Cartography and remote sensing for coastal erosion analysis

M. Basile Giannini, P. Maglione, C. Parente & R. Santamaria
University of Naples "Parthenope", Department of Applied Sciences, Directional Centre of Naples, Italy

Abstract

Italian coasts are subjected to morphological modifications that in the last decades have, in many cases, been the cause of considerable coast-line withdrawal. A detailed cognizance on dynamics and relative consequences on territory and environment is necessary to plan actions for limiting these events and their impacts. Reconstruction of temporal shoreline changes can be realized using historical and recent maps, remote sensed images and topographic survey results. Because of the heterogeneity of these data, their different levels of accuracy must be considered. In this paper one of the most emblematic Italian shorelines affected by erosion, the Domitian shoreline located in Northern Campania Region (South Italy), is considered. GIS environment is used to compare ancient and recent maps as well as remote sensed images. Cartographic layers include IGMI (Istituto Geografico Militare Italiano) products from 1876 to 1984, on a scale 1:25.000 or 1:50.000. Others are an aerial photo (1:10.000) produced in 1998 and an IKONOS panchromatic image acquired in 2005. Taking into account the heterogeneity of these documentations, to realise comparisons of their contents, all layers are related to the same cartographic datum (Gauss-Boaga Roma40), so a reconstruction of the coastal evolution from 1876 to 2005 is obtained.

Keywords: coastal erosion, GIS, historical maps, high resolution remote sensed images, accuracy.

1 Introduction

In Europe, every year, an area of about 15 km^2 is lost or seriously impacted by erosion. In fact from 1999 to 2002 over 250 houses were abandoned because of

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coastal erosion risk, while the value of another 3,000 houses is decreased by at least 10%. The undermining of coastal dunes and sea defences has augmented the risks of coastal flooding, so several thousands of square kilometres and millions of people are threatened. Erosion phenomena are induced by a combination of natural as well as human factors: the first include wind, near shore currents, sea level rise, vertical land movement; the second include coastal engineering, gas mining and water extraction, dredging, vegetation clearing. The combination of the coastal erosion, infrastructure development and the erection of defences to protect them have decreased the extensions of many coastal zones. (Doody *et al.* [1]).

The erosion process for sandy beaches includes three phases: dissolution, transport and deposition of sediments. The interactions are closely related to the dynamics of the water column on which waves, tides, coastal currents, geodynamic and climatic phenomena are active. Until the middle of last century the effects caused primarily land advancement; later, this trend was reversed because of anthropogenic pressures and, more recently, changes in sea level related to the greenhouse effect. The most severe effects in the medium term are related to the work of man.

To repair the damage and to mitigate the future impacts, phenomena models must be prepared using all available data to reconstruct evolution of shoreline, such as ancient and recent maps, air photo and satellite images.

2 Study area

The area considered concerns Campania coastal zone named Domitian that is located between the following latitudes (referred to WGS84 datum):

$$\phi_1 = 40° \; 57' \; 12'' \; N$$
$$\phi_2 = 40° \; 56' \; 19'' \; N$$

Regarding the situation resulting at 2005, the extreme longitudes of the area referred to Greenwich are:

$$\lambda_1 = 13° \; 59' \; 57'' \; E$$
$$\lambda_2 = 14° \; 00' \; 33'' \; E$$

The period extends from 1876 to 2005.

The area is included in the territory of Castelvolturno and it is shown in the following figure, fig. 1. The Domitian coast is the edge of the Campanian Plain. It is limited by Aurunci (North-West), Caserta (North), Avella (North-East) and Lattari Mountains (South). The Plio-Pleistocene coastal graben is filled by powerful layers of alluvial materials of the Volturno and Garigliano Rivers and pyroclastic deposits of the Roccamonfina and Campi Flegrei volcanic complexes. The physiography of the place is described by the tangential directions to Cape Point and Miseno Banner – Gaeta. The prevailing wave (70% frequency) comes from the west northwest and it is associated net transport towards the south-east coastal. The area study has a temperate Mediterranean climate. Rainfall is concentrated

