# Shoreline Detection from Very High Resolution Satellite Images

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**Abstract.** In the last 50 years, the inhabitants of the 19 municipalities along the Abruzzo coast have doubled and a stronger impact of the activities connected with the tourism has been experienced. The area, naturally exposed to the effects of changes of the sea level, has been characterized by a dramatic increase of erosion, due to the reduction of the solid transport from rivers to sea, as a consequence of extensive works carried out on the watersheds, to mitigate extreme rainfall and consequent flooding. The availability of data acquired by different sensors on the last few decades might be useful to assess the overall accretion/erosion trend of coastline, whereas combination of different observations taken in a restricted timeframe, may provide interesting inputs for detailed studies. In the present study, a methodology is proposed for the coastline identification from WorldView-2 images, available in 8 spectral bands, with 0.5 m and 1.8 m of spatial resolution for the panchromatic and the multispectral channels respectively. In particular, a pixel based multispectral classification is used to identify various types of land cover. The 8 bands allow to get good results, both in the classification process and with NDVI, NDWI, SAM, FM algorithms, for the identification of various land cover and in particular to separate dry from wet sand. Interesting results were obtained testing an algorithm to evaluate the relative depth of the water using the "coastal blue" band. Interesting results provided the comparison of the estimated coastline with such methodology and a topographic map of same area. This comparison highlights the changes in the study area. There are many possible applications of the proposed techniques, such as map updates and coastal change monitoring.

**Keywords.** WorldView-2, Abruzzo, multispectral classification, coastline.

## 1. Change detection in coastal environment

### *1.1. Introduction*

The coastal environment represents the transition area between land and sea. It is a natural and economic resource of extraordinary value, but it is subject to a continuous and constant transformation. The coastal environment is in fact a highly dynamic system where the erosion (coastline advance or recession) is influenced by several factors, meteorological, geological, biological and anthropogenic. For example, the growing urbanization of the coastal territory since World War II, linked to a social and economic developing, with the continuous evolution of industrial, commercial and touristic-recreational activities. The coastline detection is a complex issue, starting from the uncertainty to identify a clear and universally accepted definition of the coastline itself and then to define appropriate methods of coastal monitoring and its changes. Currently, remote sensing is becoming one of the most relevant methods for this kind of study, thanks to many advantages of this technique (ability to capture large areas in one image, high geometric resolution of the satellites sensors, ability to acquire the scene in multiple spectral bands.

### *1.1. Coastline changes*

The term "dynamic coast" indicates the complex phenomena that govern the coastline evolution over time. The description of the coastline evolution requires an analysis of river and marine dynamics; in fact coasts receive most of the sediments that nourish the beaches from land by rivers. The sea, through the action of waves and currents, contributes significantly to model the coastal shape, performing a triple action of erosion, transport and accumulation of coastal sediments. Such modeling work of the sea, can determine the coastline recession when the erosive effects prevail, or a progress if the accumulation processes prevail. Often both phenomena act simultaneously in adjacent coastal areas. In Italy, two main morphological types of natural coasts are found to alternate:

- high and rocky coasts (morphologically rough coast, with very steep walls, often sub-vertical, parallel to the shoreline), about 34% of the total;

- low and sandy shores (more or less extensive beach in very weak slope, with the possible presence of dune systems) for approximately 58%.

The coastline amplitude can be influenced from the subsidence and eustasy effects. Subsidence is a long-term process of slow subsidence of the ground linked to natural constipation of fine sediments in floodplains, often exacerbated by the extraction of water and hydrocarbons from subsoil. The term eustasy indicates changes in the long term, positive or negative, of sea level, connected to climatic factors [1].

Furthermore, sudden coastline variations can be induced by tectonic movements, mostly associated with strong magnitude earthquakes. An important morphological parameter comes from the study of the historic changes of the shoreline, which allow performing various analyses to define the natural tendencies of coastline evolution. Thus, it is possible to identify areas subject to local erosion or enhancement due to construction of coastal works, to calibrate numerical models of shoreline’s evolution and to estimate the solid balance sheet of the coastline.

