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A PROPOSED METHODOLOGY FOR COASTAL RISK MANAGEMENT

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Abstract: Coastal erosion is a gradual process that alters the distribution of sediments and modifies the geomorphology of the coasts. It may result in the destruction of natural coastal defences (sand dunes, cliffs, etc) and the increase in land instability which may in turn result in flooding of the hinterland and landsliding of coastal areas with steep slopes and unstable materials. The damages induced by such hazards include loss of life, property, infrastructure, and land. The costs of emergency action, remediation and prevention can often represent a significant burden to the communities affected and to national governments. According to predictions, climate change impacts, including sea-level rise and extreme weather patterns, will lead to the increase in the frequency and intensity of such hazards. Risk-based decision-making is seen to provide the means of addressing the challenges put forward by climate change. The complexity and interrelation of the processes acting on coastal locations call for an integrated framework for the assessment of coastal risks and the identification of the appropriate measures for the prevention and reduction of erosion, flood, and landslide risks. In this paper, existing models for the mapping of pressures on coasts and current development practices and tools will be reviewed, before a holistic methodology is proposed in order to assist decision-makers in effective coastal risk management.

Keywords: GIS, Remote sensing, Decision Support Systems, Coastal risks.

1. Introduction

The shoreline achieves several socio-economic functions (tourism, industry, recreation, etc). This coastal heritage is however threatened. In fact, coasts are very sensitive natural ecosystems and they are facing increasing natural and anthropogenic pressures that result in their greater vulnerability. It is expected that climate change will result in Sea-Level Rise (SLR), changes in weather patterns, and increase in frequency and intensity of extreme events (e.g. storms, drought). As a result, erosion, flood and landslide hazards will be exacerbated on many coasts, leading to the depletion of coastal resources and exposing people and assets to considerable losses.

The development of risk assessment and management strategies to avoid the degradation of the coastal heritage requires a thorough understanding of coastal evolution and natural processes. Various forcing factors are involved in coastal morphological changes in a complex manner and their interactions have not yet been thoroughly explained. During the last decade, advances in coastal risk assessment were achieved through manifold EU-funded projects: A European initiative for sustainable coastal erosion management (EUROSION), Responding to the Risks from Climate Change in Coastal Zones (RESPONSE), Coastal Research and Policy Integration (COREPOINT), etc. However, most projects were focusing on the Northern and Western European coasts. Therefore, the coastal stakeholders from the Mediterranean and Balkan countries did not sufficiently benefit from the new knowledge acquired, nor the developed tools or the tested practices, whether successful or not.

GIS and remote sensing technologies have great potential when deployed in coastal risk assessment (Saroglu et al., 2003; Tassetti et al., 2008). Remote sensing offer the advantage to capture the coastal processes over a large area, frequently updated data are available for monitoring purposes and several models were developed and tested providing satisfactory results. The diversification in the scales of the complex patterns of coastal interactions in space make the use of GIS ideal for coastal risk assessment purposes. The major asset of using a GIS system in coastal risk management is its capacity to store, handle and analyze a high number of spatial layers (Bartlett and Smith, 2005). The spatial dimension of the issue addressed is clear, since many of the forcing agents such as wind, runoff, tides, and waves are spatially distributed over the coastal area. The combination of different layers corresponding to coastal risk factors through spatial analysis tools and their statistical analysis make of GIS a necessary tool for the evaluation of coastal risks. However, in many cases decision-makers can not operate GIS due to inadequate experience or interface complexity (Canessa and Keller, 2003), therefore a Spatial Decision Support System (SDSS) specially designed for coastal risk management is required. Canessa and Keller (2003) stresses the need to have a flexible SDSS that accommodates the characteristics of coastal decision-making and helps structuring the coastal management process.

The paper aims at presenting an integrated methodology for the management of coastal risks focusing on the erosion, flood, and landslide risks. In particular, it aims at describing a Spatial Decision Support System adapted to the management of coastal risks by decision-makers. In the first section, the existing legislation and regulation relative to coastal risk management is reviewed, a set of models for climate prediction and the assessment of erosion, floods, and landslides risks are presented and specific decision support tools are reviewed. The second section is dedicated to the proposed methodology. The detailed structure of a Spatial Decision Support System for coastal risk management is described. The third section discusses the limitations of the proposed approach. Finally, a conclusion is provided in the last section.

This paper presents a methodology as a preliminary result of a project that will be implemented within the framework of the ENPI-CBC Mediterranean Sea Basin programme (2007-2013). During this project, the proposed methodology will be applied in four study sites in Greece, Cyprus, Egypt, and Tunisia.

