IMPROVING RESILIENCE AGAINST EXTREME AND RARE EVENTS IN COASTAL REGIONS: AN INITIAL METHODOLOGICAL PROPOSAL - THE CASE STUDY OF THE CITY OF RETHYMNO

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Abstract

Coastal floods are regarded as among the most dangerous and harmful of all natural disasters affecting urban areas adjacent to the shorelines. Rapid urbanization combined with climate change and poor governance often result in significant increases in flood risk, especially for coastal communities. Significant efforts are currently focusing on forecasting, prediction and early warning capabilities using state of art science and technology to help policy makers and emergency services develop robust risk reduction strategies. However, forecasting and prediction is only part of the answer. Of equal importance is the ability to develop broader management strategies, supported by appropriate institutional and organizational arrangements. Preparing for effective response to extreme events not only involves technology but also significant social, economic, organizational and political considerations. This lack of integration between social aspects and technical measures, within a robust sociotechnical representation and understanding of risk and its evolution is provided by PEARL– an EU funded project – to be completed by 2017, which is developing adaptive risk management strategies for coastal communities focusing on extreme hydro-meteorological events, using a multidisciplinary approach, integrating social, environmental and technical research and innovation. In the present paper the general methodology of the program is briefly presented and the suggested approach concerning the coastal area of Rethymno is discussed.

Keywords: Climate change, coastal flood, coastal vulnerability, extreme events, rare events

1. Introduction

Coastal floods are regarded as of the most dangerous and harmful of all natural disasters [1] affecting urban areas adjacent to the shorelines, which are associated with large and growing concentrations of human population, settlements and socio-economic activities. It is expected that, due to climate change, coastal communities around the world will be increasingly affected by floods. In fact, some are already considered vulnerable to ongoing climatic variability [2]. According to the International Disaster Database (EM-DAT) such floods have shown the fastest rate of increase relative to other types of disasters (see for example CRED 2004 and CRED 2011). Rapid urbanization combined with climate change and poor governance can only increase 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). That in turn can lead to greater devastation of coastal communities. The 2009 ISDR Global Assessment Report on Disaster Risk Reduction and the 2011 report, of the same title [5;6], both strongly emphasize governance as a critical element. In Europe, the Floods Directive (2007/60/EC) stresses [7] the importance of assessing and mapping flood risk and some national initiatives (e.g., [8]) argue for the need to identify flood risk in a broad, multidisciplinary and comprehensive manner. The EU Directive 2008/114/EC emphasizes the need to improve protection of European critical infrastructures. These directives, and other equivalent international legislation, recognize and explicitly require risk analysis to be utilized as a primary tool for infrastructure management, addressing all aspects of the process to improve understanding of risk in order to implement more effective operation and maintenance, and develop best practices to minimize impacts on the public and the environment. Climate change is expected to cause accelerated sea-level rise with elevated tidal inundation, increased flood frequency, accelerated erosion, rising water tables, increased saltwater intrusion, increasing storm surges and increasing frequency of cyclones [9].

Thus there is a need to improve forecasting, prediction and early warning capabilities (especially over a wide range of spatial scales) using state of art science and technology to help policy makers and emergency services to develop robust risk reduction strategies. In this context, forecasting and prediction is only part of the answer. Of equal importance is the ability to effectively warn the populations of the areas that will be affected. All warning systems feature multiple lines of communications (such as SMS, e-mail, fax, radio, texting and telex, often using hardened dedicated systems) enabling emergency messages to be sent to the emergency and rescue services, as well as to population-alerting systems (e.g. mass alerting systems through SMS, IVR and sirens). For such systems to be effective, it is essential that they are integrated into much wider policies and norms and supported by appropriate institutional and organizational arrangements [10].

Therefore, preparing for effective response to extreme events is not only a technological act but also, very much, a social, economic, organizational and political one (see for example, White et. al., 2001[11]; IRDR, 2009 [5]; Pelling 2010 [12]; Vojinovic and Abbott, 2012 [13]). However, in current practice, the predominance of almost exclusively technocratic and piecemeal approaches has led to the development of less effective and less efficient means of responding to floods and flood-related disasters. There is a clear evidence of a lack of interaction between social aspects and technical measures and this appears to be a major hindrance for solving some of the greatest problems associated with floods and flood-related disasters. This was especially highlighted in the Chengdu Declaration for Action of the UN International Strategy for Disaster Reduction, where local capacity building, national-local cooperation and awareness feature prominently in the policy agenda. It has also been recognized by other (non-EU) projects such as CCaR.

