

Comparative Analysis of the Remotely Sensed Coastline with Geological Cartography: The Case Study of the Puglia Region

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Abstract. As part of the Polytechnic of Bari's research project on the evaluation of the geological risk in the coastal environment (DICATECH), the planimetric position of the coastline of the Puglia Region was analyzed using a digitally extracted orthophoto made available from the Office of the State Property of the Puglia Region in 2017.

Remote sensing data analysis led to the geometric extraction of the shoreline from orthophoto maps through automatic extraction and visual digitization techniques. Particular attention was paid to the geological analysis of the coast, with respect to its morphological characters. A comparison study was conducted using the most recent cartographic surveys available on the official geological cartography (CARG project).

The results have allowed a more detailed and in-depth definition of some aspects of geological cartography and the various elements of geohazard as well as a clearer reconstruction of the mechanisms of interaction between the various processes involved in geohazard.

The detailed analysis of some of the most representative cases has also confirmed the complexity of the coastal issues and highlighted some crucial questions about the making of geological cartography and coastal maps of the ongoing CARG project to further investigate.

We call for a greater in-depth knowledge of the geomorphological and meteomarine characteristics of the coastal environment to observe its evolution through accurate and continuous monitoring over time. This allows the analysis of evolutionary trends and both natural and anthropogenic factors influencing the delicate balance of the coastline.

1 Introduction

As part of the Polytechnic of Bari's research project on the evaluation of the geological risk in the coastal environment (DICATECH), the planimetric position of the coastline of the Puglia Region was analyzed using a digitally extracted orthophoto made available from the Office of the State Property of the Puglia Region in 2017.

Starting from a summary of the geomorphological and evolutionary characteristics of the Apulian coast as can be deduced from the most recent sector studies, a scientific

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method was followed that is able to contribute to the updating of the thematic supporting cartography to identify and evaluate the degree of geological risk, by virtue of the geometric evolution conditions of the Apulian coastline.

A Bibliographic survey of the geological knowledge already available in the GIS environment was carried out and it was decided to take the coastline of the Hydrogeomorphological Map and the Regional Coastal Plan from the Puglia Region (2011) as a reference for this update.

Remote sensing data analysis led to the geometric extraction of the shoreline from orthophoto maps through automatic extraction and visual digitization techniques. Particular attention was paid to the geological analysis of the coast, with respect to its morphological characters. A comparison study was conducted using the most recent cartographic surveys available on the official geological cartography (CARG project). The analyzes were performed using the Free Geographic Information System and Open Source QGIS.

In some coastal stretches, coinciding with the most recent cartographic surveys available on geological sheets of official cartography (CARG project), the existing strengths and criticalities were analyzed with the aim of continuing the methodological studies aimed at the problem of the uniqueness of the data useful in the analysis of integrated territorial planning and soil defense.

The results have allowed a more detailed and in-depth definition of some aspects of geological cartography and the various elements of geohazard as well as a clearer reconstruction of the mechanisms of interaction between the various processes involved in geohazard.

The detailed analysis of some of the most representative cases has also confirmed the complexity of the coastal issues and highlighted some crucial questions about the making of geological cartography and coastal maps of the ongoing CARG project to further investigate and the consequent need to complete the updating of the official Geological and Geomorphological Cartography.

We call for a greater in-depth knowledge of the geomorphological and meteo-marine characteristics of the coastal environment to observe its evolution through accurate and continuous monitoring over time. This allows the analysis of evolutionary trends and both natural and anthropogenic factors influencing the delicate balance of the coastline.

2 Materials and Methods

The planimetric position of the coastline assumes particular importance in the space of the interface between the submerged and emerged sector and in the points where the "free surface" of the water meets the land. This interface is a line that can be considered continuous. Awareness is widespread on the variation of the position of the water surface. However, the effects of the variations due to the different configuration and position of earth over time (i.e., tectonic, volcanic phenomena, with uplift or lowering effects and sedimentary processes, both erosive and depositional) should not be overlooked.