### *1.2. Coastline detection*

The coastline is a portion of land that contains the emerged and submerged areas (Figure 1) and is subject to continental and marine geomorphologic processes. The shoreline determination and its restitution is a key element in the coastal environment’s monitoring for emerged and submarine zone.

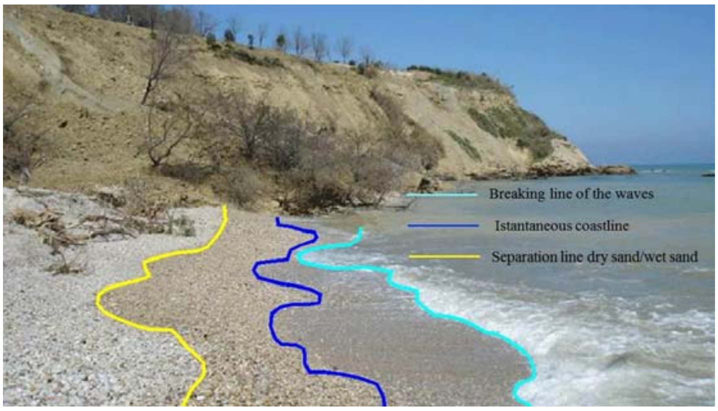


Figure 1: Limits identified in coastal environment.

The coastline is the clearest expression of how this sector is particularly dynamic, requesting to record the changes more or less immediately [2].

The evaluation of the coastline's position and its changes, is an important consideration for scientists, engineers, and other operators involved in coastal management. The position of the coastline and its historical change can provide important information for the design of coastal protection works, coastal development plans, the calibration and verification of numerical models [3]. As well as the continued interest for the coastal areas, the risk and consequences of the development of anthropogenic structures are very important (on the coast are concentrated over two-thirds of world population).

Therefore, the coastline's planning has to be supported by the monitoring of the shoreline by means of repeated surveys often to correct the seasonal variability of the singularities induced by intense storm and to identify more efficient methods for its extrapolation, reaching a good compromise between accuracy, cost and time. An effective monitoring requires the development of technologies capable of providing useful contributes to the protection, prevention, intervention and management.

There is no single method to model the coastline, which would be commonly accepted by coastal communities, although in the last decade a great progress in mapping technology has been reached. For example, the development of new and more accurate GPS equipment, new and very high resolution satellites and the availability of very efficient devices for the assessment of coastal topography such as LIDAR (Light Detection and Ranging) [4].

### *1.3. Current techniques for coastline mapping*

In this paper, the acquisition methods of submerged beach are not considered, but focus is made on the techniques of emerged beach survey. Currently the most common methods in use are [5], [6], [7]:

- Geodetic survey and GPS (RTK), allowing high accuracy (millimeter with geometric leveling, centimeter with total stations and GPS positioning systems), but provide a survey for single points only;
- Aerial photography, which needs to be orthorectified (through the knowledge of a DSM), but provide a continuous survey, representing the entire study area at the time of the acquisition; the accuracies obtainable are at centimeter or subdecimeter level, but the costs are high;
- Airborne videography, based on a similar approach to aerial photography, where the camera is replaced by a video-camera. This technique is promising, but its application may focus more on qualitative recognition of changes rather than on quantification of changes, due to a general lower resolution of the data;
- Video systems that allow continuous (typically every hour) collection of image data with a resolution from centimeters to meters. Typically they are composed by four to five video cameras, spanning a 180º view, and allowing full coverage of about four to six kilometers of beach. The scanned image is oblique and must be orthorectified and geo-referenced [8].
- Remote sensing; it is a technique increasingly competitive compared to the other afore-mentioned, especially with reference to high resolution satellites of last generation. Compared to photogrammetry it allows a very speed data acquisition and processing with comparable accuracies due to the high spatial resolution. The ability to record the scene in multiple spectral bands is also important: it allows for much more information than the visible bands and can create thematic maps of the area using multispectral classification.