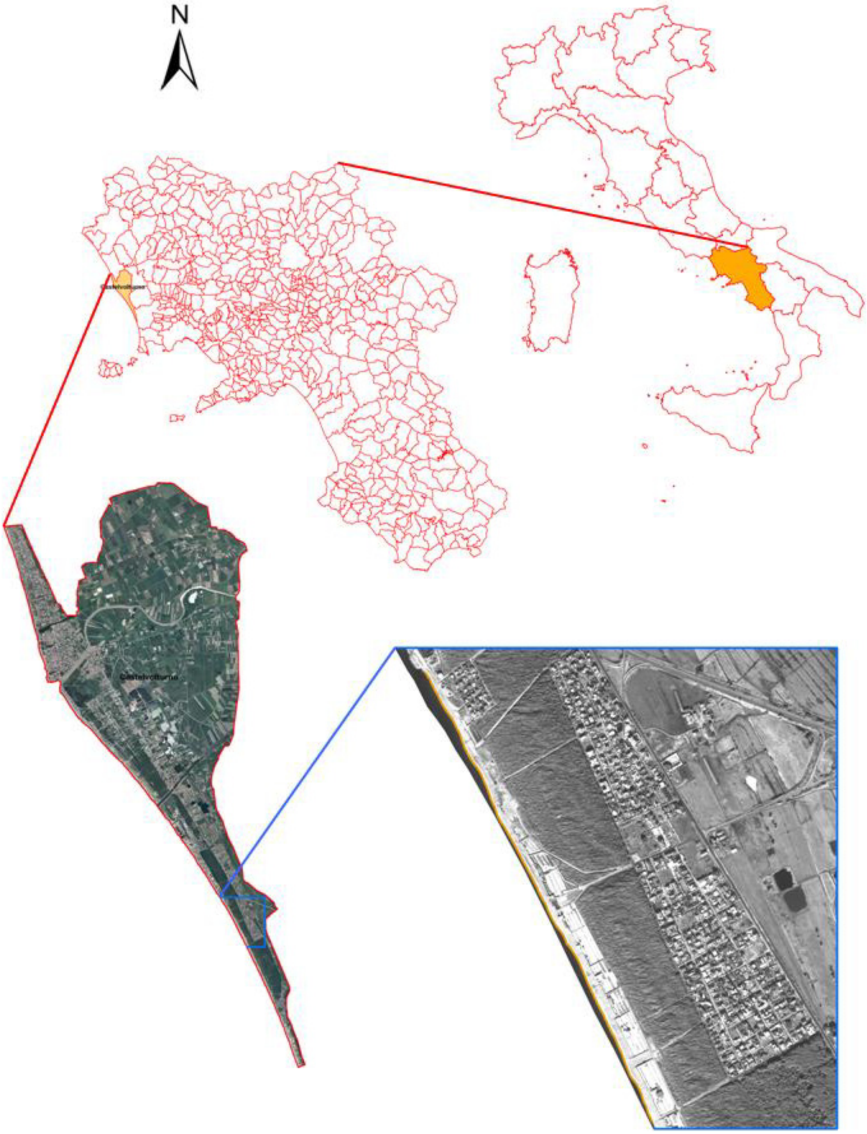

Figure 1: Castelvolturno and study area territorial framework.

during autumn and winter and usually has its maximum in the months of October and December. The minimum rainfall occurs during the period of summer (from May to September) with minimum in July. The prevailing winds on the coast are those coming from the west and southwest (Gatto [2], Cocco *et al*. [3, 4]).

3 Data set and early elaboration

In this paper six information sources concerning Domitian coast are considered. The first two are paper maps referred to Bessel ellipsoid:

- IGM map named “Marano di Napoli” (1876), in scale 1:50.000;
- IGM map named “Lago Patria” (1905), in scale 1:25.000.

In Bessel’s datum, the geodetic coordinates of the origin are: ϕ_0 = 41º 55′ 25″.42 N and λ_0 = 12º 27′ 14″.00 East of Greenwich, (for consequence λ_0 = 00º 00' 00" because considered the national Prime Meridian), and with an azimuth to Monte Gennaro: α_0 = 62º 38′ 20″.03. These geodetic coordinates were derived from the astronomic observatory of Capodimonte near Naples. The projection of these maps is the Natural or Samson-Flamsteed projection (Surace [5], Clifford *et al*. [6]).