2. Overview of methods

2.1. Overview of existing legislation and regulations

The improvement of coastal risk management, focusing primarily on erosion, flood, and landslide risks, is a crucial issue that is in line with a set of legislations and policies: (i) the European Floods Directive (2007/60/EC), (ii) the International Strategy for Disaster Reduction (ISDR 2000), (iii) the Integrated Coastal Zones Management (ICZM), (iv) the United Nations Convention to Combat Desertification (UNCCD 1997) as far as soil degradation through erosion and salinization is concerned, (v) the European Water Framework Directive (2000/60/EC), regarding the management of coastal waters and groundwater (contributing to land instability) and river basin management planning, (vi) the Agenda 21 programme of Action of the United Nations for achieving the sustainable development with Chapter 17 dedicated to the protection of coastal areas among others and (vii) the recommendations of the Intergovernmental Panel on Climate Change (IPCC) on the design of National Adaptation Plans (IPCC 2007). The development of an integrated methodology for the management of coastal risks will permit to fulfil the obligations of many countries towards national, European, and international legislation and regulations. The legal and administrative frameworks for managing coastal risks are further described within the Good Practice Guide of the RESPONSE project (RESPONSE, 2006).

2.2. Overview of existing models

2.2.1. Climate modelling

Climate change is expected to have impacts on coastal locations. According to IPCC's Special Reports on Emission Scenarios (SRES), a positive (respectively negative) trend in temperatures (respectively rainfall) are expected in the Mediterranean basin, resulting in a decrease in annual runoff by 20-30% in south-eastern Europe by 2050 and a global mean SLR of 0.09 to 0.88 m (optimistic scenario) by 2100. These experiments show a localised increased storminess in parts of the Adriatic, Aegean and Black Seas (IPCC, 2007).

Climate modelling consists in predicting the distributions of rainfall, temperature, the frequency and intensity of storm surges, and the SLR. Jacob et al. (2007) provide an inter-comparison of several Regional Climate Models (RCMs) for Europe. Also, within the program ENSEMBLES (Ensembles based predictions on climate changes and their impacts), an estimate of uncertainty in future climate was produced by applying several RCMs to the Mediterranean area from the Iberian Peninsula to the Balkan Peninsula. Among the RCMs used are the CNRM-RM4.5, C4IRCA3, and KNMI-

RACMO2 (Lenderink, 2003). These models differ by their level of uncertainty in the climate predictions. The Aladin model was evaluated in the Balkan Peninsula, providing accurate simulations along coastlines, where no major topographic constraints are affecting the simulations (Kostopoulou et al., 2009).

2.2.2. Erosion risk modelling

The EUROSION project reviewed 60 erosion case studies covering a big diversity of coasts. The outcome of the project is that knowledge about the forcing agents of coastal erosion and their interactions is fragmented and empirical. EUROSION also revealed that replicability of existing models may be hazardous, since the coastline response to engineered mitigation solutions may not be conform to model predictions (EUROSION, 2004a).

Several empirical and semi-empirical models have been designed for the study of coastal erosion processes but the theories and assumptions they are based on are not often compatible. For the study of the long-shore sediment transport process for instance, the CERC equation (1971) is widely applied but valid for a limited number of situations (e.g. open straight coasts, mild slope shoreline, estuaries, etc.) while the Bijker formula covers a wider range of situations but requires considerable field measurements and computation resources (Charlier, 1998). Özhan (2002) suggests to study coastal sediment transport together with three other components of the coastal morphodynamics in order to predict future erosion (wave prediction and transformation, wave breaking and breaker zone hydrodynamics, and morphological changes of the sea bed). Marine sediment deposition can be modelled with the 3D hydrodynamic model, called Princeton Ocean Model (POM, 2009), linked with a sediment transport module. The inputs of the model are the sediment characteristics and distributions and the hydrodynamic regime, while its outputs are the rates of marine erosion and deposition. Soil erosion (inland process) can be modelled through the Revised Universal Soil Loss Equation (RUSLE2 2003). This method expresses the long-term average annual soil loss (A) as a function of the rainfall erosivity (R), the soil erodibility (K), the topographic factor (LC), the support practice (P), and the crop and land management factor (C).

In general, further improvements are needed to existing models in order to really stick to the conditions prevailing in a specific area: Andrews et al. (2002) described a model for coastal dunes while ESTMORF is a model more appropriate for the simulation of morphological changes in estuaries (ESTMORF, 2009).

