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Geographic Information Systems applied to Integrated Coastal Zone Management

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ABSTRACT

The littoral is the area where marine and terrestrial processes superpose and interact. Limits of their respective actions are imprecise, as processes which are characteristic of each of these environments do overlap. This particular characteristic makes the littoral zone complex and vulnerable to human activity, which in many cases, causes irretrievable damage to the natural equilibrium. Integrated Coastal Zone Management (ICZM) promotes sustainable coastal development by adapting the use of natural resources in a way that avoids serious damage to the natural environment. This requires an integrated and organized action of all institutions that are involved in coastal development.

Geographic Information Systems (GIS) besides being a useful tool for drawing maps on different scales and projections constitutes an excellent instrument for data analysis and integration due to its ability to identify spatial connections between different information layers. In this way, it is possible to build models for geomorphological evolution and predict changes in the coastal areas.

In order to illustrate this, three examples of GIS applications are presented, which are currently being developed in different areas of the Spanish littoral, coastal hazards, shoreline evolution and coastal sand dune evolution, respectively.

1. Introduction

Coastal areas have been traditionally the source of wealth for many municipalities that were mainly dedicated to the fishing industry. At the end of the 19th century, tourism in Europe sprung forth, the beach acquiring great relevance as a place for rest and leisure. Since then, the coast has been subjected to an intense exploitation aimed at offering progressively more demanding tourist services. Notwithstanding its value as an important generator of economic, social and landscape resource, it is often forgotten that the coast is a very vulnerable environment, with the highest biological and geological values, that needs strong protective measures in order to be preserved.

In this scenario, the diversity of uses and activities developed in the littoral area makes it necessary to seek the most suitable way to attain compatibility among them and, at the same time, preserve the environment. On the other hand, the threat of climatic change, and the prognoses of a sea-level rise that would flood coastal land, makes it necessary to elaborate coastal development scenarios that take into account all elements. This is the approach undertaken by the ICZM (Integrated Coastal Zone Management), which is trying to define the sustainable management of the littoral. Its implementation is based on two main groups of factors: Firstly, it needs a deep knowledge of the physical environment as well as the relationship between the agents and processes of each one of the fields involved (marine, coastal and terrestrial). Secondly, it needs an appropriate territory management. These factors are, in turn, conditioned by the legal, social and environmental aspects that are established by public, national and local administrations (Rodríguez et al., 2003a; Barragan, 2003). For some years, efforts have been made to implement proper management rules (e.g. CE 13/2002), and methodologies which deal with all the mentioned coastal factors and aspects (Fig. 1). These methodologies come from different institutions (UNESCO, European Commission…), forums and different working groups that suggest policies in order to carry out these tasks in an efficient way (Bondesen, 1996; PNUMA, 1996; Intergovernmental Panel on Climate Change, 1996, 2001, 2007; Olsen et al., 2003; EUROSION, 2004; Coastal Zone Management Program, 2005).

Because of the need to integrate and manage all these factors and aspects related to the coastal zone, GIS appears to be the most appropriate tool to deal with those tasks. This clearly shows the spatial and temporal evolution of dynamic processes as well as the factors that control their behaviour in order to analyze these scenarios better, evaluate the impact on littoral environments and manage them properly (O'Brien et al., 1995; Moe et al., 2000; Li et al., 2000; Zhang and Grassle, 2002; Hamada, 2004). Since GIS was one of the tools recommended in Word Coast Conference in 1993 (Vellinga and Klein, 1993), a number of different projects using GIS applications and methologies for coastal zones have been developed (e.g. BALTICSEA-WEB, Laitinen and Neuvonen, 2001; Ocean Biogeographic Information

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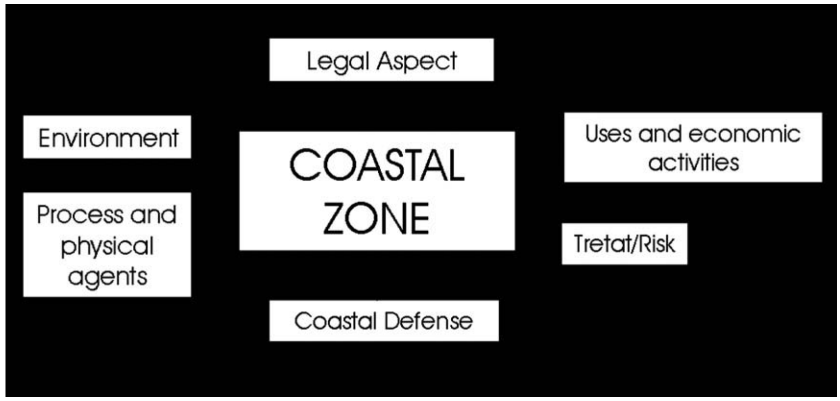

Fig. 1. Flow diagram showing the integration of all aspects and factors having influence on the problem of coastal management.

