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Assessment of coastal erosion susceptibility at the national scale: The Italian case

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Abstract. To improve the present national and local sustainable planning capability for the coastal zone a GI application for the Italian Coastal Susceptibility Assessment was planned within an institutional agreement between ENEA and the Land Defence Service of the Italian Ministry of Environment. Taking into account previous European actions a suitable methodology to assess, in a quantitative way, the susceptibility of beaches to be eroded has been set up.

The methodology balances the coastline trend as evaluated for a defined time period with the present coastal areas morphology and land use, this in order to derive a value that expresses the evolutionary process in terms of probability of the loss of goods within the 'Homogeneous Coastal Tracts'.

The trend in the movement of the sea-land line has been used as *geo-indicator* of a complex dynamic balance that refers both to marine and inland systems, and a vector GI application was built and locally applied in southern Italian coastal areas.

The present shoreline position and some other information describing the intrinsic beach morphologies, and having significance for the coastal erosion hazard assessment, have been derived from the national 1:10.000 ortho-images of the National Cartographic Reference System provided by the Italian Ministry of Environment. The illustrated GI application – CoSTAT – keeps the nominal scale of all data collected or produced. In this analysis the coastal dune presence is analysed as factor limiting coastal erosion susceptibility. Applying a matrix calculation a quantitative evaluation of erosion susceptibility degree was achieved and plans were made to develop new information for a suitable use of Italian coastal areas.

The work describes the methodology, the conceptual framework and the results of a local application.

Keywords: Coastal dune; Coastal Homogeneous Unit; Geomorphology; GIS; Ionian Sea; Risk analysis.

Abbreviations: ENEA PROT-PREV = Italian National Agency for New Technologies- Natural Risks Prevention and Effects Mitigation Division; GIS = Geographic Information System; CHU = Coastal Homogeneous Unit; IGM = Italian Military Geographical Institute; ICZM = Integrated Coastal Zone Management.

Introduction

The morphology of the sea-land line and changes in its relative position depend on short, medium and long-term dynamics which may result in changes in the dynamic balance between the inland drainage basin and the marine basin (Scor 1991; Niedoroda et al. 1995; Bondesan et al. 1995; Palanques et al. 1990; Stanley & Warne 1993; Simeoni & Bondesan 1997).

The requirements for assessing the state of that fragile sea-land balance may be frustrated by real difficulties to (1) dispose of adequate data in terms of quality and completeness, (2) monitor coastal short-term development and (3) model medium/long-term coastal development scenarios.

Quantitative data and detailed measures are required to highlight variations of less than 1 m magnitude. In addition, because of the sensitivity and dynamism of the coastal system it is necessary to regularly update our assessments and to discriminate between permanent changes resulting from real changes in the sea-land balance and temporary changes resulting from seasonal or tidal effects.

The great economic and socio-anthropological values of this environment, especially in the Mediterranean, is well known amongst local and national authorities, but to integrate them with environmental values depends on our knowledge and possibilities to monitor the coastal state and its development. Until today there has been an excellent but dated framework available in Italy, the Italian Coastal Atlas at scale 1 : 100 000 (Anon. 1986). However, we do not have more detailed information on the entire coastline. The many local studies on shoreline development are not archived in national databases, nor used to update the present general knowledge.

With all this in mind and within an institutional agreement with the Italian Ministry of Environment, a GIS vector application for coastal state assessment, with respect to erosion susceptibility, was planned by ENEA (the National Agency for Energy, Innovation and Environment) and carried out jointly with the Earth Science

Department of Ferrara University. During the development of this GIS application we are taking into account previous European programs and the scientific literature on this topic as well as some previous own methodological studies within ENEA as proposed in European R&S projects (Margottini & Casale 1999), this all to estimate coastal erosion susceptibility.

The application is based on Arc/Info and ArcView 3.2 and is not limited to the sea-land boundary but includes the entire coastal zone, while taking into account the possibility that the shoreline will move back in the coming 30 years. The data base on which the GIS Co-STAT is based contains very accurate information on present coastal zone morphology and land use that could become a baseline for future monitoring of the vulnerability for coastal erosion and flooding.

The aim of this paper is to illustrate a simple but sound approach to make use of the available basic data accuracy (mainly on sea-land boundary dynamics), and to enable the inclusion of new data, so that the system could become a real tool for national and regional coastal planning.

The background context

At a world level 70% of our beaches are retreating, 20% is stable, 10% is advancing (O'Riordan 1995) while at the same time the human population living in the coastal zone is strongly increasing. For Italy the Coastal Atlas (Anon. 1986) highlights the importance of coastal erosion at the national level. Out of the 5961 km littoral coastline referred to in the Italian Coastal Atlas, 3612 km are sandy beaches, of which more than 960 km are classified as subject to erosion.