2.2.3. Landslide risk modelling

Landslide activity results from the instability of the ground. Landslides are generally triggered by heavy storms and rainfall, coupled with soil erosion on steep slopes. Areas with unstable materials and high soil moisture are at risk, and the problems posed by these factors are compounded by human activities such as deforestation and the construction of roads and buildings (RESPONSE, 2006). Landslide risk can be modelled within a GIS. Using as input the physical attributes of existing landslides, similar patterns are identified in the area under consideration taking into account possible climate changes. The output is a landslide risk assessment map. Tassetti et al. (2008) have analysed the correlation of five instability factors with landslide events: geology, land use, slope, aspect, and precipitation for the modelling of cliff recession due to landslides.

2.2.4. Flood risk modelling

Up to an additional 1.6 million people each year in the Mediterranean and northern and western Europe might experience coastal flooding by 2080 (IPCC, 2007). The main drivers for coastal flood hazards are storm surges and SLR. Flood risk due to SLR can be analyzed through watershed modelling and 3D GIS analysis. The effective runoff is estimated at several rain events based on the climatic profile of the area, and the flooding zones are designed with 3D GIS analysis using a detailed Digital Terrain Model of the coastal area. A coastal inundation model, called HYDROF, was applied in the UK on the entire coastline. The model is a 2D tidal inundation model which uses a model grid built on merged marine and land topographic data. Its use for coastal flood mapping was recommended in Martini and Loat (2007). Barredo et al. (2008) propose to estimate flood water depth using surge height information for each coastline segment for several return periods and a DEM at 100 m cell size. Bates et al. (2005) developed a simplified 2D fluvial hydraulic model LISFLOOD-FP for the assessment of coastal flood risks in the UK.

2.3. Overview of existing tools and development practices

There are several information technologies that were used for coastal risk management. Local Information Systems (LIS) were developed within the projects EUROSION (2004b) and COREPOINT (2007) in order to enable the organization, archiving, basic processing, and representation of coastal data. Expert Systems were also used for coastal data analysis. The expert system COAMES allowed the analysis of coastal geomorphology through the use of aerial photography (Moore et al., 1999), while SimCoast^{TM} is a commercial fuzzy logic rule-based expert system designed to enable researchers, managers and decision-makers to create and evaluate different policy scenarios for coastal zone management (SimCoast, 2009).

Spatial Decision Support Systems (SDSS), on the other hand, grant decision makers the ability to utilize all available information, data and knowledge about overall coastal processes with an optimum efficiency. In fact, scenario development, spatial analysis, and advanced modelling are major capabilities of SDSS. The leading edge of intelligent SDSS is moving towards clever knowledge-based systems and combinations of neural networks, fuzzy logic, genetic algorithms, and hybrid systems.

Van Kouwen et al. (2008) analysed the capacity of manifold decision support tools to overcome a set of knowledge-related and process-related challenges and concluded that no tool offered the functionalities that could satisfy all the challenges. This is a minor issue since the importance of a functionality is related to the application the tool is developed for. Uran (2003) compared five other tools for coastal zone management in order to highlight the reason for which SDSS that were developed for coastal zone, river, and water management are hardly used in the Netherlands. The reasons identified are: they are too detailed, time consuming and costly to use; they are complex systems; the uncertainty of the model output; the degree of appropriateness for solving the decision question; the need for training in the use of a particular SDSS; the limited involvement of users in the development phase. All these elements lead to unsuccessful SDSS.

3. Results

The above review reveals the existence of various models for the assessment of coastal risks such as erosion, landslides, and floods. It also points out the need to capitalize on existing knowledge acquired on coastal processes and the best practices already implemented in order to avoid the production of a methodology hardly useful to decision-makers because it is not applicable to or inappropriate for the application targeted.

3.1. Proposed methodology

In order to ensure the effective management of erosion, flood, and landslide coastal risks, a methodology is described hereafter. The latter has the following characteristics: it is an integrated approach that accounts for manifold processes at work on coasts, analyses them in order to generate separate maps of flood, erosion, and landslide risk, and then combines those maps into an overall coastal sensitivity map. In this concern the approach is holistic. The methodology is also highly adaptive in order to be applicable in coastal areas with different typologies, climate conditions, morphology, vegetation cover, etc. Beyond the risk maps, the construction of a SDSS is also proposed in order to provide valuable output to decision-makers such as suggested technically, economically, and environmentally sound measures for coastal risk management.

3.1.1. Modelling coastal processes

The proposed methodology consists in the identification of a set of pressures on coastal areas benefiting from the scientific background on coastal processes and their interactions. The processing steps are: the mapping of their spatial patterns, their qualitative and quantitative analysis, and the evaluation of their impacts on coastal environment.