To this study, the shoreline and coastline take the form of a sector in space, within which the real line is present with a certain level of reliability. The digitization of the coastline considers its variability due to factors related to the movements of the sea and

land surfaces (vertical and horizontal variations of the coast profiles and sea level) and the uncertainties related to the procedures used. It will therefore be considered conceptually as the expression of an area of uncertainty conditioned by the scale of restitution**.**

The only directly detectable line has been digitized. This was obtained by measuring the position of the shoreline at a given instant, namely the instantaneous shoreline. This generalized line leads back to INSPIRE's definitions of shoreline or coastline.

The remote sensing investigations had a two-dimensional approach which can be rendered in three dimensions by making the appropriate considerations on the spatial variations of the coast and its consequent final uncertainty of positioning and representativeness.

The geometric extraction of the shoreline from orthophotos directly on the visible bands or through the automatic extraction techniques typical of remote sensing was considered a method applicable to the regional context of this study. Particular attention was paid to the standard coding of the shoreline, with clearly assigned attributes and codes.

For the instantaneous shoreline to be transformed into a shoreline (and in its case coastline), it was considered as a first approximation to a standard tide level.

In this work, the coastline was digitized on video using the 2017 orthophotos as a basis.

Contourlines were subsequently extracted from the DTM obtained from the frames of the same 2017 flight. But it was not possible to obtain contourline 0 for the entire coast. in the stretches of high coast, a good correspondence was noted between the digitized coastline on video and the coastline extracted from the 2017 DTM coinciding with the 0.5 m contourline. Also, all the stretch coinciding with UF1_2017 (beetwen Marina Di Chieuti and Vieste) was acquired observing the frames in rough sea conditions. This could have caused problems in acquiring the 0m altitude level. Therefore, due to the objective technical problems it was decided to use the extracted level lines only as a further comparison with the coastline typed on the screen and to better refine the digitization itself.

Both the physiographic units defined by the Regional Coastal Plan and the municipal, provincial, and regional ISTAT limits of 01/01/2020 have been attributed to the coastline thus obtained. The analyzes described below were carried out on the level thus organized. Information on the characteristics of the coast has been included in the GIS, such as the division of the coast into Physiographic Units and Subunits. The coast has been classified, maintaining the typological subdivision of the Hydro geomorphological Map shown in Fig. 3.

3 Geological and Cartographical Framework

Structurally, the Puglia Region is mainly included in the geological domain of "Avampaese" and subordinately in the geological domain of "Fossa" (Fig. 1).

The geological considerations developed in this study were inspired by the cognitive tool available to the Puglia Region: the "Hydrogeomorphological map", which was considered a starting point for the appropriate detailed investigations of both scientific and applicative nature (Palumbo 2009).

Despite the apparent "simplicity" and "uniformity" of the morphological and hydrological-hydraulic structures of the great morphogenetic regions that constitute it, the Apulian Region contrasts an extreme variability and complexity of numerous and often interacting dynamic phenomena taking place, some capable of directly threaten man and his activities.

