Landform characteristics and the impact of human structures on the coastal area of Pozzallo (South Sicily, Italy)

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Abstract

A geomorphologic approach, combined with GIS tools, was used to investigate a 26 Km long coastal sector in South Sicily, Italy, affected by important erosive processes. The applied methodology allowed for a database to be obtained involving all coastal characteristics, providing helpful information on coastal processes and general sediment circulation patterns. Coastal erosion, mainly linked to the construction of a port, was locally contrasted by the construction of hard structures, especially rip-rap revetments and breakwaters, generating environmental stress in the downdrift area. Nowadays a nourishment project has been planned to solve existing erosive problems, but there is still the lack of a general erosion management plan that should be principally based on the installation of a by-passing system.

Keywords: erosion, port, Pozzallo, Sicily.

1 Introduction

Coastal retreat is the landward displacement of shoreline because of marine erosion or flooding [1]. Usually, it is contrasted by protection works constructed on very specific sites, to solve concrete and urgent problems. Most of them constitute a temporary remedial without a general erosion management
plan [2 and 3]. According to [4, 5 and 6], coastal erosion management must be organized at fully scales (i.e. at a large, regional scale) in which the dynamics of the whole coastal system is represented. In this sense, [7, 6, 8 and 9], affirm that for a deeply understood of coastal erosion problems it is important to know the areas of inputs, transfers, storage and outputs of sediments.

This paper would like to be a “first step” in the direction of improving the general knowledge of erosion problems and sediment circulation patterns within a 26 Km long coastal sector in South Sicily (Italy). Obtained results are useful information to develop an integrated coastal erosion management program aimed to partially solve erosion problems and review location of human activities and arrangements.

2 Study zone

Administratively, the study littoral belongs to different municipalities within the Ragusa Province, South of Sicily, Italy (figure 1). Coastal zone, E-W elongated and Southward exposed, is composed by sandy beaches of different width, rich in quartz (≈ 65%), carbonates (≈ 30%), containing also feldspars and heavy minerals [10 and 11].

![Figure 1: Landforms and human occupation along the study area.](image)

Beaches are backed by dune ridges and cliffs, cut in sandstones, marls and limestones, dividing littoral in morphological cells [5]. No significant sedimentary inputs derive from cliff retreat because eroded sediments are generally too fine, being rapidly winnowed by waves and currents. Fluvial inputs [10 and 11] are not significant because many of the rivers are predominantly derived from chalk catchments. Additionally, sediment supply, important at an historical scale, was greatly restricted because of weirs and dams that favour rivers silting up during summer periods and, in last decade, because the artificial canalization of rivers and streams to avoid the flooding of urbanized areas.

Dealing with marine climate, the zone is a “microtidal environment” [12], principally affected by winds blowing from the second and third quadrants.
According to KNMI data (Leo observations), most important storms hit the coast preferentially from the third quadrant, with deep water values of significant wave height ($H_s$) of 8 m and 11 sec. associated period ($T$). Less important storms approach from the second quadrant with $H_s = 5.5$ m and $T = 10.5$ sec. Due to coastal orientation, the studied sector is stricken by storms approaching from East and West directions that give rise to important longshore currents, and from south approaching directions, that form a predominantly cross-shore transport.

During the last decades, the study area has recorded a great increase of human activities, constituting an important economic resource for the hinterland. Nowadays, many man-made structures or recreational activities are threatened by coastal retreat. In order to counteract this process, breakwaters and several rip-rap revetments were built when destruction of property was imminent, without any adequate plan or consideration of their long term side-effects.