2. Objectives of the research and Work Plan

The ongoing research aims to link risk and root cause assessment through enhanced FORIN methodology, event prediction, forecast and warning, development of adaptive structural and non-structural strategies and active stakeholder participation.

More specifically the aims of the whole project are:

- to design and develop adaptive risk management approaches that minimize social and economic losses and environmental impacts and increase resilience to extreme hydro-meteorological events in coastal regions in Europe
- to improve the forecasting, prediction and early warning capabilities for extreme hydro-meteorological events by embedding the technologies, methods and concepts above, into the social, technical, institutional, organisational and economic realities faced by coastal communities
- to develop a comprehensive risk reduction framework that can identify all possible cases of risk and develop strategies that can cost-effectively reduce vulnerabilities of coastal communities
- to strength the risk governance and the role of various actors involved in early warning response plans (such as governing authorities, municipalities, townships, and local communities).
- to build a pan-European knowledge base gathering real case studies and demonstrations of best practice across the EU

The PEARL consortium is a multi-disciplinary partnership with expertise in technical, economic and social areas dedicated to knowledge development and transfer. The partners include knowledge producers, climate modelers, socio-economists, technology development institutions and high-tech SMEs, disaster risk experts, science-policy experts, risk insurers, global collaboration and standardization institutions, key providers of coastal protection measures end-users and stakeholders through the 7 EU cases studies. To achieve its objectives, PEARL has been structured around 8 work packages, including 7 European case studies covering different coastal regions and several international case studies (i.e., extreme hydro-meteorological events case studies and also Tsunami case studies and amongst others they will include the case study or lessons learned from Great East Japan Tsunami).

In summary, WP1 is an important project's starting point, and will aim to develop an understanding of formation of vulnerabilities and risk in coastal regions by applying the extended FORIN methodology as described in [5] and [6] and developing the vulnerability assessment framework. As such, it will look into all possible root causes and their interdependencies and it will develop a framework for the integrated risk assessment work. Extreme events scenarios will be analyzed and developed in WP2. WP3 will aim at developing methods for assessment of impacts and vulnerabilities due to individual and coinciding hazardous events. WP4 will deal specifically with advancements of 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 it will 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 the developed concepts, methodologies and tools will be tested and demonstrated in the case study work in WP6. WP6 will also explore the efficient 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 the data infrastructure developed with previous projects. WP7 will focus on dissemination and outreach, supporting an international knowledge and practice community, while fostering clustering activities with other projects and interfacing with relevant tsunami work. WP8 will undertake project management and coordination, with direct input from a selected team of high profile international collaborators and advisors.

3. The Rethymno Case Study

The PEARL project will examine 7 case studies from across the EU among of them is Rethymno in Crete, to develop a holistic risk reduction framework that can indentify multi-stressor risk assessment, risk cascading processes and strengthen risk governance by enabling an active role for key actors. This area of study (see Figure 1:) is sited at the Prefecture of Rethymno, which is one of the four Prefectures of Crete in Greece. Rethymno city's population stands at 32,468 inhabitants (Census 2011) which characterize it as the 3rd most populous urban area in Crete. Rethymno city is the center of commercial, administrative and cultural activities of the homonymous Regional Unit where most of the human activities are been developed along the coastline of the harbour area. The area includes the Port of Rethymno, and the adjacent coastal area (a total area of about 4 km^2). The Port is located in the Northern end of Crete, within the homonymous bay.

