is to integrate local issues with the under investigation flood resilience strategies' multi-functionality in the urban space, in order to get the maximum advantage (Alves *et al*., 2016). In general, it can be argued that the incorporation of optimisation methods, either single or multi-objective, within flood risk studies can provide useful insights and information to the decision making process, thus contribute in the development of robust, resilient and future-proofed floodplain systems. The PEARL Toolbox (Figure 1) provides a collection of tools and methods related to optimisation algorithms. These were collected using a systematic way and are accessible through the online PEARL Toolbox. The collection process, used the following steps:

1. Identification of a limited number of "root" publications, i.e. the most influential publications in this field

2. Based on the "root" publications additional, "child" publications were examined, i.e. publications with reference to the "root" ones

3. A metric was introduced for the estimation of significance of the publications based on their age and the number of citations that they have received. Using this metric a number of publications have been selected for populating the PEARL Toolbox as source of optimisation algorithms

4. Metadata of the selected publications were imported into the PEARL Toolbox

The PEARL Toolbox web application documents all the algorithms, which were collected following the above process, and are divided in Optimisation and MCDA algorithms. It provides only a reference knowledge base for both tools and algorithms, providing information on their basic characteristics (author, title, year of publication, source type etc.). The end-user is able to access the PEARL Toolbox database to find methods and tools that meet certain criteria (open source or commercial, operating environment, etc.).

2.3. ABM for assessing the performance of the case study area under different socio-economic and flood events scenarios

The PEARL project recognises that dealing with risk is a socio-technical process. The relationships between the system's parts are mutual, emergent, dynamic, and non-linear and strengthening any kind of measure depends on the overall system's behaviour. Following this notion, Agent Based Modelling (ABM) was selected as an additional tool within the PEARL Toolbox. The main reason for this selection was ABM's ability to simulate the dynamic interaction between different components of a complex system i.e. the socio-economic and the water system components (Koutiva & Makropoulos, 2016, Filatova *et al*., 2013). The new ABM tool, called the PEARL ABM SAS (Koutiva *et al*., under review), simulates how authorities prepare against flood risk by implementing alternative intervention options under different socio-economic conditions and different flood event scenarios. The decision making agents, first explore the options and prioritise them based on their preferences, then try to cooperate with relevant stakeholders, and finally implement their decisions if funds are available. The model was designed and validated using work that has been already completed within the PEARL project, such as the Root Cause Analysis (RRCA) Framework (Mavrogenis, 2016), the creation of the Learning and Action Alliances (LAAs) (Gourgoura *et al*., 2015, Makropoulos *et al*., 2015), the stakeholders' workshops, and the household surveys conducted within the PEARL project. The end-users are able to use the PEARL ABM SAS using the online interface (Figure 3) accessible through the PEARL Toolbox (Figure 1). The user is able to setup the ABM through this web interface. The web interface supports the creation of input data and their storage in a database. Subsequently, the ABM simulates the decision making process and the response of the area. The results of the simulation process are saved in the database and also presented to the user, through the web interface using appropriate graphical elements (tables, charts etc.). The user needs to specify a scenario by identifying the setup parameters of the PEARL ABM SAS that best describe the specificities of the case the user wants to investigate. These setup parameters involve: a) the selection of the socio-economic conditions that are created by choosing the availability of funding for flood risk management, b) the expected magnitude of extreme rainfall and coastal flooding events within a ten year timeframe, c) the annual preparedness actions that strengthen a city against the seasonal flooding period d) the resilience measures that help to safeguard the city against floods, selected using the PEARL Knowledge Base and assessed using the proposed optimisation and MCDA algorithms and e) the decision making authorities' preferences regarding the importance of different characteristics of the flood resilience measures.

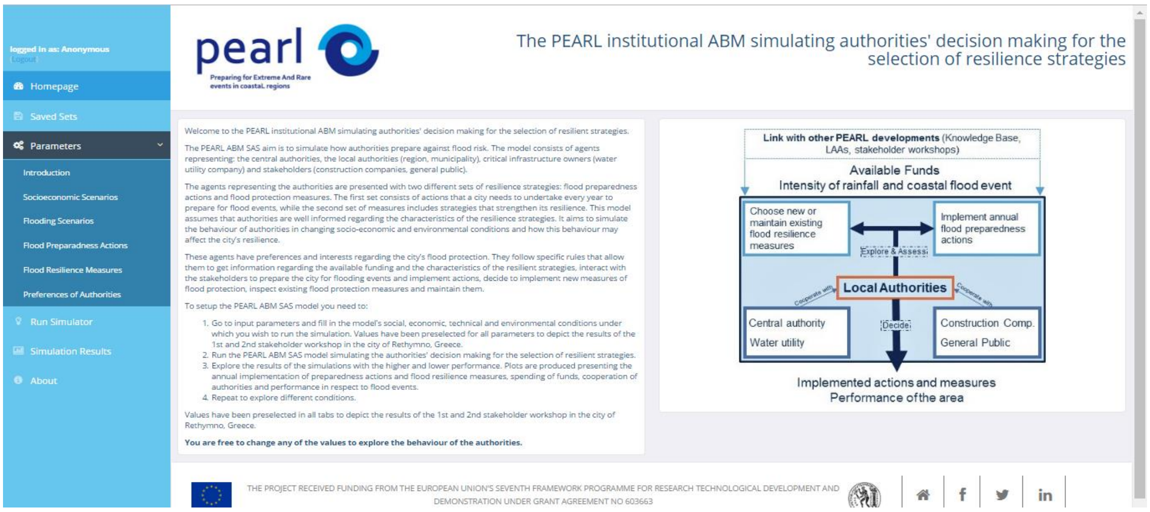

Figure 3. PEARL ABM SAS interface for input of setup parameters and visualisation of simulation's results.

After selecting the input parameters the user is able to save them for future reference. When ready, the user is able to run the PEARL ABM SAS model with the parameters set and the results are automatically presented when the simulation is over, by opening another tab of the interface. The same scenario is executed ten times in each run.. The results with the highest and lowest performance are presented in a direct comparison. They include an annual performance indicator of the area over the simulated ten year period. This indicator is a comparison between the qualitative severity of floods and the qualitative positive effects of implemented actions and measures and aims to transfer knowledge to the decision makers by exploring scenarios and not to assess the outcome, of actual flood risk management decisions, which is the subject matter of flood risk modelling.

3. Conclusions

The main aim of the PEARL Toolbox is to support the decision makers in exploring the response of the city to the flood management decisions under different flood event scenarios and socio-economic conditions. The developed web application PEARL Toolbox allows the end-users to search for software tools supporting the selection of resilience strategies and publications that describe software tools and document their effectiveness. Additionally, the PEARL Toolbox allows the end-users to discover how Agent Based Models (ABM) can simulate resilience processes. They are also encouraged to actually use the newly developed agent based model (the PEARL ABM SAS) which simulates how authorities prepare themselves against flood risk and aims to support the exploration of alternative intervention options under different socio-economic conditions and different flood event scenarios. The PEARL Toolbox, combined with the PEARL Knowledge Base, provide methodological framework that authorities, responsible for the flood risk management of a city, may follow to select appropriate flood resilience measures and strategies by exploring the response of the integrated social, technological and environmental water system.

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