In our present culture, focusing on economic and social aspects, coastal erosion is considered as an unacceptable landward movement of the coastline (Cooper & McLaughlin 1998). Highlighting this erosional trend could trigger a broader perception of the need for integrated coastal management, but at the moment we still lack tools for a real planning of these fragile and highly dynamic environment.

Risk analysis will complete the more conventional evaluation of coastal dynamics expressed in terms of withdrawal/growth/steadiness of the sea-land boundary. Achieving a risk assessment implies a quantitative estimation of movements of the sea-land boundary, of the possibility that in a given time there will be losses in beach area, and subsequent economic and, implicitly, human losses. Subsequent steps of a risk analysis include first of all the assessment of potential hazards. The second step concerns a susceptibility assessment, i.e. the quantification of the sustainability of the local environment towards the possible hazard event and an estimation of the probable losses for the environment involved. The final step in the risk analysis implies a financial estimation of losses connected to human losses and damage to human activities. In Mediterranean coastal areas risk analysis is sometimes restricted to estimations of losses in environmental 'goods'.

In Italy many studies on coastal dynamics are carried out and locally coastal risk assessments are done. The Italian coastline may move up and down with some m up tp 20-30 m over a period of 20 - 30 yr. Given the length of the coastline (see above) it is very difficult to obtain a general picture of coastal dynamics. At the same time the economical relevance of an adequate management of coastal environments is obvious, particularly in Mediterranean countries including Italy, and natural risk assessment is urgent, especially at the national level. Many methodologies have been described in the international scientific literature.

Given the scale of coastal dynamics in Italy it is necessary to analyse the phenomena very accurately and to relate the methods adopted to the different scales of observation. For local morphology and topographic relief methods with a high resolution are necessary.

No national geographical databases were available for Italy and a national institutional programme is required to collect and homogenize the existing data. For the time being the Coastal Atlas mentioned above has to be used even if it is not accurate enough for coastal risk assessments. However, cartography exists for the whole country at scale 1 : 25.000 in the form of maps of the Italian Military Geographic Institute (IGM) from the 1960s, which can be used to describe events from the recent past, For actual studies numerical ortho-images at scale 1 : 10.000 have recently become available via the web from the Italian Ministry of Environment. This is a recent outcome of a national agreement among the main national and local authorities on cartographic standards and supplies. Possibilities to derive information from indirect sources, notably satellite images, have not yet been explored because of the high costs involved or because they are not suffciently accurate.

The proposed and applied methodology for CoSTAT GIS application derives, from these cartographic bases, the sea-land boundary trend and proposes to set up a geo-referred database with a stepwise approach that allows to measure some main features of the present coastal areas and to support a numerical estimation of coastal erosion hazards/risks. This evaluation is based on physical features of emerged and submerged beaches.

The general approach is restricted to sandy beaches and recognizes homogeneous littoral stretches, ' Coastal Homogeneous Units' (CHU), which are bordered by natural features such as promontories or river mouths and which have little exchange with neighbouring stretches.

The methodology applied for CoSTAT

The methodology applied is related to a general integrated environmental risk assessment model developed in some European Research projects (Environment Programme) co-ordinated by ENEA from 1999 to 2001 (Delmonaco et al. 1999). This methodology implies (1) the assessment of the intrinsic possibility that a specific risk-event, i.e. beach erosion, will happen, (2) the evaluation of the dangerousness, i.e. the quantified probability that the risk-event happens, and (3) the comparison between the results of this assessment and the risk based on human losses and expected material damage in a given return time (Casale & Margottini 1999).

In the international scientific specialist literature the sea-land boundary is considered the 'most obvious' environmental geo-indicator for coastal risk/hazard assessment (Berger et al. 1996). Shoreline development is in fact the outcome of a more complex interaction between several geological parameters and environmental variables that could be too long and complex to isolate and assess individually.

The CoSTAT application derives the 'present' shoreline position from the recent national source for Italy: the 1:10.000 ortho-images. The past position of the sea-land boundary – a zero point for the assessments – is traced from IGM 1 : 25000 topographic maps. From these data it is possible to estimate a sea-land boundary trend for the last 30 years. Beyond the present shoreline position, much new information has been collected from the digital ortho-images as polygons and polylines inside a geo-referred GIS that stores the attributes of the shore zones with significance for coastal erosion hazard/risk assessment (Fig. 1):

- Coastal landform;
- Features of the sea-land boundary;
- Position and features of the internal seashore edge;
- Boundaries of Coastal Homogeneous Units.