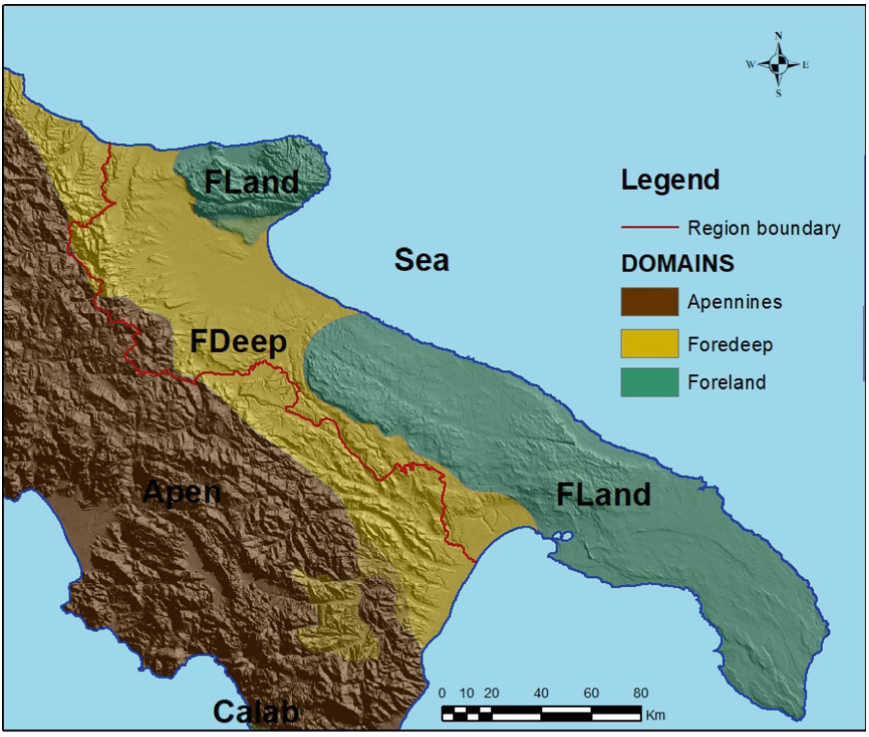

Fig. 1. Geological-structural schematic. Image by (Palombella and Gallicchio 2012) - High-resolution DTM for studying quaternary morphology and stratigraphy of plain areas (Ascoli Satriano, FG). Rend. Online Soc. Geol. It., Vol. 19 (2012), pp. 52–54, 3 figg. © Società Geologica Italiana, Roma.

The geological-structural set-up is crucial to better understand the origin of the different types of coasts present in the area. Among the rocky and/or cliff-like coasts, the coastal stretches of the eastern and southern slopes of the Gargano as well as the southernmost portion of Salento are worthy of note, characterized by steep slopes, in some cases over a hundred meters high.

The Hydrogeomorphological Map of Puglia aims to constitute a coherent and updated framework of knowledge of the various physical elements that contribute to the current configuration of the natural landscape, with reference to the morphological and hydrographic attitude. It delineates its morphographic and morphometric characteristics and interprets its origin according to geomorphic processes, natural or induced by man. The

geo-lithological characters contribute significantly to the understanding of the structural elements of the coastal geomorphology.

Figure 2 shows the lithological distinctions that have been entered in the database of the hydrogeomorphological map.

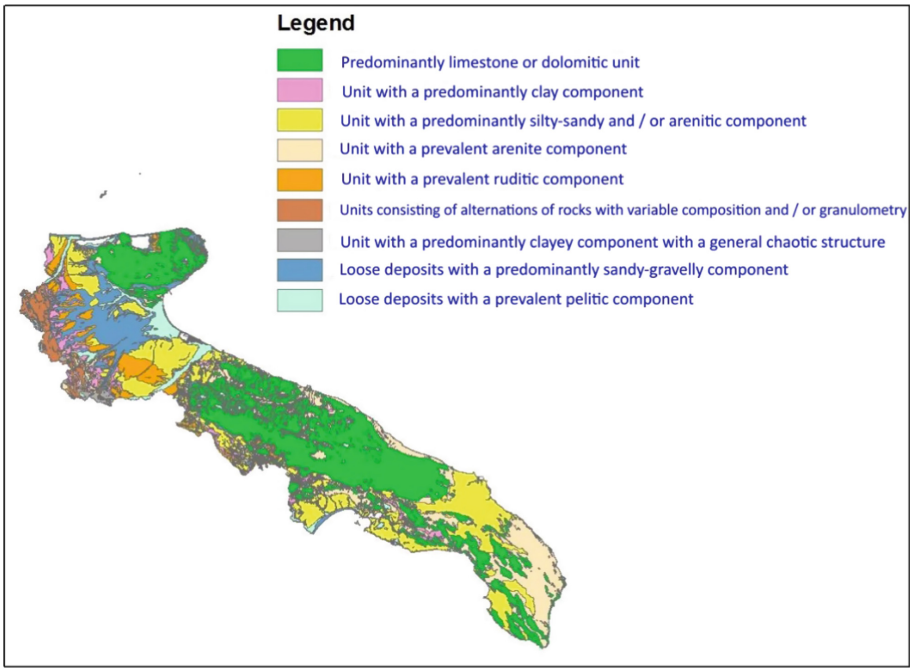

Fig. 2. Geo-lithological characters of Puglia region (by the Hydrogeomorphological Map of Puglia)

In the database, geomorphological details such as the coastline, the forms of river modeling, the slope forms, the hydrographic network “le lame” and rivers were also considered. Figure 3 shows the information level of the coastline.