The short revisiting time (a few days) also allow carrying out monitoring studies of the area under examination, by means of images acquired at different times.

### *1.4. WorldView-2 imagery*

WorldView-2 was launched on October 8, 2009. It is the first high resolution commercial satellite with 8 multispectral bands; in fact WorldView-2 includes 4 new bands at 1.8 meter of spatial resolution in addition to the standard 4-band (blue, green, red and near infrared): coastal blue, yellow, near infrared, and rededge-2 (Figure 2). It works at an orbital altitude of 770 km and can simultaneously collect panchromatic imagery at 0.46 m and multispectral imagery at 1.84 m of spatial resolution. The high spatial resolution allows discrimination of a lot of details, such as vehicles, the shallow waters and the individual trees, while the high spectral resolution provide detailed information on various areas such as quality of road surface, the sea depth and plant health.

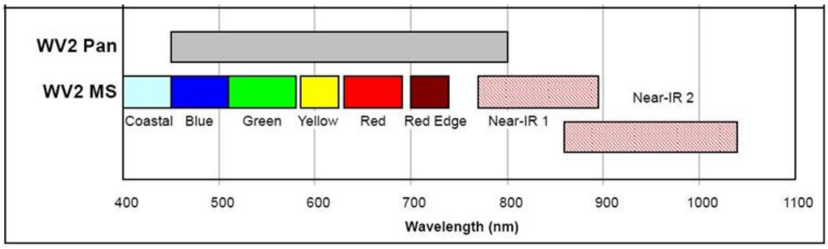


Figure 2: Spectral bands of the WorldView-2 satellite.

These bands offer several advantages to users in the identification of a greater number of ground cover classes (e.g. more variety of vegetation), in the extraction of a greater number of features, in monitoring changes in the use of the soil and any building abuses and violations and in displaying images more realistic, very similar to the natural human vision. Further information on WorldView-2 satellite can be found at http://www.digitalglobe.com [9].

## 2. Experimentation

### *2.1. Study area and available data*

The image used in this experimentation was a WorldView-2 image, representing a portion of the coast of Ortona (Chieti, Abruzzo) as shown in Figure 3.

Ortona is located on the shores of the Adriatic Sea and except for the first part where there is a large sandy beach, present a high rocky coast. The land alternates between flat and hilly areas.


Figure 3: Study area.

In this work we want to test the ability to automatically detect the coastline (or rather the instantaneous coastline) from that image. In particular, our research is directed at an identification of an algorithm that allows the coastline extraction in automatic or semi-automatic mode. All process were performed using the commercial software ENVI 4.7 of Exelis Visual Information Solutions, software for display, analyse and classify different types of digital images [10].

*2.2. Single band analysis and bands combination*

The first operation performed in this work was the pansharpened creation of a representative zone of the study area (Figure 4), through the algorithm Gram-Schmidt which allows to integrate the geometric detail of the panchromatic image (0.5 m of spatial resolution) with the radiometric information of the eight multispectral bands but with lower spatial resolution (1.8 m) to produce a multispectral image with high resolution (Figure 5).

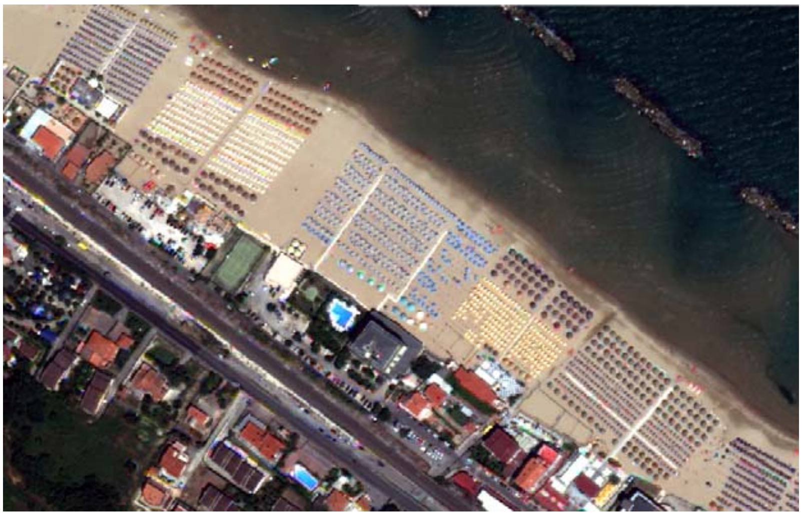

Figure 4: Pansharpened image.

