Decision-making tool for mitigation of the coastal erosion and extreme wave impacts in the coastal zone, in the context of climate change

S. Liaros[1], S.E. Poulos[2,3*], N. Kampanis[2], J.D. Alexopoulos[3], G. Alexandrakis[2], A. Karditsa[2,4], G. Ghionis[3], Emm. Vassilakis[3], M. Hatzaki[3], P. Nastos[3], P. Nomikou[3], V. Kotinas[3], E-S. Stanota[1], A. Nteris[1], V. Methenitis[2], G.S. Mitsika[3], D. Lampridou[3], E. Margaritou[2], S. Skovolas[1], K. Nikolaou[1], A. Stamatoglou[1], I.K. Giannopoulos[3], V. Gkossios[3], A. Konsolaki[3], G. Kontostavlos[3], M. Konstantopoulou[3], M. Panagou[1], N. Gkogkos[1], L. Roussos[1], I. Exintavelonis[1], H. Roukouni[1], K. Stamatoglou[1]

[1] Ilida Consulting Engineers S.A., 63 Arch. Elis, 27059, Havari, Ilia (info@ilida-eng.gr)
[2] Institute of Computational Mathematics, Foundation for Research and Technology, 100 Nikolaos Plastira, Vasilika Vouton, 70013 Heraklion, Crete (kampanis@iacm.forth.gr)
[3] Faculty of Geology & Geoenvironment, National and Kapodistrian University of Athens, Panepistimiopoli – Zogafou, 15784, Attiki (jalexopoulos@geol.uoa.gr)
[4] Department of Ports Management and Shipping, National and Kapodistrian University of Athens, Psachna Evias, 34400, Evia (kkarditsa@pms.uoa.gr)
[*]Corresponding author: e-mail: poulos@geol.uoa.gr

Abstract

The tool assesses natural factors and the impact of human activities as well as the available mitigation measures in a cost-benefit perspective and with a view to mitigating the impacts of climate change. Therefore, the tool is designed to respond to both erosion (as a natural disaster) and erosion due to human (inappropriate) intervention, as well as CM&D (e.g., sea level rise, extreme wave events). The innovation of the project is based on the creation of a multi-parameter decision making tool (ILIDA_KIT) related to climate change mitigation and resilience to coastal erosion and extreme wave events in the context of integrated coastal zone management. ILIDA_KIT relies on a multi-disciplinary interactive platform in a GIS environment that through the development of a set of appropriate indicators (environmental, anthropogeographic, economic) can be parameterised. The ultimate purpose of the tool is to select the most appropriate intervention (intensity, size, time horizon) measure, based on the cost-benefit analysis, considering both the protection and the sustainable development of the coastal zone.

Keywords: Coastal zone management, sea level rise, environmental indicators, coastal works

1 INTRODUCTION

The coastal zone, which represents an interface space, between ocean and land areas, is highly dynamic but also sensitive to natural changes and human interventions (Martins et al., 2002). Coastal areas are essential also to many local and national economies as it hosts about 10% of the world's population that live or work in it. On the other hand, coastal populations are highly vulnerable to climate change, being particularly affected by rises in sea level and wave height, coastal erosion, cyclones, and flooding (Carmo, 2018).

In particular sea-level rise may cause coastal flooding, seawater intrusion, inundation of land habitat changes in shorelines and a series of environmental impacts (e.g., lead to the degradation of coastal ecosystems such as salt marshes, mangrove forests, seagrass beds, soft sediments, kelp forests and coral and oyster reefs. Moreover, as marine economy corresponds to a considerable proportion of national GDP and employment in many coastal countries, extreme weather fluctuations, sea-level rise and other climatic changes will affect sectors such as tourism, fisheries and aquaculture (Allan, et al., 2021). It is also clear that human action (strong urban and industrial pressures), has been the primary cause of the current imbalances, both, directly (through local actions) and indirectly (through contributions, to global warming and climate change) (Bullimore, 2014). It is, therefore, crucial to discuss schemes of intervention that are acceptable to stakeholders and local communities. Meanwhile, coastal managers and policymakers should make effective and, timely decisions on the use of appropriate adaptation measures, for the immediate and longer time-periods.

The objective of the project is the development of a multi-parameter decision making tool (ILIDA_KIT) for the successful management of coastal erosion and the impacts of extreme wave events, with emphasis on coastal zones of tourist interest, in the context of integrated coastal zone adaptation management and, in particular, on mitigation and resilience to the already manifested climate change.

2 METHODOLOGICAL APPROACH

The methodological approach of the ILDA_KIT implementation includes the following stages:

Stage-1: In the first stage, the causes of erosion (as a natural disaster, human intervention, or climate change) are identified, as well as the frequency and magnitude of extreme wave events and their evolution over time. An optimal methodological approach is sought to assess the contribution of natural factors to the evolution of coasts, and in particular beaches facing erosion, and the impact of extreme wave events. Next, the contribution of anthropogenic factors to coastal evolution, whether direct (e.g., coastal structures) or indirect (e.g., river dams). The existing institutional framework is recorded and evaluated and good practices in addressing the impacts of climate change from Greece and elsewhere are analyzed. Considering the above physical and social information, the critical coastal area for the implementation of the tool is spatially defined.

