COASTAL DYNAMICS: SHORELINE DETECTION IN SICILIAN BEACH

Giorgio Manno*, Vincenzo Liguori, Carlo Lo Re, Giuseppe Ciraolo
Dipartimento di Ingegneria Civile, Ambientale e Aerospaziale (DICAA), Università degli Studi di Palermo, Viale delle Scienze Bldg. 8, Palermo, Italy

Abstract:

In our days Sicilian coast suffer of severe erosion, with a total of 1139.3 km2 of coastal area, 20% of them are in advancement and 33% in recession. Shoreline position and its celerity of changing in time, can provide important informations for bulwark design (e.g. breakwater, seawall, ecc.) and to develop coastal management plans. The shoreline is located between land and sea, it has dynamic nature and for this reason it is subjected to change, both in short and long term. These changes are caused by geomorphological processes (making of bars, berms, ecc.), hydrodynamic (wave motion, tides and currents) and by unexpected and quick factors as storms and tsunami. Therefore, the analysis of the shoreline variability, in terms of erosion and expansion, is crucial for an overall understanding of these phenomena. This research examines the issues related to the uncertainty to identify the shoreline position, that changes in time, as above mentioned. The study was done considering geological, geomorphological and hydraulic aspects. The case study investigated is represented by Marsala (Trapani) shoreline. The beach has sandy sediments from Holocene age. These sediments are in continuity of sedimentation on whitish debris composed by organic limestone from Pleistocene age. The diachronic analysis was carried out on both emerged and submerged beach and has also provided a geomorphological characterization performed in situ. Geomorphological-descriptive data, measured in situ, have been compared to remote sensing data. It should be noted that the comparison between orthophotos and maps is subjected to several uncertainties, due to graphics and geo-referencing errors. Moreover, it has to be stressed that the values of tidal and climate waves are related to the particular acquisition time. As a matter of fact it was necessary to perform a maritime hydraulic study in order to take into account the sea fluctuations during the considered period. The run-up is related to the height and length (or period) of the waves, as well as to the composition and particle size of the beach sediments, that determine the beach slope (Nielsen and Hanslow, 1991). The obtained results allowed to assess the uncertainty and the consequent errors in the evaluation of the shoreline position, for fixed slopes. In particular, it was found that, in many cases, it is not possible to assess the shoreline rise and fall, for values lower than 30 m.

Keywords: coast, beach, shoreline, waves, tides.

1. Introduction

The shoreline erosion has direct consequences on geomorphological and ecological systems of the environment, since these are fragile systems, and extremely vulnerable to the antrophic impact. The shoreline is defined as the intersection between low sea tide and land surfaces, and spatially divides maritime and terrestrial water bodies [1]. A long time deficit of sediment income causes the regression of the shoreline, highlighting a local equilibrium rate of sediment and consequently the dynamical nature of the beach [4]. An accurate diachronic analysis requires the knowledge of the uncertainties in the shoreline positioning, which are both of hydraulic and remote sensing typologies. Traditionally, shoreline is three-dimensionally mapped by means
of stereography on aerial photographs that, where available, are used to detect past shoreline position \[2\]. However these studies allow retrieving only the instantaneous position of the shoreline that should also be considered from a temporal point of view. This research aims to take into account both wave and tide effects, acting during the image acquisition, on the user shoreline digitization. Each wave instantaneously determines the shoreline motion; the sea-wave of operational interest depends on the “ordinary sea-storm”.

2. Geological And Geomorphological Characterization

The Marsala coastal zone is a geological plane having NW-SE principal direction; its altitude is slightly decreasing from NE to SW (sea direction). The landscape is characterized by a constant and regular morphology, typical of the wide coastal planes that were modelled and smoothed by Quaternary sea action. The beach is located in the south of Marsala town and extends for approximately 3 km between Torre Tunna (northern headland: \(37^\circ45'32.26''N, 12^\circ27'40.00''E\)) and Torre Sibilliana (southern headland: \(37^\circ43'36.31''N, 12^\circ28'11.23''E\)). Geological lithology close to the ground surface, is made up by calcarenitic coastal sediments of Quaternary Age, which were modelled by periodic eustatic oscillation. Following a trasgressive phase during the Mean Pleistocene, a calcarenitic-sandy plate formed above the Marsala calcarenites (named Grande Terrazzo Superiore - G.T.S. after Ruggeri and Unti, 1974 \[18\]). Seven maritime terraces lie between the G.T.S. and a Versiliano terrace \[19\] at increasing depths (3, 10, 20, 30, 50, 75 and 100 m u.s.l.). Terraces were identified by alternating steps and erosion planes due to sea regression, highlighting the coastline morphology in recent geological periods. The beach is made up of monogrernular thin sand (102-103 μm) with sparse diagenesis in the Torre Sibilliana area \[19\].

3. Methodology

Methodology includes several steps aiming to estimate the uncertainty in shoreline positioning (Fig.1) by means of remote sensing data, namely: the geological and geomorphological characterization of the study area, in order to identify the sediment size and composition constituting the beach and determining its average slope; the diachronic analysis through orthophotos acquired for suitable period to identify erosion phenomena; georeferencing, mosaicking of the images and digitization of the shoreline at a suitable scale; the characterization of the ordinary sea-storm for each wind direction and year; the wave motion propagation from offshore to nearshore; the estimation of the ordinary sea-storm maximum run-up; the displacement computation of the shoreline due to tide influence. Wave motion plays the most important role in characterize the instantaneous shoreline position \[12\]. In order to study the wave propagation from off to near shore the geographic aspect of the coast needs to be known. It allows calculating the wind sector in terms of angle amplitude, wind direction, blind sectors due to islands interferences. Once identified the wind sector, wave data recorded by the southern Mazara del Vallo buoy were acquired.