Figure 5: Multispectral, panchromatic and pansharpened image.

Pixel-based classification techniques have been applied on that image and some algorithms useful for the vegetation and water study were used (such as the NDVI vegetation index and the NDWI normalized index) in order to better define the coastline location.

The Normalized Difference Vegetation Index is a simple algorithm to estimate the vegetation density and condition, which exploits the different response of the vegetation to the spectral bands of the visible (red) and near infrared, and provides a dimensionless numerical value between -1 and +1. It is calculated by:

$$NDVI = \frac{NIR - R}{NIR + R}$$

It can be also used to obtain useful information about the coastline; in fact it assumes values between -0.1 and -0.5 at the separation from sand/water.

The Normalized Difference Water Index is used to study the areas covered from water. It is similar to NDVI but using the green band instead of the red one.

$$NDWI = \frac{NIR - G}{NIR + G}$$

With this algorithm, water assumes positive values, while terrain and vegetation have negative values; dry sand, due to its high reflectance in green band and in near infrared band, is characterised by positive values but near to zero.

*2.3. Vegetation and water automatic detection*

The ENVI software enables a complete analysis about the vegetation in the image, using the information contained in the red and infrared bands by vegetation delineation algorithm. This algorithm automatically creates three classes of vegetation (sparse, moderate and dense) that can be used in a multispectral image classification as Region of Interest (ROI) (Section 2.4). Performing a cross-section to the coast line on the image obtained by the algorithm NDVI, a sharp change of slope of the curve at the points of passage sand-sea can be seen (Figure 6).

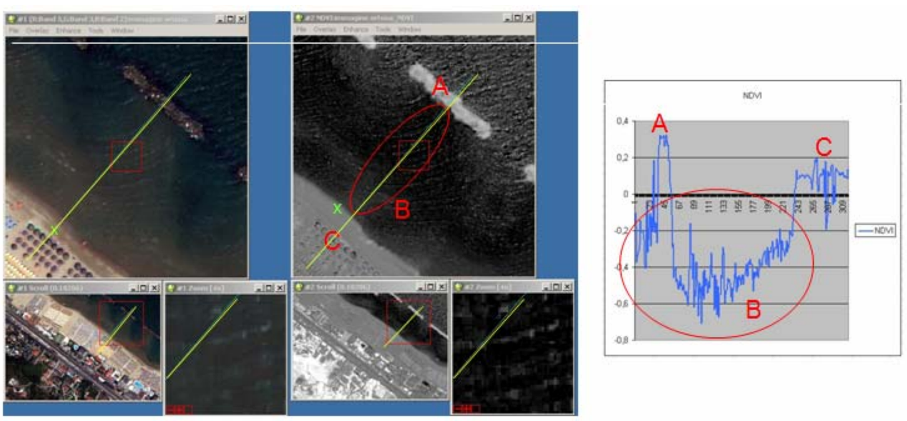


Figure 6: RGB image, NDVI, cross section.

A similar process allows to study the presence of areas covered by water, using the information contained in the green, blue, red and infrared bands, and separating them into Muddy Water and Dark Water, through the algorithms MF (Matched Filtering), SAM (Spectral Angle Mapper) and their ratio that shows the best separation between the dry sand and the wet sand with a sharp change of the slope of the curve (Figure 7).