Pressure and impact indicators are processed and analysed following the principles of the DPSIR framework. Since coasts are at the interface between land and sea, factors are divided into land-based factors (vegetation, geology, wind, water discharge and sediment supply by rivers, etc) and marine factors (waves, alongshore currents, rip currents, undertow, overwash, etc). A multi-factor approach is then adopted to account for the multiple physical forcing agents that affect the coastal locations. Several socio-economic pressures on the coast (demography, land use/cover change, tourism, industrial activities) are also mapped. In addition, the potential ecological impact on the coastal ecosystems is described. The ecological factor is defined through functional assessment of the coastal ecosystems, using available datasets such as habitat maps of the area leading to an ecosystem sensitivity map.

3.1.2. Coastal area delimitation

In order to define the geographical extent of coastal areas the RICE concept is used. RICE refers to Radius of Influence of Coastal Erosion and was introduced by the EUROSION project. According to this concept, the coastal area corresponds to the land that lies up to 500m from the coastline. The study site in Greece is the Gulf of Kalloni in the Island of Lesvos, as shown on figure 1. The RICE area towards the land and towards the sea is also mapped on figure 1.

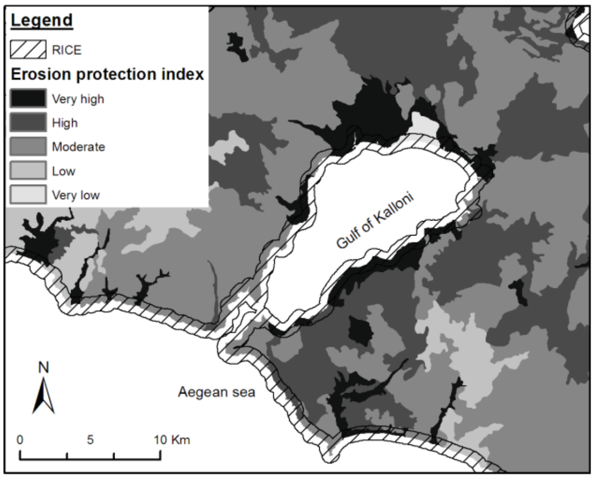

Fig. 1. Study site in Greece: the Gulf of Kalloni.

3.1.3. Data requirements

The data requirements considering the modelling steps described above are: administrative maps, meteorological data, satellite images, oceanography data (bathymetry, tide, wave, currents, etc), soil and topography maps, Land Use and Land Cover maps, and socio-economic data (demography, tourism, industry).

Previous results such as the erosion protection map in the Island of Lesvos (see fig. 1), obtained from the project "Integrated Monitoring System for Desertification Risk Assessment" (MOONRISES) (INTERREG III B ARCHIMED, 2007-2008), constitute valuable data inputs for coastal risk assessment.

3.1.4. Spatial Decision Support System (SDSS)

Van Kouwen et al. (2008) introduced a set of functionalities that help meeting the challenges related to successful decision-making. The terminology corresponding to these functionalities will be used hereafter where appropriate.

The use of a SDSS is proposed in order to improve the interpretability of risk-related geodata. In fact, when decision-makers have in front of them maps of spatial patterns of pressures, impacts and coastal risks, they are not necessarily able to analyse and retrieve the essential information that would help them select the appropriate sustainable measures that should be applied and decide where exactly they should be implemented. The SDSS therefore will allow supporting policy actors by "making complex information more understandable" (Van Kouwen et al., 2008). The proposed SDSS is an application specific tool that is tailored to the user's needs. The "stakeholder participation" is being promoted at critical steps of the tool's development in order to identify the end-users's needs, specify their perception of the tool, and help structuring the coastal risk management problem. Among all typologies of SDSS (Bhargava et al., 2007), the model-driven SDSS is more appropriate for coastal risk management through an integrative approach (Power and Sharda, 2007). Also, the possibility of parameterizing the models is given to the user in order to take into account the particularities of the study area.

3.2. Structure of the proposed SDSS

For stakeholders, planning the necessary actions to prevent and mitigate coastal risks is a complex task. Making choices and taking clear decisions require the knowledge of the various sources of pressure on coastal ecosystems and the consideration of multiple existing constraints. In order to be able to fulfil the functions that are expected by decision-makers for effective coastal risk management a specific SDSS structure is proposed (see fig. 2).