### 3 Methods

According to [13, 14, 15 and 16], landforms characteristics and land use activities of the study area were obtained through several field observations and the analysis of recent aerial photographs and topographic maps. Following [17, 18, 19, 20 and 21], aerial photographs were scanned, geo-referenced and computer rectified to solve scale and distortion problems [22, 14 and 23]. Two data sets were used: the aerial photographs of 1977, at an original scale of 1:16,000, and the one, geo-referenced, of 1999 at scale 1:12,500, both realized by the Sicilian Regional Administration. In a further steep, beach dimensions were measured with GIS tools on the geo-referenced aerial photos, and coastline evolution was reconstructed. Ground Control Points (GCPs) for the 1977 photo registration were obtained from the 1999 ones. Taking into account the smooth topography of the study area, an affine transformation ($1^{st}$ order) was applied in the registration process [24]. The number of GCPs used varied from one photograph to another, ranging form 10 to 14 units. Their position was located in unequivocal places such as groins and building corners according to [25]. The error in the geo-referenced photographs was controlled with the RMSE (Root Mean Square Error).

Shoreline position, which can be identified with seaward vegetation limit, dune foot, etc. [15 and 26], in this work was defined as “the water line at the time of the photo”.

### 4 Results

#### 4.1 Landform units

A schematic distribution of landforms, human occupation and coastal structures are presented in figure 1.

#### 4.1.1 Beaches

Littoral is mainly composed of open and pocket fine-sand beaches of different dimensions, from hundreds of meters to several kilometres. The longest beach is
Santa Maria del Focallo, extended 11.2 Km, and the smallest one is close to Point Ciriga.

The dry beach width is about 30 m, with wider beaches observed updrift, or in correspondence, of human structures or natural headlands (figure 1). Morphological seasonal changes are on the scale of tens of meters, being wider beaches observed during summer time, i.e. from June to August [27].

Beach face slopes are usually very smooth and consist of fine sands. Field observations show that the nearshore zones present smooth slopes (1-2%) characterized by large surf zones with spilling breakers, typical of dissipative beach states [9 and 28]. One or more longshore bars are often observed and control breaking wave processes. Finally, the gentle nearshore slope favours wave refraction processes and wave fronts usually arrive at the shoreline with a small approaching angle.

4.1.2 Dunes
Their morphodynamic is related to the action of dominant winds that blow from the third quadrant, giving rise to generally small W-E elongated incipient foredunes and single dune ridges, parallel to shoreline. Ridges (2 to 6 m in height) are developed especially at Santa Maria del Focallo beach (figure 1), where they present a degraded vegetal cover composed by Mediterranean bushes. In other areas vegetal cover consists of pioneer plants. In the area of study, there are only few sedimentary supplies also during fair weather condition. The foredunes have almost disappeared and dune ridges suffer periodical erosion during winter periods in the most part of littoral. By the other way, great quantities of sediments are landward transported because of aeolian processes, being definitely lost to sedimentary budget.

4.1.3 Cliffs
Cliffs and promontories, 6-7 m in height, are a quite common morphology along the Ragusa Province littoral. Rocks with a low degree of resistance are constituted by the sandstones of the Pleistocene marine terraces and the Low Miocene marls that outcrop at Pietre Nere and at Point Ciriga (figure 1). These “weak” rocks are mainly affected by landslide rock falls types due to wave erosion at the foot of the cliff. The presence of rock blocks at cliff foot, remnant of previous falls, should have the function of reduce cliff erosion but, during heavy storms, sea waves overpass them and reactivate erosive processes.

4.2 Human constructions and interventions

4.2.1 Coastal occupation
Dealing with urban development in the study littoral, it was greatly increasing during the last decades, as in other Mediterranean areas. Small, pre-existing villages, with fishing or agricultural activities as a primary source of life, recorded a great expansion, and essentially linked to the construction of summer houses vacated to the local tourist demand. The table 1 show the changes of numbers of inhabitants in winter and summer time for the most important villages present along the study littoral.
Table 1: Population of most important villages along the littoral.