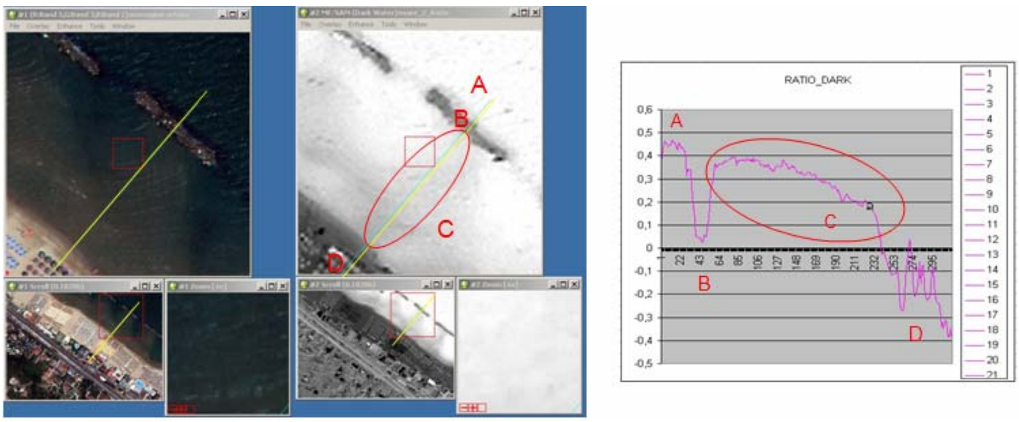


Figure 7: RGB image, MF/SAM, cross section.

Another algorithm used in image processing shows a clear separation between the sand and the sea is the Relative Depth. This tool uses a bathymetry algorithm developed by Stumpf and Holderied (2003), which correlates the various bands in the multispectral image, in particular the coastal and blue bands. The "Relative Depth" function allows a useful analysis of the seabed at depths up to 14 meters (Figure 8) though not representing the absolute depth of the water present in the study area (values range from zero to one).

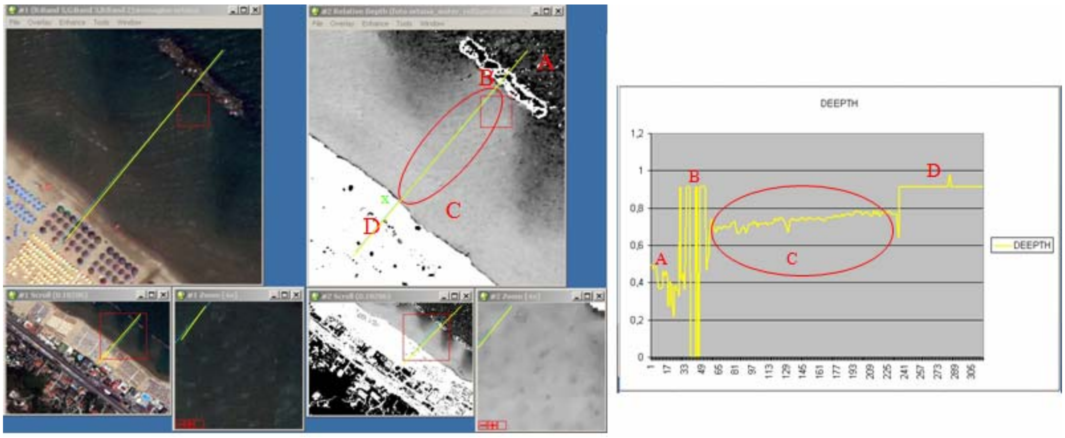


Figure 8: RGB image, Relative Depth, cross section.

In Figure 9, all curves obtained at the same section representing the indices NDVI, NDWI, FM, SAM, FM/SAM and the Relative Depth were superimposed. All curves have similar trend, especially in correspondence of the passages between dry sand-wet sand and wet sand-water, in which there is a sharp change of slope (dashed lines).