The tool embeds the following components:

a) Input/output components to specify the location of the coastal pressure indicators to be imported and of the produced risk maps to be exported.

b) Validation components to check that the minimum dataset is provided and that the imported data has the required format.

c) Pre-processing components aimed at the transformation of the indicators through standardization, classification and rating.

d) Multi-criteria components aimed at the selection of specific weighting factors taking into account local conditions. In fact, the drivers affecting erosion, flood, and landslide risks can vary from one site to another (fires, storms, urbanization, etc). For this reason, a multi-criteria analysis will give the possibility to SDSS's users (through the use of weighing coefficients) to prioritize one factor over another according to how much it contributes to the processes under study. This component leads to the production of final erosion, flood and landslide risk maps, plus an overall coastal sensitivity map. The Analytic Hierarchy Process (AHP) (Saaty 1994) is a widely used Multi-criteria analysis technique.

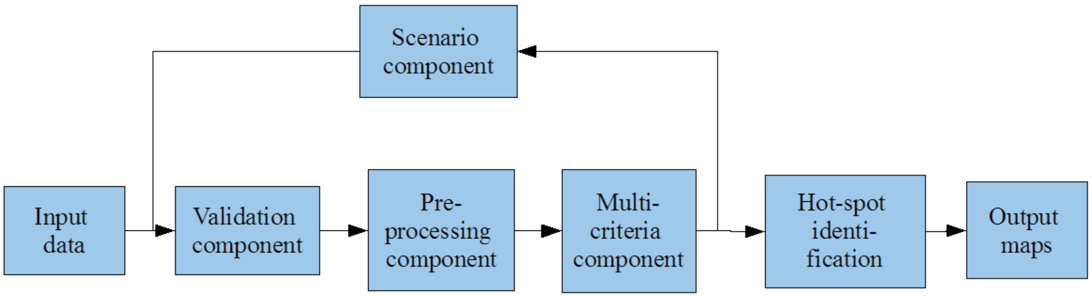

Fig. 2. Flowchart of the Spatial Decision Support System (SDSS).

e) Scenario components that allow the simulation of a change in the distribution of one or several indicators. Such scenarios assist stakeholders in simulating potential changes in climate conditions and exploring their effects on the vulnerability of coastal ecosystems. In fact, after SDSS's users establish the current level of risk, they can seek to identify the increasing level of risk resulting from climate change in order to implement sustainable policies to prevent or manage those risks.

f) Hotspot identification components that allow the localization of areas with a high vulnerability. With the automatic identification of the hotspots, stakeholders get a crucial indication about the areas where measures should be implemented in priority.

g) Graphic components. The SDSS has a graphic interface linking all other components together, thus providing a user-friendly piece of software to the end-user. The interface is simple and functional in order to avoid reluctance from decision-makers.

The implementation of such a tool requires experience in GIS, Remote sensing, software development and multi-criteria analysis. Components are tested individually and integrated in a final operational software.

4. Discussion: limitations

One major problem in the application of the proposed methodology is the possible lack of the minimum data set to run the models. Therefore the production of a protocol for data collection and the use of geodatabases for the regular storage of raw and pre-processed data are recommended in order to ensure the reliability of the data and increase the possibility of monitoring crucial parameters in the long-term with the systematic collection of data series of similar quality.

An additional issue that should be considered with care is that many models are coupled in the proposed approach. The integrative aspect is advantageous for the holistic analysis of interlinked processes. One drawback though is that uncertainty through modelling is increased. This may require from the developers to include functionalities for the visualization of uncertainties inherent to the output information.

Even though stakeholders are consulted during the development cycle of the SDSS, their training, once the tool is operational, is one major condition to its successful use in the future. In particular, the training will ensure that decision-makers know how to utilize all the tool's functionalities and are aware of its limitations and of the possible uncertainty of its outputs.

5. Conclusion

The erosion, flood and landslide coastal risks are commonly faced by many countries of the Balkan Peninsula and are expected to increase due to climate change impacts. This paper contributes to the protection of these locations from such risks by the proposal of an integrated methodology specially designed to cope with complex processes that are at work on the coasts. The methodology is based on a highly adaptive approach (parameterization of models, weighting factors, and minimum dataset) in order to ensure its applicability in coasts of various types. In particular, a SDSS presenting a user-friendly GUI and multi-criteria and scenario analysis components will benefit policy-makers as they will be able to run scenarios as examples of what can happen under particular assumptions such as changes (increase or decrease) of pressures on the coastal areas and they will be able to explore the vulnerability of coastal ecosystems under a changed climate. Based on information on the coastal sensitivity map, decision-makers will be able to decide whether and where to proceed with new engineering works and to prepare for possible damages that may occur. As a result, the proposed SDSS will contribute to promote the sustainable management of coastal risks by local and national decision-makers, thus helping to minimise the risks to life and property and achieving their balance against other considerations such as economic development, conservation, and recreation. The results from the application of the proposed methodology will be presented in future communication.

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