Stage-2. In the 2nd stage, all the information needed to manage coastal erosion (current and future) and extreme storms in general are gathered, in order to be applied to the pilot area. The information to be collected concerns the geo-environment, socio-economic characteristics, as well as the institutional framework in national and European context (ILIDA CONSULTING ENGINEERS S.A.). The physical and human geographic characteristics will be extracted from satellite data, historical aerial photographs, existing maps and environmental studies, and additional field work will be carried out. The western coastal zone of the Peloponnese and the northern coast of the Messinian Gulf were selected for the development of the tool (Fig.1); this choice is based on the fact that ILIDA CONSULTING ENGINEERS S.A. and the Department of Geology and Geoenvironment (NKUA) have long experience in research of these areas.

Stage-3: In Stage 3, the vulnerability of the coastal zone to erosion and extreme wave events is parameterized (development / use of indicators) based on the intensity, frequency of occurrence of the phenomena and their spatial impact (current and future) on the coastal ecosystem (geo-environment). Subsequently, their impact on human presence and activity (society-economy) is assessed through the development and use of appropriate indicators. In addition, the available technical interventions (indirect or direct), the institutional framework and the physical parameters governing their selection and, finally, an estimate of their implementation (construction) costs, are described and analyzed.

Stage-4: In stage 4, the ILIDA_KIT will be developed, which through a multi-criteria analysis will be used to select the action (no intervention, mild technical intervention, hard technical intervention), which methodologically results from a computational process on an interactive information platform from information layers structured in GIS and quantified in the form of indicators. The tool will be applied to the selected area and then tested with other coastal areas (e.g., Katerini Beach, Kokkini Hani in Crete) that have already suffered erosion and host coastal projects to address it.