The third and the fourth paper maps are referred to Hayford ellipsoid and they are:

- IGM map named “Lago di Patria” (1954), in scale 1:25000;
- IGM map named “Quagliano” (1984), in scale 1:25.000.

For both maps Hayford ellipsoid is oriented on Potsdam in Germany (ED50 datum). The projection is the Universal Transverse Mercator (UTM) (Bezoari *et al*. [7]).

The fifth information source is a digital aerial ortho-photo produced by Campania Region in 1998, in scale 1:10.000, and referred to Gauss-Boaga Roma 40 datum.

The last one is an IKONOS panchromatic (digital) image. It is acquired on 11.04.2005 and referred to WGS84 datum.

Obtained raster files of the four maps, georeference operations have been conducted with GIS software.

For georeferencing maps and remote sensed image polynomial functions (PFs) are usually applied (Errico *et al* [8]):

$$P_n(X,Y)=\sum_{i=0}^{m_1}\sum_{j=0}^{m_2}a_{ij}X^iY^j \tag{1}$$

where, if n is the level of polynomial function, the following relations must be satisfied:

$$0\le m_1\le n;$$
$$0\le m_2\le n;$$
$$m_1+m_2\le n.$$

The coefficients a_{ij} of the polynomials are computed using points named Ground Control Points (GCPs) of which coordinates (X, Y) in the original image as well as (X’, Y’) in reference to cartographic datum are known. The minimum number of points required for the computation of the coefficients is given by the formula:

$$N = \frac{(n+1)\cdot(n+2)}{2} \tag{2}$$

Additional data are used to get the optimal transformation with the smallest overall positional error in the selected points. These errors are originated by poor positioning of the mouse pointer on the image and by inaccurate measurement of coordinates on the map. The accuracy of the transformation is indicated by the average of the errors in the GCPs as well as in other additional points named Check Points (CPs).

In this application IGMI maps in Samson-Flamsteed projection have been georeferenced with 2th order polynomial functions while for the other ones 1st order PFs have been sufficient. Statistical characterizations of the results are shown in tables from 1 to 4.

Table 1: Residuals (in meters) obtained for the 8 Ground Control Points used to georeference the IGMI map named “Marano di Napoli” (1876).

	Δxy medium (m)	Δxy minimum (m)	Δxy maximum (m)	σ_{xy} (m)
Polynomial Function 2nd order	**5.39**	**1.67**	**12.71**	**4.24**

Table 2: Residuals (in meters) obtained for the 12 Ground Control Points used to georeference the IGMI map named “Lago Patria” (1905).

	Δxy medium (m)	Δxy minimum (m)	Δxy maximum (m)	σ_{xy} (m)
Polynomial Function 2nd order	**2.97**	**1.26**	**5.26**	**1.25**

Table 3: Residuals (in meters) obtained for the 17 Ground Control Points used to georeference the IGMI map named “Lago di Patria” (1954).

	Δxy medium (m)	Δxy minimum (m)	Δxy maximum (m)	σ_{xy} (m)
Polynomial Function 1st order	**0.92**	**0.14**	**1.84**	**0.47**

Table 4: Residuals (in meters) obtained for the 18 Ground Control Points used to georeference the IGMI map named "Quagliano" (1984).

	Δxy medium (m)	Δxy minimum (m)	Δxy maximum (m)	σ_{xy} (m)
Polynomial Function 1st order	**2.69**	**1.18**	**5.28**	**1.12**

IKONOS panchromatic image (pixel size: 1 m x 1 m; spectral band: 0,45 µm – 0,90 µm) is a product named GEO with accuracy of 25 meters (Space Imaging [9]). To ensure better accuracy, a clip of this image concerning only the study area has been considered and re-georeferencing operation has been conducted using polynomial functions, with 30 GCPs; also 15 Check Points (CPs) have been introduced for better evaluation of the accuracy, fig. 2. Plane coordinates in Gauss-Boaga Roma40 of GCPs as well as CPs have been derived from the above mentioned aerial ortho-photo. Satisfactory results have been obtained with 5th order transformations.