From available earlier data we can collect:

- Beach lithology;
- Height above sea level of the beach;
- Main pathway of coastward waves;
- Position of submerged beach slopes;
- Beach slope.

Some of this information is derived trough spatial analyses:

- Width of the present sandy beaches;
- Coastal exposition towards the main waves.

CoSTAT is a stepwise GIS application that includes subsequent phases of data collection, structuring and analysis aimed at achieving a quantitative assessment of susceptibility for coastal erosion (Fig. 2).

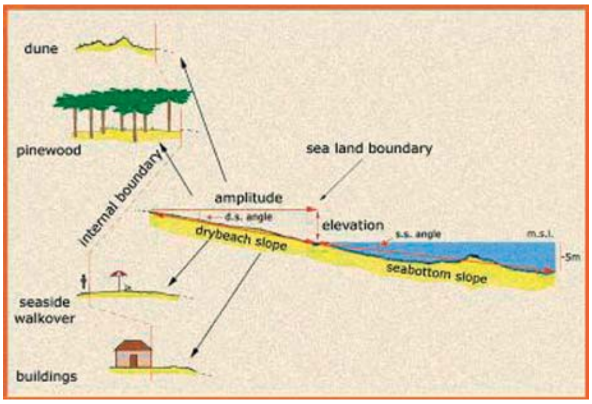

Fig.1. Significant features of sand beaches included in the CoSTAT database.

After the acquisition and collection of these data in a geographic database for describing intrinsic beach physiography and supporting a classification of coastal areas in terms of intrinsic homogeneities, a first step in CoSTAT was to quantitatively assess the trend in the sea-land boundary resulting from the spatial comparison of former and present cartography. The assessed movements were related to a defined time span depending on the relief data of earlier carthography; on average, this time span is ca. 30 years.

A further step concerns the linking, for each CHU, of this first classification with the actual significant morphological features of the beach, notably its width. Supposing a constancy in the developmental process for the studied coasts over the next 30 years and applying a

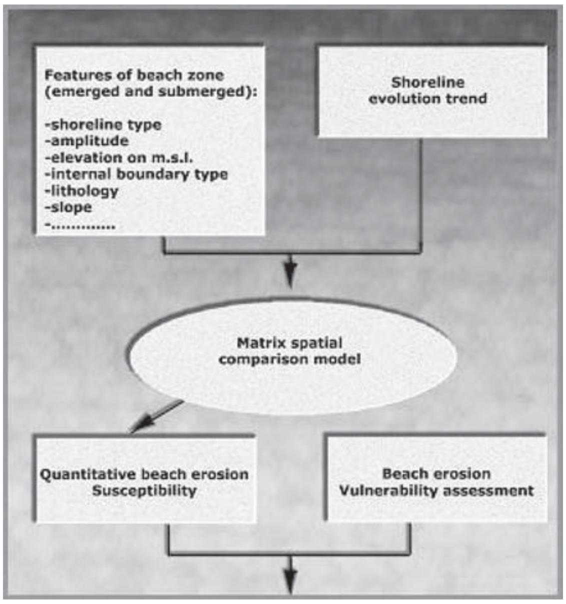

Fig. 2. Methodological steps in CoSTAT.

matrix model (Fig. 3) a quantitative evaluation of coastal erosion susceptibility could be achieved. Within each CHU all other significant features can be considered essentially as constants

The model is based on the ratio between the value of sea-land boundary shift in the analysed period (from time T_0 to T_1) and the beach emerged at time T_1. The outcome is a quantitative estimation of coastal erosion susceptibility for emerged beach areas, i.e. the probability of loosing natural elements (the beach) in a defined time span – in this case 30 years. The estimated susceptibility values SV are arranged in four classes of coastal erosion susceptibility (Fig. 3):

- Very high: SV > 2;
- High: 1 < SV < 2;
- Medium: 0.5 < SV < 1;
- Low: SV < 0.5;

It is important to clarify that the sea-land boundary extracted from the available (past and present) cartography (from scales 1 : 10000 to 1 : 25000) will be used in future spatial comparisons while considering accuracy limits as imposed by the cartography used. The system used at present cannot detect movements of less than 30 m. This is indicated in the thematic maps by lines which are as thick as the maximum possible error they contain. This refers in particular to movements of the sea-land boundary. It should also be noted that we cannot yet correct for variations in tidal height, weather conditions, and date and hour of every ortho-image.