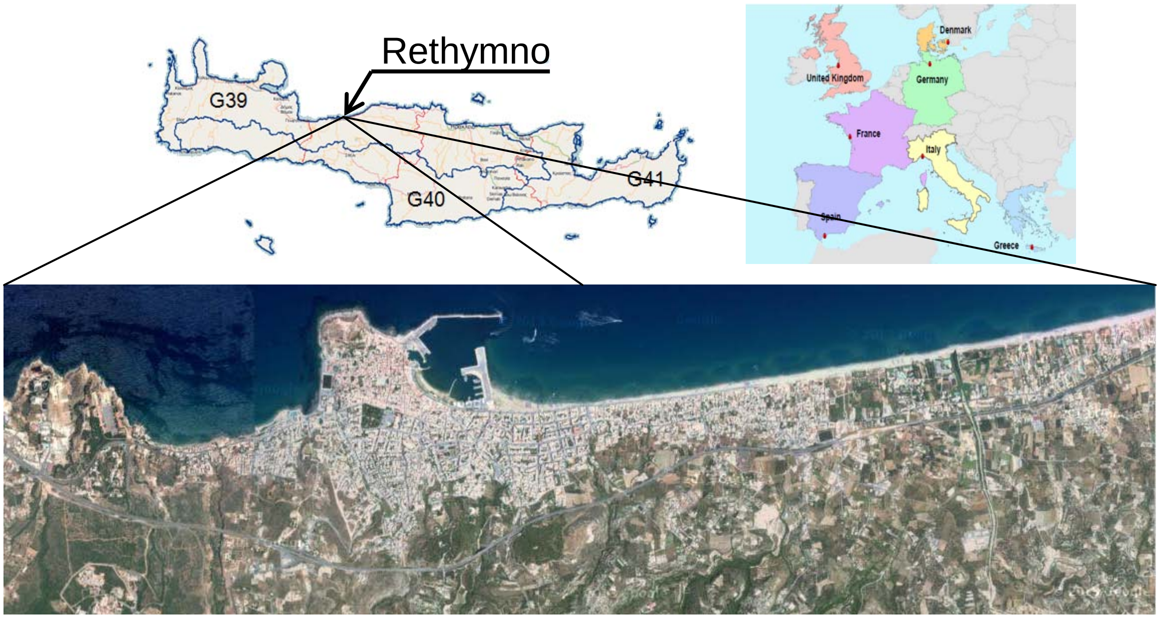

Figure 1: Rethymno, Crete

Figure 2: River basins and geomorphology of Rethymno

Flooding has always been a serious problem for Rethymno causing an ongoing threat to its residents, homes, business and public infrastructure. Rethymno is located in the drainage basin of the north part of Vrysinas mountain making stormwater flow through the urban area inevitable (Figure 2). Therefore, major flood events have been encountered throughout the years, resulting in serious damages mainly in the Old Town of Rethymno and the east low-lying areas (Figure 3).

In addition, the coastal zone of Rethymno is exposed throughout the year to strong N and NW winds (7-8Bf) with great fetches, resulting in the development of great waves. Changes in wind conditions – probably due to climate change - had resulted in causing storm events more frequently than in the past. More specifically extreme weather conditions with strong winds resulted in the creation of storm waves combined sometimes with flush floods form ephemeral streams. As a result – of the extreme waves- violent wave overtopping as it seems in Figure 4 occurring along the windward breakwaters of the harbour and threats the stability of breakwaters as well as the safety of human population. Wave overtopping also results in flooding of the harbour's surface area. Further huge quantities of seawater (see Figure 4) penetrate from the west (Parking area), which overflow the harbour's surface area as well as the wider coastal area causing interruption in loading and unloading operations, damage to the port facilities and the cargo, traffic problems and damage to coastal shops and restaurants. Additionally, the adjacent to the harbour recreational beaches are exposed to erosion spoiling the coastal site and affecting the tourism's contribution to local economy.

The simultaneous occurrence of extreme hydro-meteorological events poses real threat to Rethymno's community and emphasizes the need for specific actionable roadmaps that will enhance the existing infrastructure and operational strategies against the danger of flood by helping stakeholders to identify areas that are sensitive to floods and also to define efficient flood management strategies, engineering, environmental and socio-economic measures for Rethymno case study.