Figure 2: IKONOS Pan image with Ground Control Points and Check Points used for georeferencing.

Statistical characterizations of the results are shown in table 5 for GCPs and in table 6 for CPs.

To obtain a correct overlay, also the four IGM maps have been reported in Gauss-Boaga Roma 40.

Table 5: Residuals (in meters) obtained for the 30 Ground Control Points to georeference the IKONOS image.

	Δxy medium (m)	Δxy minimum (m)	Δxy maximum (m)	σ_{xy} (m)
Polynomial Function 5th order	**0.62**	**0.04**	**1.94**	**0.49**

Table 6: Residuals (in meters) obtained for the 15 Control Points to georeference the IKONOS image.

	Δxy medium (m)	Δxy minimum (m)	Δxy maximum (m)	σ_{xy} (m)
Polynomial Function 5th order	**0.97**	**0.33**	**1.72**	**0.41**

4 Shoreline evolution

Every single coastline considered has been obtained by vectorizing the coast profile from geo-referenced maps or remote sensed images concerning different periods, fig. 3.

The study of the shoreline evolution has been conducted considering pairs of temporally consecutive coastlines and evaluating, for each pair, the surface of the beach eroded or added, and its metric accuracy, fig. 4–5.

Particularly graphical errors (0.2 mm referred to scale) for maps, spatial resolution for remote sensed images, georeferencing and datum transformation errors have been considered, taking into account propagation of variance (Cina [10]).

Propagation of variance for a linear case (such as the combination of graphical and georeferencing errors) is supplied by:

$$\sigma_y^2 = a_1^2 \cdot \sigma_1^2 + a_2^2 \cdot \sigma_2^2 + \ldots + a_n^2 \cdot \sigma_n^2 \tag{3}$$

for $y = a_1 * x_1 + a_2 * x_2 + \ldots + a_n * x_n$.

Propagation of variance for a nonlinear case (necessary to calculate eroded and added area) is supplied by

$$\sigma_y^2 = \left(\frac{\delta f}{\delta x_1}\right)_{(0)}^2 \cdot \sigma_1^2 + \left(\frac{\delta f}{\delta x_2}\right)_{(0)}^2 \cdot \sigma_2^2 + \ldots + \left(\frac{\delta f}{\delta x_n}\right)_{(0)}^2 \cdot \sigma_n^2 \tag{4}$$

for $y = f(x_1, x_2, \ldots, x_n)$.