The buoy is part of the National Wave-meter Network (Rete Ondametrica Nazionale) and is located (37°31'00''N, 12°32'00''E) near the Mazara del Vallo harbor \[12\]. In order to describe the methodology, the term “ordinary sea-storm” needs to be defined. A sea-storm is a succession of sea states during which the significant wave height, \(H_s(t)\), is usually greater than a critical threshold, \(h_crt\), while it is lower than the threshold only for periods shorter than \(\Delta t_{crt}\). To simply retrieve the ordinary value, records were filtered.
Fig. 1. To left, the hydraulic maritime study. To right the topographic and morphological characterization.

Fig. 2. To left: computational domain (dashed line) of the study area, with wind and critical wave directions. To right SWAN outputs: arrows indicating the waves propagation direction over imposed to the significance waves height [m] shown by a colour scale.
and sea storms were grouped, for each year, depending on 30° sectors centred on 12 incoming directions ranging between 15° and 345° N.

For each sea-storm height peak values were retrieved and the average time period was calculated. The height peak was been propagate with a spectral wave model (SWAN: Simulating Waves Nearshore - Fig. 2) and then calculate horizontal run-up with the empirical formula (Nielsen and Hanslow, 1991). To quantify the maximum tide level aiming to retrieve the effect of tide oscillation on the shoreline position, records of the close Porto Empedocle marigraph were used (37°17′11.20″ N, 13°31′37.30″ E). The station is part of the marigraph national network (Rete Mareografica Nazionale) set-up by ISPRA. The marigraph recorded homogeneous data suitable to be used within this case study during the decade ranging between the 1st of January 1998 and the 26th of October 2008.

4. Study Area And Results

In order to accurately assess both linear and surface variations of Lido Signorino beach in the last 12 years, a GIS based model has been set-up. Orthophotos acquired between 1994 and 2006 (Figure 4) built up the dataset. It includes the grey scale Volo Italia 1994 images characterized by 1 m nominal spatial resolution (RS), the color scale Volo IT 2000 (RS= 1m) and the Volo IT 2006 (RS= 0.5 m). The images were georeferenced in a common projection system (UTM WGS84 33N) with an accuracy 1m. Surveyed beach bathymetry (May 2010) was used to represent the true bathymetry and a common reference to compare the shorelines. Georeferenced images were mosaicked over the whole littoral zone and the shoreline was digitized for each year using a GIS platform. The comparison highlights errors due to both digitizing accuracy (2 m) as well as to the spatial resolution, georeferencing accuracy, instantaneous tide and waves.

By analysing the coastline morphology, the wind sector amplitude is 131° and ranges between 195° and 300° N clockwise, however the close island of Favignana (the Egadi archipelago) blinds the northern part of the sector narrowing it to 105° (195°÷300° N). The buoy records vertical oscillation within 20 m (0.01m resolution and 3% accuracy) and between 0°÷360° (1.5° resolution and 0.5°÷2° accuracy). Wave heights, Hs [m], maximum and mean wave periods, Tp and Tm [s] and wave direction, Dm [°N], between the 1st of July 1989 and 4th of April 2008 were acquired and processed applying a geographic transposition, to take into account the differences in wind exposition between the beach and the boundary of the calculation domain. A wave propagation analysis from off to near-shore allows the retrieval of the beach run-up. The ordinary value has been assumed as the minimum of the peak values for each sea-storm, since it is reached at least once a year during the observational period. The shoreline analysis has been carried out on the 285° N direction, characterized by the more frequent sea-storms and higher peaks. The significant wave height is Hs = 5.62 m, with a period Tp = 10.11 s These values were used for SWAN model. The graphical output of a generic simulation is reported in Figure 2. By analysing those data, the significance height Hs = 5.32 m and period T = 7.79 s for given bathymetry (-60 m) have been retrieved, that were successively used for the run-up assessment. The average slope of the foreshore beach is tan βf = 0.0836, (Figure 3) and assuming Horms = 3.76 m (0.706 Hs), mean wave run-up is estimated to be about 10.89 m.

Since maxima fluctuations within the study period resulted in about 0.4 m and the average beach slope is 8.36 % the shoreline positioning uncertainty due to tide variation is 4.78 m.
Fig. 3. Vertical profile, orthogonal to the shoreline, of Lido Signorino beach (Marsala).

Fig. 4. Shoreline position and maximum run-up during the 1994 (left panel), 13/05/1999 (central panel) and 27/08/2005 (right panel) acquisitions.

5. Discussion and Conclusions

The proposed methodology, even if in a preliminary phase, allows evaluating tides and waves influence in positioning the shoreline through remotely sensed images. These are often the only tools available to build-up the morphological evolution of a beach in the last decades with sufficient accuracy. Shoreline positioning through airborne images are often affected by uncertainty in the user visual interpretation of the wet/dry boundary of a beach, due to both waves and images characteristics at the acquisition time. The study case shows that wave motion, together with local sea characteristics, produces a positioning error of about 30 meters. Shoreline and run-up delimit a zone strictly dependent on ordinary sea storm, during which they are both submerged and that therefore should be assumed as respect zone and should undergoes the rules of the maritime state property. Uncertainties due to sea level fluctuation, causing an error of ≈ 10 m, must be superimposed to those caused by the run-up (≈ 10.89 m). Methodology limits are strictly related to offshore buoy data quality and availability. Run-up has been estimated using an empirical relationship retrieving an accurate value, even if the implementing of a hydraulic model to verify shoreline position is actually in progress. However the knowledge of maritime conditions during the remote sensing overpass is fundamental to rigorously verify the positioning.
References