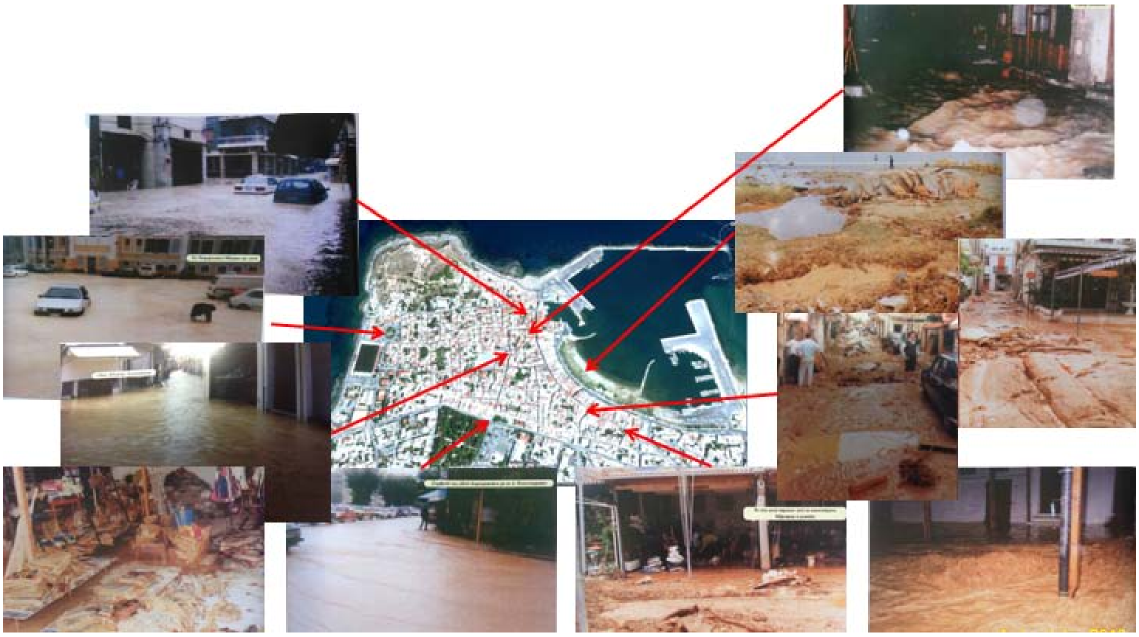

Figure 3: Historic floods in Rethymno (1969- 1991)

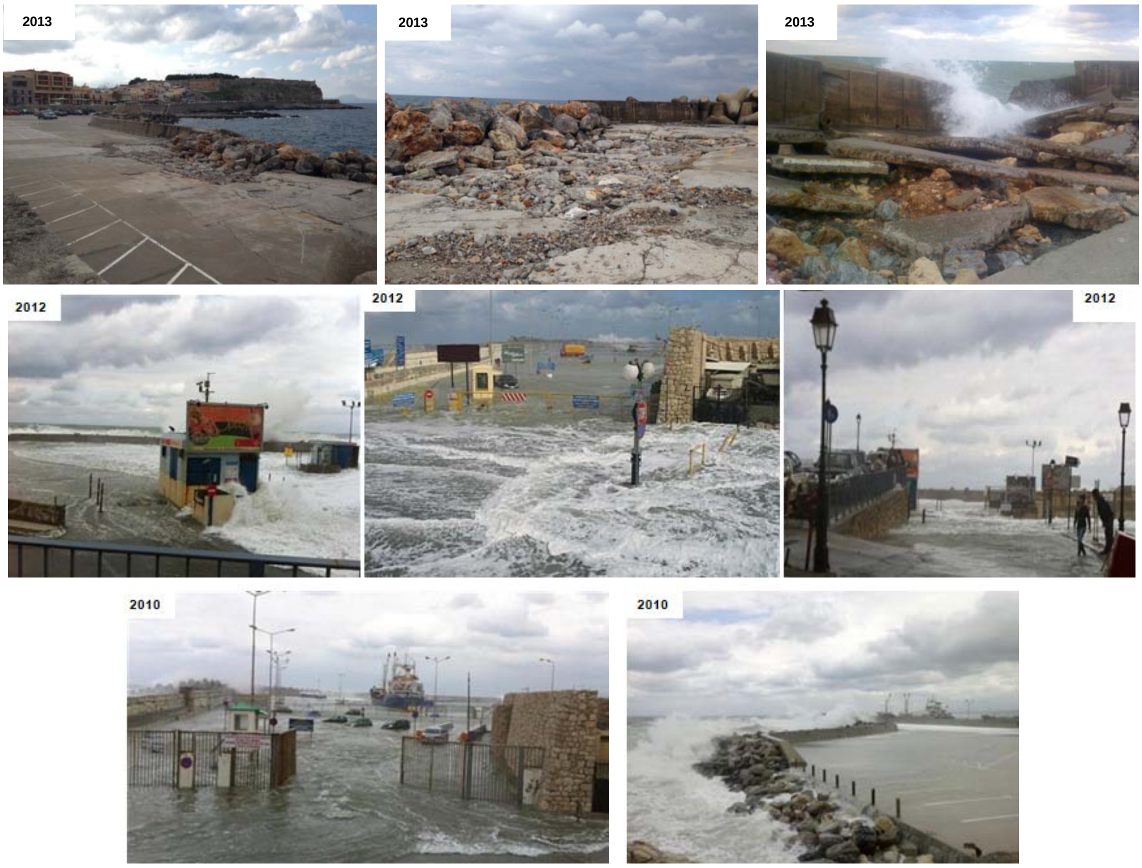

Figure 4: Recent floods at the harbour area of Rethymno (2010- 2013)