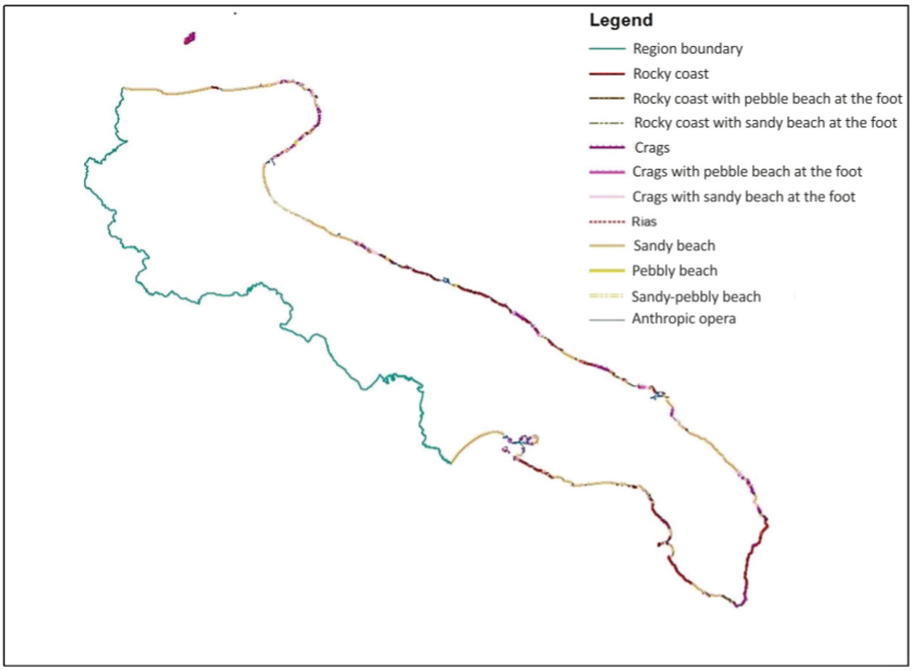

Fig. 3. Coastline. The typological subdivision used is shown in the legend**.**

4 Coastline Digitized on Orthophoto of 2017

The length of the Apulian coast digitized in this study shows a 1250 km development of the coast from the mouth of the Saccione Torrent in the Adriatic Sea to the outlet of the Bradano River in the Ionian Sea, including the coastal strip of the Mar Piccolo basin of Taranto.

The coastal strip is a particularly sensitive area at the interface between land and sea; its morphology is influenced by both natural and anthropic factors, which directly determine its equilibrium and evolution. Coasts can be classified on the basis of the lithoid elements that constitute them, and therefore are divided into: rocky coasts (high and low) and beaches. Then there are the coastal stretches characterized by Anthropic operas.

Table 1 shows the overall linear extension (in km) of the different types of coastal morphology, as identified in the Regional Coastal Plan (Reina 2011), updated with the new digitization performed on aerial shots in 2017, and the relative frequency in percentage terms referred to the entire Apulian coastal perimeter. The table includes to the overall length of the anthropic works resulting from the digitization.

Table 1. Types of coast updated with the new 2017 digitization.

Type of coast	Lenght (km)	% Lenght
Rocky coast	329.26	26.20
Rocky coast with pebble beach at the foot	8.99	0.72
Rocky coast with sandy beach at the foot	33.61	2.67
Crags	173.10	13.77
Crags with pebble beach at the foot	3,85	0,31
Rias	4.38	0,35
Pebbly beach	12,24	0,97
Sandy beach	298.55	23,76
Sandy-pebbly beach	1.00	0,08
Anthropic opera	370.22	29,46
Fictitious trait	0.84	0,07
TOTAL	1256.70	100

In summary, the Apulian coast, digitized on orthophotos of 2017, is mainly made up of the following coastal types: 27% of low rocky coasts plus 29% anthropic opera stretches; sandy beaches make up 24% while we have 15% of crags. The coastal development also includes the anthropic works overall length.