At present the CoSTAT application does not give a risk assessment: the data base contains part of the basic information to sustain this final step, but there is a lack of information on the economic use of the beach. The susceptibility model does not include either an evaluation of the adjoining coastal dunes, but it is intended to include these in the future. At present there is only a note on the presence or absence of coastal dunes as derived from the ortho-images.

Results

The methodology in its present state was applied to a coastal stretch in southern Italy which was selected for the presence of important signals of erosion in recent years: the Ionian littoral in the Basilicata Region, between the Bradano and Basento river mouthes, constituting a CHU. The retreat of this coastal stretch is mainly due to a decrease in sediment supply from the dammed rivers. The intrinsic features of the beach are derived both from past studies and direct surveys, and analyses (Cocco 1976).

Intrinsic indicators for coastal erosion susceptibility and risk assessment are homogeneous because the entire littoral tract has a continuous beach of fine sands at 2-3m above the present sea level, and the sea-land boundary always extends towards N30° E. The sea bottom slope (from the shoreline to the 5 m isobath) ranges from 0.8 to 1%.

The sandy beach is bound landward by coastal dunes and a historical pinewood. Further landward there is a wide zone of reclaimed land, lying below the present sea level, where vegetables are grown, partly in glass-houses. Up till now there are no major engineering works to protect the coast.

This part of the littoral is largely free from permanent buildings, but there are some bathing facilities. There is a plan to destroy part of the coastal dunes close to some holiday villages with the main aim of obtaining car parks near the shore.

The coastal dunes behind the beach make up a discontinuous formation that is generally only a few m high. In many places there is surface or linear erosion and dunes are reshaped where the actual beach width range from some to some hundreds of m. The state of the coast here is subject to increasing deterioration in all

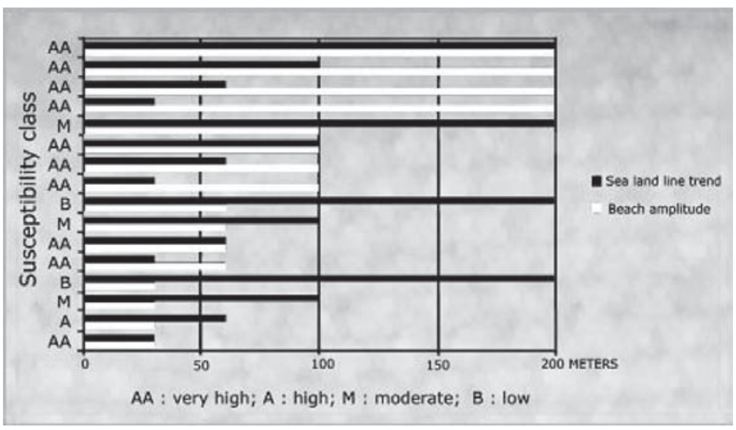

Fig. 3. Cross-relationships matrix model for the erosion coastal susceptibility assessment. AA = very high; A = high; M = moderate; B = low.

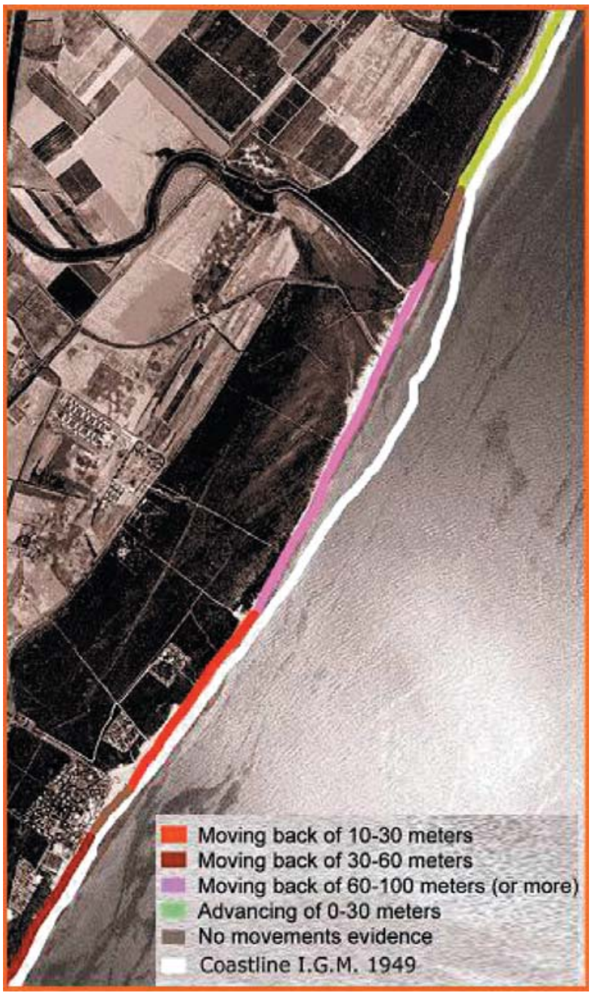

Fig. 4. The sea-land boundary trend in the past 30 yr in a Ionian littoral tract between the Bradano and Basento mouths.