4. Methodology

The starting point in Rethymno case study will be to understand the formation of hazards under extreme events and develop a multi-scale integrated modeling framework which will enable to capture and simulate extreme events individually and in coincidence. Therefore, a model chain (Figure 6) will be set for atmospheric, storm surge, flood plain, waves, river and pipe networks in order to understand the formation of hazards and model extreme events individually and in coincidence from the ocean till the origins of Rethymno's river basins.

In that direction, global simulation will be held for the analysis of climate change and sea level rise. In detail, the global ocean model MPIOM will be used with enhanced resolution around Europe, which is able to model the full luni-solar ephemeridic tidal potential. Over the northeast Atlantic and Europe a regional atmospheric model REMO will be interactively coupled to this ocean model in order to get a high resolution atmospheric forcing. A hydrological discharge model developed by the Max Planck Institute will also be used (AR4-A1B model simulation).

Estimation of Wave Characteristics will be made using a 4-level downscaling approach by assessing climate change effects on the marine climate of the Aegean (Figure 5). Sea level change due meteorological tide will be examined at Level I with the Mediterranean Basin to be the area of computational grid at first and then, at Level II, the boundaries will be set on the Greek Seas. Temporal scales will also differ accordingly. In detail, temporal data analysis will start with a 3 hr time step at Level I which will be replaced with a 6 hr time step at Level II. Simulation of wave height will be accomplished at Level III. The wave prediction system for the Greek seas will be based on SWAN model. Within PEARL, the SWAN model will be used to analyze wave conditions on different temporal and spatial scales from the long-term overall wave conditions at the ocean model scale to the local extreme event wave conditions at the scale of the flood protection constructions. Temporal and regional distribution of the wind with a time resolution of one hour will be used for the simulation of the wave spectrum with SWAN. Climatic simulation and predictions will be produced for the periods 1961-2000 and 2000-2100. Finally, local coastal area wave conditions will be simulated at the area of Rethymno's Port at Level IV.

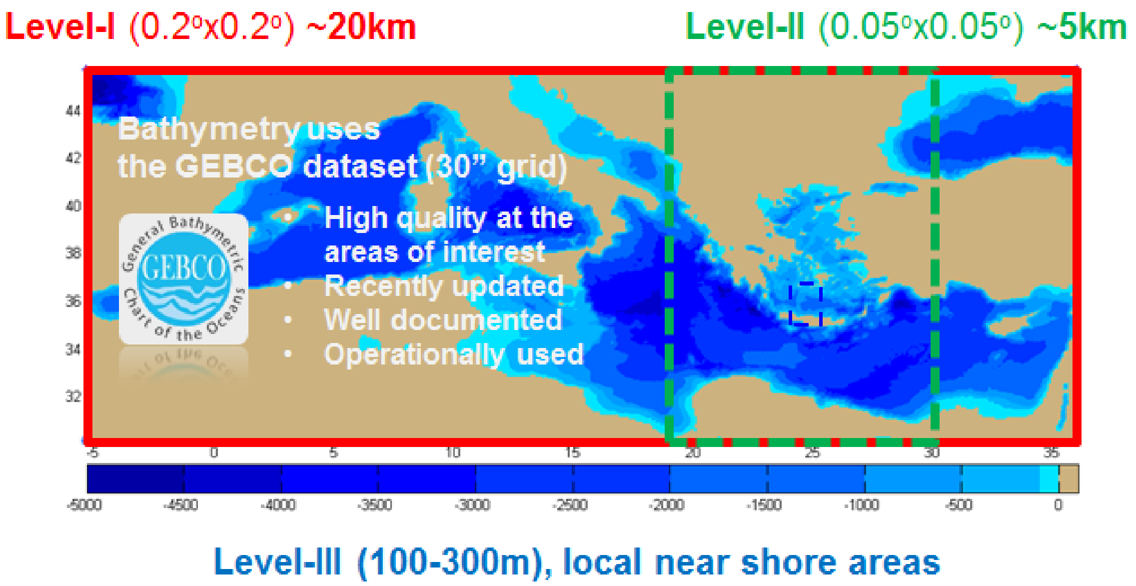

Figure 5: Estimation of wave characteristics using a 4-level downscaling approach