<table>
<thead>
<tr>
<th>Village</th>
<th>Winter population</th>
<th>Increment during summer time</th>
<th>Total population in summer time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampieri</td>
<td>1,000</td>
<td>18,000</td>
<td>19,000</td>
</tr>
<tr>
<td>Marina di Modica</td>
<td>3,000</td>
<td>25,000</td>
<td>28,000</td>
</tr>
<tr>
<td>Pozzallo</td>
<td>17,500</td>
<td>5,000</td>
<td>22,500</td>
</tr>
<tr>
<td>Santa Maria del Focallo</td>
<td>0</td>
<td>8,000</td>
<td>8,000</td>
</tr>
</tbody>
</table>

4.2.2 Ports and harbours
Small marinas and pier rope haulages exist at several places, such as Marina di Modica, Sampieri and Pozzallo. These areas, initially used for traditional fishing purposes, nowadays host small pleasure boats.

Pozzallo port, the biggest one in the Province, presents an 1864 m long, N-S oriented, main dock, and a maximum depth of 15 m. It was constructed in the seventies to support the industrial activities developing in the hinterland. This structure, still underused, is devoted to pleasure and fishing boats and cargo ships. The port blocked longshore sediment transport, with sand accumulation at East side, close to the structure. As a consequence, beach facilities and recreational structures have been greatly implemented during last years on this enlarged beach (figure 2).

![Figure 2: Accretion recorded East of Pozzallo port.](image)

4.2.3 Protective structures
Among the defensive structures, detached breakwaters of calcareous blocks were built along the littoral to stop more than to prevent coastal retreat, resulting in the
downdrift shifting of erosive problems. Nowadays, the great majority of them are connected to the shoreline by tombolos (figures 1 and 3).

Sea walls and rip-rap revetments are also present in very narrow coastal sectors, usually to preserve summer houses. Location and characteristics of protective works are presented in Table 2.

### Table 2: Characteristics of most important protective structures.

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Material</th>
<th>Number</th>
<th>Unitary length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pietre Nere beach</td>
<td>breakwater</td>
<td>rocky blocks</td>
<td>1</td>
<td>140</td>
</tr>
<tr>
<td>St M. Focallo beach</td>
<td>Rip-rap revet</td>
<td>Concr. blocks</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Point Ciriga</td>
<td>breakwater</td>
<td>rocky blocks</td>
<td>4</td>
<td>75</td>
</tr>
</tbody>
</table>

A nourishment project was designed for Santa Maria del Focallo beach to stop erosive processes linked to the Pozzallo port and the breakwaters at Point Ciriga. This project is not still founded because considered too expensive (11,000,000 €), for the high cost of the borrow sand.

## 5 Discussion

Study littoral is divided in several cells of different dimensions, within which sediments circulate. Effects of coastal embaymentisation, because of natural and artificial structures, are quite evident on beach plan form and surf zone circulation.

Concerning cell boundaries, these are places characterized by discontinuities in rate or direction of sediment transport: they can be “fixed”, if stabile, or “transient” or “free”, if their position changes with time [5 and 7].

![Figure 4: Surfaces of beach erosion and accretion (km²) calculated around Pozzallo area comparing the 1977 and the 1999 aerial photographs.](image-url)

In study littoral the former are essentially associated to engineering structures, the latter are not necessary associated with any morphological. This way, small
headlands and cliffs observed along the study littoral allow periodic bi-
directional transport that, according to field observations, takes place along
narrow zones parallel to shoreline, extended to a variable depth, depending on
wave conditions and bottom morphology. Furthermore, headlands bypass takes
easily place because of sand transport on the top of longshore bars. Bypass
processes occur frequently in correspondence of small headlands, while in
correspondence of most important ones (Sampieri and Marina di Modica),
sediments trespassing is more difficult and takes place during important storms.

By the other way, Pozzallo port causes artificial compartmentalisation, more
important than natural one. It constitutes an artificial, fixed and absolute limit,
that block littoral transport giving rise to important accretion updrift and huge
depletion downdrift.