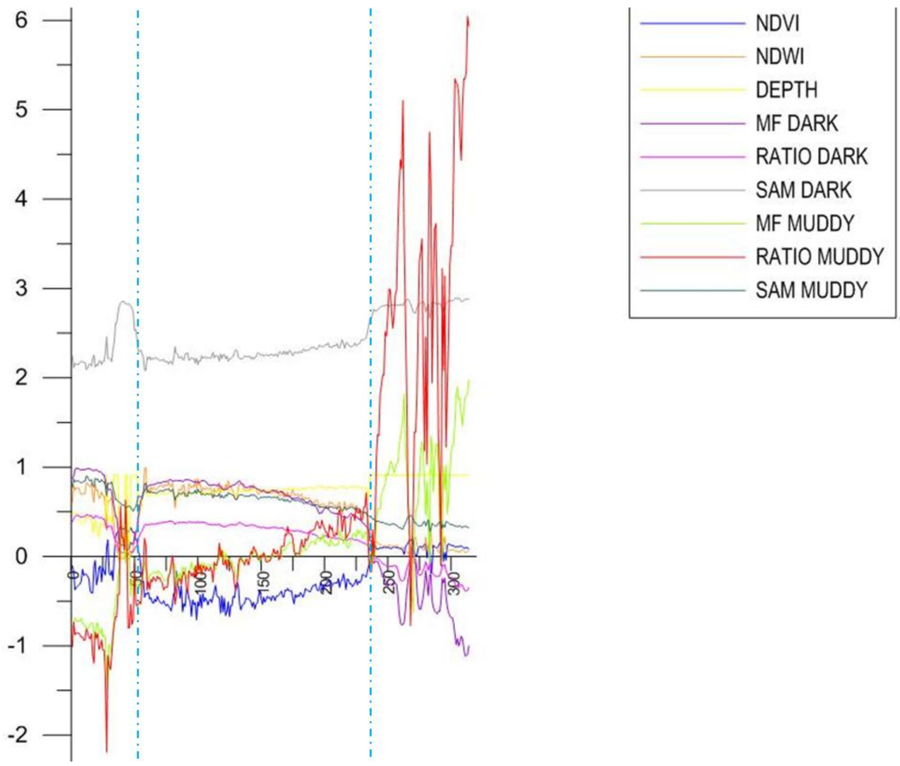


Figure 9: NDVI, NDWI, SAM, FM, FM/SAM, Relative Depth.

*2.4. Multispectral classification*

Finally, a supervised multispectral classification using Maximum Likelihood algorithm was performed on the study area. Several regions of interest (ROI) have been defined including 4 different types of buildings, dry sand, wet sand, roads, pools, sidewalks, shade, water and three classes of vegetation identified automatically by the tool vegetation delineation. As a result, a new image was obtained in which each pixel is associated with a digital number representative of the corresponding class of land cover (Figure 10).


Figure 10: Classified image.

Classification works well with buildings and vegetation, as for the separation of dry sand-sea-wet sand. The separation between these classes can be vectorised obtaining a shapefile used for further analysis. For example, one can compare the instantaneous shoreline obtained from satellite imagery with the one shown on existing maps, so an update of it can be obtained (Figure 11). This process may seem inaccurate because it assumes that the instantaneous shoreline and coastline are coincident, however in many technical specifications of regional maps (including the Region of Abruzzo), it has predicted that the coastline must be vectorised as visible on individual frames and then in reality to examine the instantaneous shoreline.

Figure 11: Coastline superimposed on regional map.

The comparison shows that the present coastline (red) has not significantly changed compared to 2003, the year of the last update of the regional map of Abruzzo, so we can suppose that there has been a very little erosion.

*2.5. Relative Depth*

The results obtained evaluating the relative depth are very interesting: using the new “Coastal Blue” band useful information for the study of coastal areas can be obtained, due to its penetration of the clear water, up to 14 m of depth. Using this band in the calculation of Relative Depth, the sand and the sea cliff assume constant value equal to 0, while the trend in correspondence of the sea shows the shape of the seabed (Figure 12).