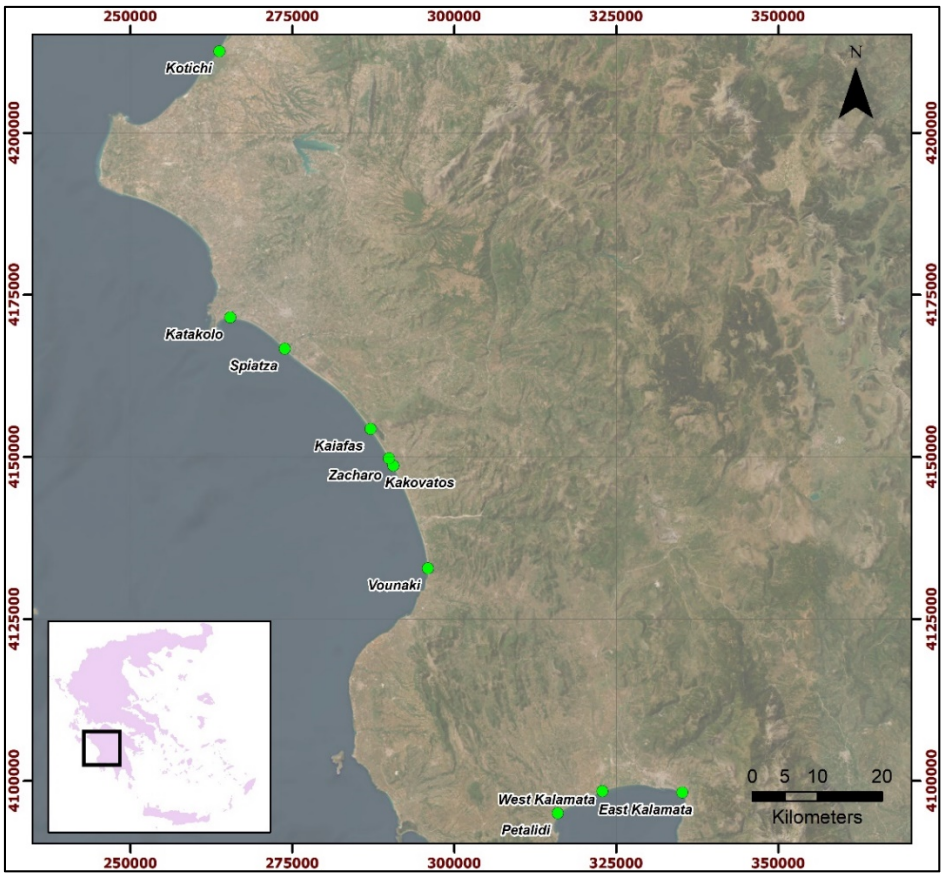

Figure 1. Coastal sites under investigation

Table 1. Work packages (WP) and the scope

WP-1. Assessment of natural processes related to coastal zone formation/evolution and to disasters due to climate change and extreme wave events.	The scope of WP-1 is to identify the factors that control the morphological evolution of the coasts and in particular of the beaches and the factors that cause coastal erosion (CE) and extreme wave events (EWE).
WP-2. Registration of the current state of the coastal zone	The purpose of WP-2 is to obtain all the necessary data and information to develop the assessment indicators (WP-3) for the evaluation of the impacts of coastal erosion (CE) and extreme wave events (EWE), which will then be integrated into the ILDA_KIT (WP-4).
WP-3. Development of an Evaluation Indicator System	The objective of the WP-3 is to develop the scientific methodology to exploit the data selected in WP-1 and WP-2 by developing a system of indicators that provide a basis for assessing both the vulnerability of the coastal zone to erosion (current and future) and the spatio-temporal occurrence of extreme wave events together with the socio-economic evaluation of their impacts.
WP-4. Design - build - implement a decision making system tool – ILIDA_KIT	WP-4 aims at the design, operational implementation and subsequent actions for the commercialization of the ILIDA_KIT decision making tool.

3 COLLABORATIVE ORGANISATIONS

The project is materialized by three partners: (1) Ilida Consulting Engineers S.A.; (2) Institute of Computational Mathematics (Foundation for Research and Technology); and (3) Department of Geology & Geoenvironment (National and Kapodistrian University of Athens).

ILIDA CONSULTING ENGINEERS S.A. undertakes the preparation of implementation and supervision studies regarding Environment and sustainable development, Topography – GIS, Spatial planning – Urban planning, Project Management-Technical Consultanting, National Cadastre, Hydraulic and Architectural works, Reenactments and Transportation Projects. It also participates in research projects related (directly and indirectly) to the above objects and the utilization of research products. The company also develops computer software and services related to the design or supervision of technical projects and the provision of services in the fields of business organisation, time and cost management of projects and planning.

Institute of Computational Mathematics (ICM) conducts research in applied mathematics and simulation science belonging to the Foundation for Research and Technology-Hellas (FORTH). Within ICM, the Laboratory of Coastal and Marine Research is active in research and applications related to the coastal environment, with applications in coastal hydrodynamics, hydrology, development of high resolution monitoring systems, and integrated environmental planning systems. It focuses on innovative scientific and research activities, in areas such as risk assessment and prevention measures regarding the socio-economic impacts of climate change and in the planning and management of activities in the coastal zone.

Department of Geology and Geoenvironment of the NKUA, participates with three (3) laboratories: (1) *Geophysics Laboratory* specialized in applied studies of geological and lithological conditions, geo-environmental investigations, determination of aquifer quality, investigation of landslides and subsidence, through the application of sophisticated techniques of high resolution (electrical resistivity tomography, ground penetrating radar, seismic refraction tomography, etc.); (2) *Laboratory of Climatology and Atmospheric Environment*, focusing on the study of climate variability, both on a regional and global scale, the impact of weather and climate on public health, the investigation of causes and processes related to extreme weather events (heat waves, droughts, floods, tornadoes, etc.); and (3) *Laboratory of Physical Geography* which is involved in the investigation of processes related to the evolution of the landscape (including human activities) with the synergy of GIS and remote sensing technologies.

4 PROJECT'S OUTPUTS

ILIDA_KIT, in the context of integrated coastal zone management, relies on a multi-disciplinary interactive platform in a GIS environment that through the development of a set of appropriate indicators (environmental, anthropogeographic, economic) can be parameterised. The results of the tool are as follow:

- Assessment of the main causes (natural and human) of erosion, including assessments of beach retreat due to climate change.
- Provide a response to the relationship between extreme wave events and climate variability and change, including future approaches (2050 and 2100).
- Comprehensive assessment of the impacts and costs of climate change on different components of the natural (ecosystem) and socio-economic coastal environment.
- Selection of the most appropriate interventions (answer to the question: No intervention - No intervention but with change in human presence and action - Mild technical intervention – Hard technical intervention) to address erosion and the effects of extreme wave events based on realistic construction cost/benefit (socio-economic) estimates.
- The creation of an integrated (WEB-GIS) geo-spatial data base with emphasis on the geo-environmental and socio-economic conditions, which can be integrated/utilized in general management (spatial) plans of the coastal zone, in an ecosystemic direction, while

contributing to the fulfillment of contractual legal obligations of Greece (e.g., Directive 2014/52/EU).

- Significant contribution to the economy at local, regional and national level by protecting the domestic product produced in the coastal zone through appropriate interventions and saving money by avoiding unnecessary interventions (e.g., failures of costly technical projects).
- Finally, the decision-making tool produced can be used both in other coastal areas of Greece and in other countries in the SE Mediterranean region, where coastal zone management needs to be adapted to or mitigate the effects of climate change.

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