In order to have a first, broad idea of recent littoral evolution and predominant
littoral transport effects, main zones of accretion, erosion or stability, were
determined taking into account aerial photographs of 1977 and 1999 (figure 4).

At the origin, Pozzallo port was composed by an offshore dock enlacing with
land by a piper that not greatly affected littoral drift. In the eighties, the original
structure was modified by the construction of a new East pier in order to protect
the port from the waves coming from the third quadrant.

As can be observed in figure 4, shoreline advancements were recorded in
different areas: in Maganuco, and immediately East of the port (figure 2) and,
especially, in Pietre Nere (66,000 km²). A small accretion was also observed in
correspondence of the breakwater constructed in Pietre Nere and diffuse erosion
took place west of the structure. Santa Maria del Focallo and Point Ciriga
beaches recorded general erosion too.

Previous results seem to be related with the action of waves and currents from
the second and third quadrants that generate opposite transports, both affected by
the presence of the structure (figure 4).

By one way, waves and currents approaching from the East accumulate
sediments in Maganuco that is protected by the second quadrant approaching
waves because of the port.

By the other way, the prevalence of waves and associated currents from the
second quadrant accumulate sediments close to the East side of the port where
they can not be removed by waves from the third quadrant, because in the port
lee side. The consequent erosion is recorded at east of the port, in Pietre Nere,
where a summer house was protected a breakwater, and in Santa Maria del
Focallo beaches, where the littoral road, greatly damaged by erosive processes,
was protected by concrete blocks.

Important sediment sinks are also related to wind processes, especially to the
ones from western directions that favour eastward dune migration. Examples of
this process are quite common at Marina di Modica (figure 5) and Santa Maria
del Focallo. In these places, small incipient foredunes and well developed,
unvegetated dunes migrate landwards with a consequent loss of sediments. Sand
is transported inland, sometimes covering coastal roads that need periodic
maintenance. Recollected sediments are not injected in beach system and are
accumulated in city dumps.
Figure 5: The rapidly landward migrating avalanche face of a well developed dune at Marina di Modica.

Other, significant sediment sinks are related to different measures and modalities used by local Administrations in port dredging works or beach cleaning processes. Sediments and algae are periodically dredged in Pozzallo port (Table 3) and in correspondence of other smaller structures, being these works always carried out under remedial and urgent conditions, without any kind of management plan. This way, great quantities of sands were in the past accumulated in dumps or injected offshore, in deep water, subtracting them to the sedimentary budget.

Table 3: Volumes of dredged sediments.

<table>
<thead>
<tr>
<th>Location</th>
<th>Period</th>
<th>Dredged volumes (m³)</th>
<th>Destination of dredged sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pozzallo port</td>
<td>1982-1995</td>
<td>1,150,000</td>
<td>3,700 Km offshore</td>
</tr>
<tr>
<td>Pozzallo port</td>
<td>2000</td>
<td>unknown</td>
<td>Pietre Nere beach</td>
</tr>
</tbody>
</table>

Furthermore, modalities of beach cleaning and maintenance, based on the removing of large quantities of leaves of *posidonia oceanica* or other marine phanerogams, usually accumulated on beaches during summer and autumn periods, produce the abstraction of large quantities of sediments and favour beach erosion.

6 Considerations

In studied littoral, coastal erosion was contrasted by the construction of hard structures generating important environmental stress in downdrift areas. Nowadays a nourishment project has been planned to solve existing, local erosive problems, keeping in mind that a healthy beach is the best form of coastal defence and has a maximum recreational benefit.

Moreover, there is still the lack of a general erosion management plan that should be principally based on:

i) the installation of a port by-passing system,

ii) the dismissal of actual beach cleaning and port maintenance procedures that substrate a great quantity of sediments and

iii) the control of inland wind transport.
The realization of these objectives and actuations requires further studies to identify small, independent shoreline management units, and quantify littoral sedimentary budget within each unit and the whole littoral.

References