SWAN, a third-generation wave model that computes random, short-crested, wind generated waves in open sea, coastal regions and inland waters, will be then coupled with XBeach, a model developed for eXtreme Beach behavior, i.e. to model the nearshore response to hurricane impacts and storms. The significant alongshore variability due to anthropogenic or natural causes requires a two-dimensional process-based prediction tool, which will capture wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area, beaches, dunes and backbarrier during storms. The XBeach model will be applied to Rethymno's coastal area extending several kilometers in the longshore and about a kilometer in the cross-shore. The SOBEK modelling suite is expected to complete the model chain. SOBEK is an integrated software package for river, urban and rural water management which will enable to simulate combinations of flow in closed conduits, open channels, rivers overland flows, as well as a variety of hydraulic, hydrological and environmental processes.

SWAN ⟷ XBeach ⟷ SOBEK

Figure 6: Model Chain

Integrated modelling and identification of extreme event scenarios will lead to a better understanding of the coevolution of disasters due to extreme hydro-meteorological events under climate change, related to natural and technical root causes.

Subsequently, socio-economic issues will be considered so that a Holistic and Multiple Risk Assessment can be carried out in Rethymno. Associating technology, social dimension and natural processes will be accomplished through the use of Agent Based Models (ABM). An (ensemble of) ABM(s) will be developed to simulate the impact of the decision making processes of local stakeholders such us Municipality, the Municipal Water Supply and Sewerage Company, the Municipal Port Authority and the Civil Protection Authority of Rethymno on the evolution of flood risk. Evaluation of the decision making processes will be made through the outcomes of the model chain e.g. vulnerability maps, comprising structural and non-structural mitigation measures. ABM will be tested for both strategic and operational risk assessment purposes. The risk assessment will be made in Rethymno for the given scenarios through the combined use of ABM and work with stakeholders.

Following the implementation and validation of the integrated model, the possibility of linking this to local weather forecasts will be explored in order to set up an early warning system for combined risk forecasting. Due to the lack of high resolution data in the area of Rethymno, statistical approaches will be implemented in order to define the most suitable probability distributions for the generation of the extreme event scenarios and the spatial and temporal distribution of meteorological parameters such as precipitation.

A toolbox supporting selection of resilient strategies will be developed and demonstrated in Rethymno that will include advanced multi-criteria decision analysis methods as well as robust and efficient multi-objective optimization algorithms that can select and evaluate strategies and measures. Of particular interest here are also alternative approaches to “classic” optimization, such as robust optimization, which take into account the sensitivity of results to uncertainties and “real options” optimization, which allows for the evolution of flexible alternative pathways of a series of interventions, rather than one-off option selection. The evaluation of the selected resilient strategies i.e. the evaluation of the engineering, environmental, operational strategies and solution for adaptation and mitigation will be made by taking into consideration the characteristics of the resulting flood scenario (e.g. water depth, velocities, duration) and socioeconomic elements (e.g. Gross Domestic Product, insurances, etc.) and economic evaluation techniques (e.g. option value, etc.).

In the direction of decision support and policy development for strengthening resilience in coastal regions, a platform will be developed and tested through which stakeholders will interact with the key processes, tools, methods and framework. Rethymno's stakeholders will form a Learning & Action Alliances (LAAs) that will be the ultimate user of the system. This LAAs will provide the long term visions on/for the evolution of risk in their area which will in turn formulate the relevant questions/options for assessment by the system and the provision of roadmaps for risk reduction.

5. Conclusions

In the present paper an overview of the objectives and broad methodology of an EU funded project addressing issues of extreme and rare events in coastal region were presented. The specific application of the proposed methodology in Rethymno coastal region in Crete was also analyzed to some extent.

The overall result of the work is expected to be the development of an actionable roadmap for flood risk management for Rethymno, integrating different risk perceptions to support commonly agreed visions in collaboration with local stakeholders, supported by an interactive web-based, learning and planning platform. It is suggested that such a roadmap and supporting tools, methods and frameworks can assist stakeholders to enhance flood resilience in coastal areas across Europe while providing a robust framework for integrating lessons and ideas from the global effort to decrease vulnerabilities in coastal zones.

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