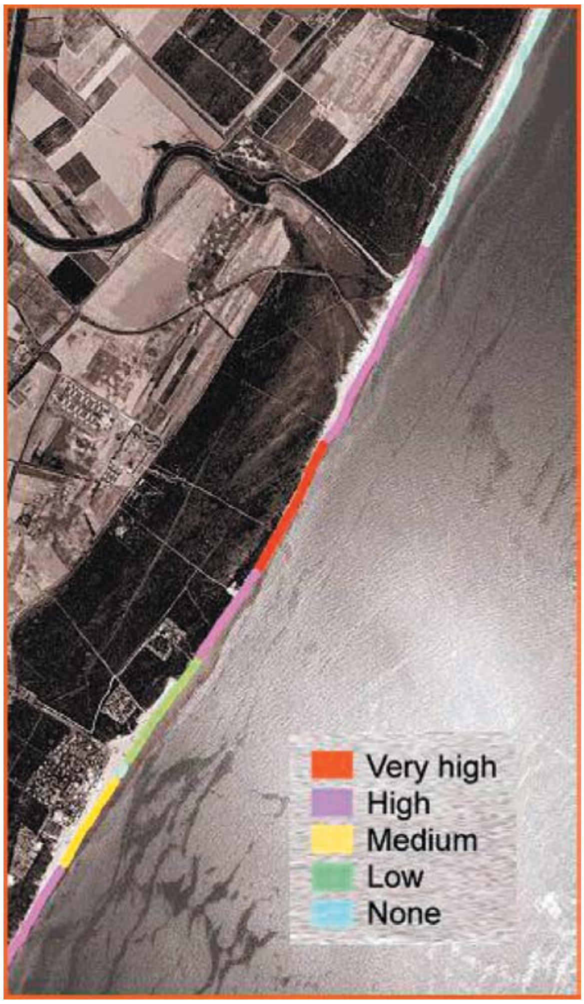

Fig. 5. Assessment of coastal erosion susceptibility in a Ionian littoral tract between the Bradano and Basento mouths.

environments which induces different effects: retreat of beaches, disappearance of coastal dunes, decline of the pinewood due to salinization of the freshwater.

Even if the littoral as a whole shows an erosive trend (Fig. 4), the susceptibility assessment for coastal erosion in the test area (Fig.5) shows a picture which is different from Fig. 3 which shows the risk for disappearance of the beach over the next 30 years. This general picture does not always correspond to the actual development.

Conclusions

Coastal erosion in Italy, as in other Mediterranean countries, is a very serious problem even if the changes are small as compared to other coastal stretches. Still, the social, ecological and economic significance of these losses could be enormous. During the last 40 years, many engineering works have been carried out without controlling coastal dynamics. Recently, again as in other countries, attention to the coastal problem and management is growing in Italy but an adequate policy towards sustainability is still missing.

The present paper aims to stimulate attention, also in the scientific community, to the relevance of surveys and research projects with implications at the country scale. Moreover the results achieved show the possibility to set up tools to sustain different intervention choices based on economic or ecological criteria and the proposed methodology could be the starting point of a broader use of this approach as a beginning of the application of a ICZM approach.

There is a large variation in interests affecting Mediterranean coastal areas and we need basic knowledge about the coastal state in terms of natural risks – as could be provided by CoSTAT or similar models – which offers to stakeholders more than a scientific analysis, but a real tool to be used for objective, systematic and quantitative information on the coastal zone.

The economic relevance of beaches in countries such as Italy makes it necessary to present support through detailed economical and ecological analyses and to refer to national or European strategies. Conflict management in coastal areas may, in fact, be difficult at the local scale. In the longer term a supranational approach would be better for solving the problem of the fragmentation of institutional competences on coastal areas.

The CoSTAT system is now at the starting point of its broad application; a first tool will be available for national policies. We are aware of the limits of the approach and of the data available, but, as explained above, the system could easily develop further when new data are included. With this aim we will continue with the project within the institutional programmes of ENEA. Finally, a CoSTAT analysis, as any other approach at the national level, cannot substitute any local detailed survey. Still, it will be very helpful to integrate detailed local surveys in a national framework.

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