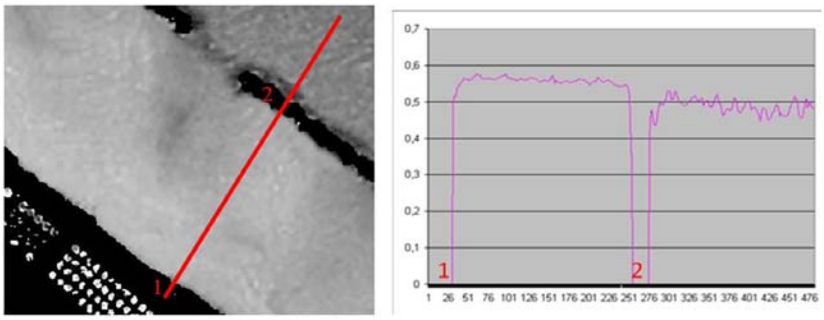


Figure 12: Relative Depth with coastal band.

If these results are integrated with bathymetric information, the absolute depth of the sea could be obtained, "scaling" the values of relative depth on the actual values of the absolute depths, for example found by bathymetric curves mapped on the IGM25 maps and derived from those of the Istituto Idrografico della Marina (Hydrographic Institute of the Navy) that has made using various techniques over the years. In this study, we have used absolute depth data detected by IGM maps and the relative depth was scaled by functions "raster math" obtaining the absolute values of depth. The median filter was used to eliminate the "noise" present on the image because the roughness present seemed excessive for this type of seabed. Finally, a section of the coastline was carried out and the profile shown in Figure 13 was obtained.

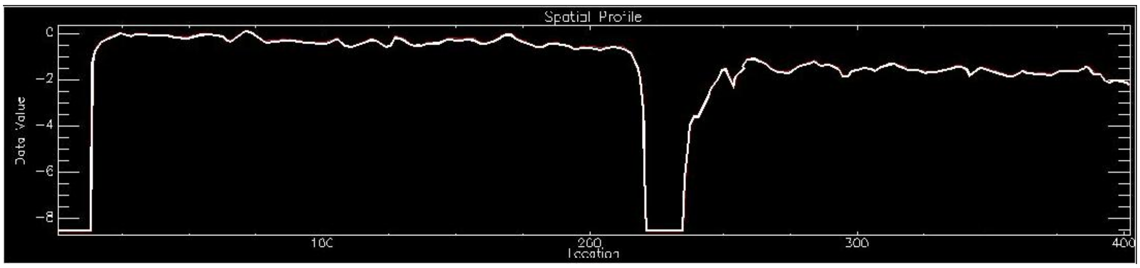


Figure 13: Absolute depth.

The shape of the seabed obtained is very similar to the expected one, from a depth value equal to 0 on the coastline to a max of -2.20 m in accordance with the bathymetric contours reported on the IGM cartography, although with some peak values probably due to the proximity to the shore and the presence of the breakwater.

This shape can be observed by extracting the contour line of the bottom (Figure 14). The morphologies revealed by circular bathymetric lines, not entirely compatible with the known morphologies of the seabed in that area, could be due to the large degree of detail of information or to the "noise" of the technique not yet been properly modelled.

Figure 14: Contours of seabed.

## 3. Conclusions

In order to test the accuracy and reliability of the procedures experimented in this work, a comparison has been mage between the shoreline extracted from satellite images and the one obtained by map, by GPS, by traditional geodetic survey carried out before and after the dates of the image. For a better validation of the test, it can also be assessed by integrating the results obtained from the WorldView images with altitude information obtained by the intersection between a digital model of the surface (from stereo images or existing maps) and a properly calibrated geoid model of the study area. As for the absolute depth, a comparison with a bathymetric survey conducted in the same area will be carried out in order to evaluate the deviation of the depth identified by the image and the actual one. The results, which surely need to be integrated and validated, constitute an important input for the use of the proposed methods for a possible update of the regional technical maps, with particular refer to the shorelines updating. In fact, the control techniques used (topographic, GPS surveys, and aerial photogrammetry), even if valid for their accuracy, still may not be particularly practical and economical for a continuous monitoring of the coastal zone. In particular, remote sensing offers the possibility to process the same area in short time, making use of these products for the continuous monitoring of the coastline much faster and more convenient compared to other surveying techniques.

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