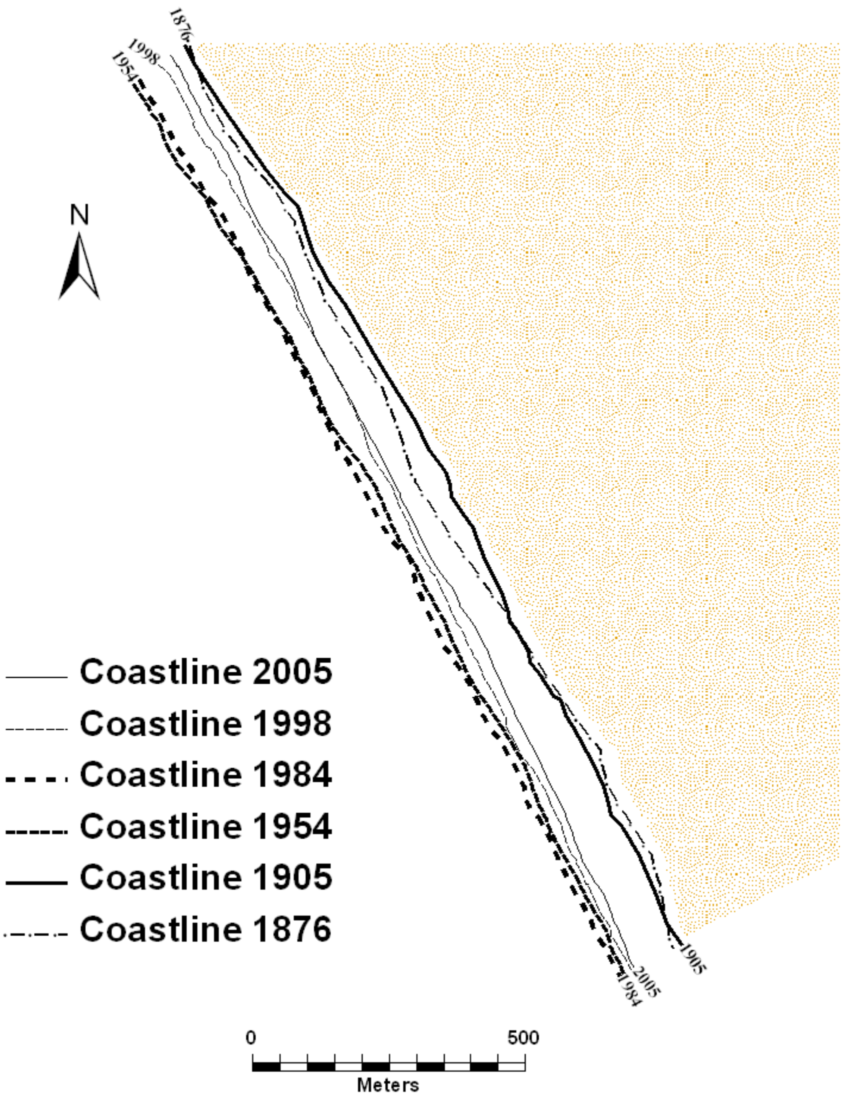

Figure 3: Coastline evolution from 1876 to 2005.