System OBIS, Zhang and Grassle, 2002; Dune Hazard Assessment Tool, NOAA Coastal Services Center, 2003; Coastal Erosion and Shoreland Development Regulation, Miller et al., 2003).

Each coastal zone needs different management strategies and therefore different GIS uses to deal with each problem. Three GIS applications are presented in this paper: 1) In coastal hazards management GIS helps with statistics analysis, needed to carry out a multivariate spatial–temporal model that estimates the probability of hazard occurrence; 2) Dealing with shorelines corresponding to different years, GIS allows the analysis of the evolutionary trends to define the behaviour of the system; 3) GIS used in studies of the evolution of dune fields is essential in order to estimate dune migration rates and analyze all the variables involved in this process.

2. GIS as a coastal management tool

In the littoral zone, GIS is increasingly used as a support tool that allows homogenisation and integration of all the available information into a geodatabase, in order to access data, generate thematic cartography, and perform spatial and geostatistical analysis (Laitinen and Neuvonen, 2001). An amount of relevant information is collected, compiled into the database, converted into more convenient units of information and, finally, introduced into a more formal information system. This characteristic is especially useful, for example, in the integration and analysis of the indices used to identify coastal vulnerability (Doukakis, 2005), offering maps of coastal risk.

The result is a versatile and flexible system. On the one hand the access and use of the data can be achieved through the database model system and on the other hand by using GIS system advantages: editing and data automation, visualization, mapping and map-based tasks, spatial consultation, spatial analysis, and geostatistical analysis. This flexibility allows GIS used in further planning applications in other scenarios (Fig. 2).

In the following sections some GIS applications to coastal management currently developed in different areas of the Mediterranean Spanish littoral are presented.

2.1. Coastal hazards GIS application

Slow but steady degradation of the coastal fringe in much of Europe has gone largely unnoticed until recently, and this will continue and accelerate with sea-level rise, and other coastal hazards. Developing methods to balance protection of people and the economy against the costs of degradation of the coastal environment will require multidisciplinary research (Nicholls et al., 2007).

A practical example of GIS use in coastal hazards is shown in the problem of rock fall in a cliff sector of the Catalonian Coast (Mediterranean Sea). The main objectives of this study are: physical and mechanical natural environment characterization, stability analysis in the area characterized by previously obtained geomechanical parameters, estimate of rock-fall occurrence probability via development of statistical models, elements-at-risk identification, vulnerability analysis, and finally the generation of a landslide risk map.

The coastal waterfront is formed by sandy beaches with smooth slopes and pebbles in some areas. The cliff-surrounded coves are formed by pebbles included in a sand–clay matrix, and covered by a calcareous crust (IGME, 1980). These materials are potentially unstable, and represent a landslide hazard to the beach (Fig. 3). The cliffs are fractured and constitute a potential danger of rocky block-fall onto the beaches where the tourist population is high in the summer.

Streams and gullies transport detrital materials and deposit them onto the beaches as a consequence of heavy rains in the autumn. A detailed hydrological knowledge of the area is needed, because superficial and subterranean waters affect cliff stability by removal of the sedimentary matrix, accelerating the rock fall.

Regarding swell, in this area, during storm and wind events, the short term rise of sea-level caused by meteorological tides could be more than 1 m in specific places. The return period for these singular events varies from 10 years (swell height = 1 m) to 100 years (swell height = 1.5 m) (Sánchez-Arcilla and Jiménez, 1994). Swell action on the cliff in conjunction with the high number of fractures, contributes to the instability of the rocks. Previous works, such as Bray and Hooke (1997), review the possible effects of longer term sea-level rise on soft cliffs. They evaluate different methods of analyzing historical recession rates and provide simple predictive models to estimate cliff sensitivity to predicted sea-level rise.

The considerable amount of information to process requires an organized working methodology. It is therefore, necessary to design and create a graphic and alphanumeric database that integrates all factors that could promote hazardous situations. A thorough and accurate study requires knowledge of the following data: lithology, slope, vegetation, structural conditions, morphological indicators, drainage, climate, fluvial and coastal erosion, seismicity and human action. Elaboration of Digital Elevation Models is useful to obtain topographic variables such as slope, orientation and curvature (Fig. 3). Moreover these models are able to define superficial drainage properties and hydrological basin characteristics. Likewise DEM is an essential tool to get a geomorphological characterization and to identify landslides.

Having collected and organized all these data, it is possible to analyze them and map the potentially unstable areas. Then, it is necessary to determine the elements at risk in the area: population density, natural environment, and socioeconomic aspects (infrastructure, economic activities, heritage, etc.) (Ministerio del Interior, 2002). The overlapping of the hazard map and the elements at risk map, allows the evaluation of the vulnerability of the zone. It is important to understand the nature and implications of the threat