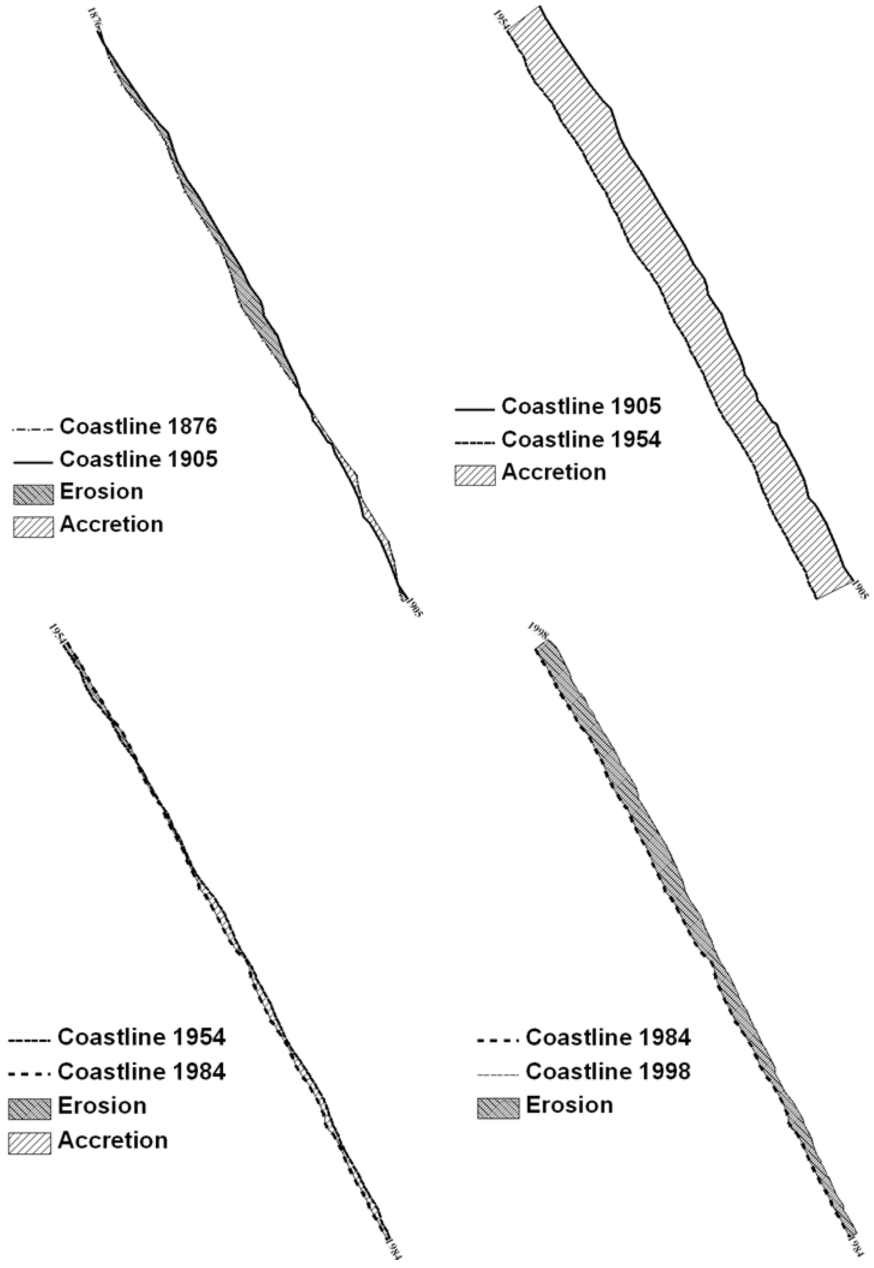

Figure 4: Shoreline evolution for each pair of temporally consecutive coastlines from 1876 to 1998.

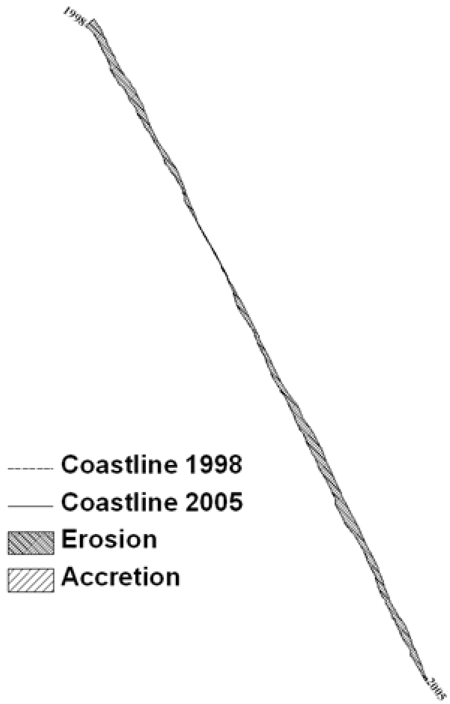

Figure 5: Shoreline evolution for each pair of temporally consecutive coastlines from 1998 to 2005.

The results are shown in the following table (Table 7).

Table 7: Eroded and added area for each time period.

Time period	Eroded Area (m^2)	Added Area (m^2)
1876 – 1905	**28356± 2586**	**8276 ± 1397**
1905 – 1954	**0**	**227118 ± 3471**
1954 – 1984	**4469 ± 484**	**17783 ± 966**
1984 – 1998	**75026 ± 1983**	**0**
1998 - 2005	**26541 ± 256**	**287 ± 27**

5 Conclusions

The conclusions to be drawn from this work are of two basic types, some about the methodological aspects, others the evolutionary process of the considered coast that is emblematic of the erosion processes that affects a considerable part of the Italian coasts.

Regarding methodological aspects, it should be noted that the availability of maps and high-resolution remote sensed images can provide useful data for the reconstruction of coastal dynamics. Considering the accuracy of different information sources and the law of propagation of variance, a quantitative analysis of the erosion magnitude and the reconstruction of the evolutionary framework are possible. The working environment consists of the most useful GIS. A fundamental role is played by the geo-referencing of information layers that often, because they refer to different historical periods, have different cartographic datum.

The overlap is possible using geometric transformations based on Ground Control Points whose coordinates can be obtained either directly from maps or, in the case of remote sensed images, from topographic survey or by comparison with other already georeferenced sources in the same datum taken as a reference. Regarding evolutionary aspects of the Domitian coast, it is interested, from 1876 to 1905, by coastal dynamics that determine the contemporary presence of eroded parts and added ones. From 1905 to 1954 only natural beach nourishment growing up and again from 1954 to 1984 eroded and added areas are present. From 1984 to 1998 there is only erosion that continues, although with less tight rhythms, until 2005, deadline for this study.

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