The results of the photo interpretation performed on the 2017 orthophotos are shown in Fig. 4.

Using the hydrogeomorphological map as a basis, the lithologies were mapped as follows:

1. Primarily calcareous or dolomitic unit.
2. Unit with a prevalent arenite component.
3. Units consisting of alternations of rocks with variable composition and/or granulometry.
4. Unit with a predominantly clayey component with a general chaotic structure.
5. Unit with a prevalent ruditic component.
6. Unit with predominantly clay component.
7. Unit with predominantly silty-sandy and/or arenitic component.
8. Loose deposits with a predominantly sandy-gravelly component.
9. Loose deposits with a prevalent pelitic component.

An analysis was carried out on the lithologies mapped along the coast, focusing on the four main typologies of the Apulian coast: sandy beach 23.76%, rocky coast 26.20%, crags 13.77 and anthropic operas works 29.46%. The four types of coasts make up over 93% of the Apulian coast.

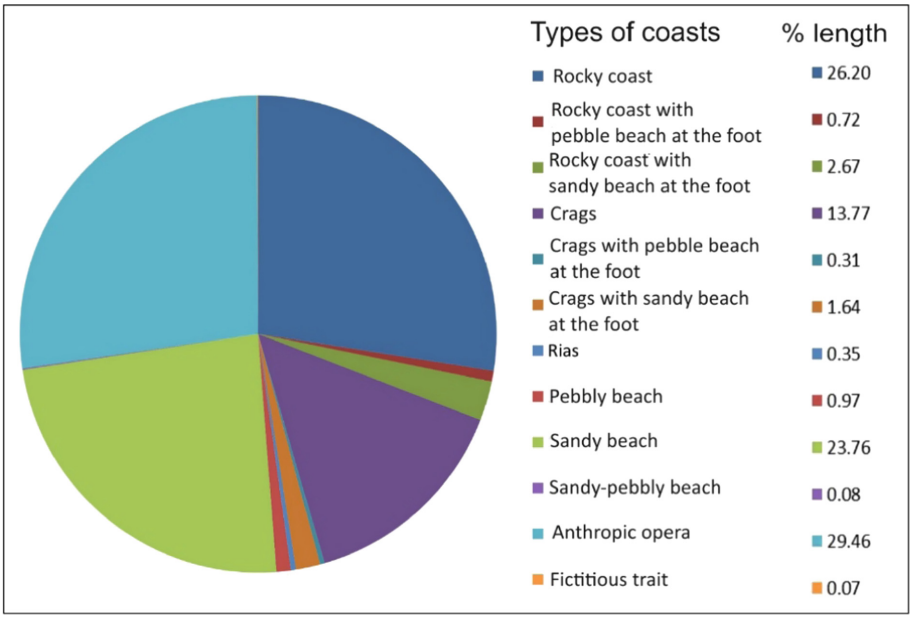

Fig. 4. Morphological classification of the Apulian coast (photo interpretation on the 2017 orthophotos)

The lithologies that have been found along the coastline for the four types of coasts are the following:

$$\begin{aligned}&\text{sandy beach} = 1, 2, 6, 7, 8, 9\\&\text{rocky coast} = 1, 2, 6, 7, 8, 9\\&\text{crag} = 1, 2, 6, 7, 8, 9\\&\text{anthropic opera} = 1, 2, 6, 7, 8, 9\end{aligned}$$

The prevailing lithologies, in percentages:

298.55 km of sandy beach are made up of 78% of the lithology 8.

329.26 km of rocky coast are made up of 1 31%, 2 32% and 7 31% lithologies.

173.10 km of crag are mainly made up of lithologies 1 42% and 2 35%.

The anthropic operas are made mainly out in the lithologies 7 24%, 8 25% followed respectively by the lithologies 1 e 2 19 e 18%.

The following lithologies were not found along the coastal strip: 3, 4, 5.

The dominant lithologies along the natural coastal development, grouped by provinces, are divided as follows:

	Bari	*BAT*	*Brindisi*	*Foggia*	*Lecce*	*Taranto*
Dominant lithologies	1 e 2	8	2 e 7	1 e 8	1, 2, 7 e 8	7 e 8
Percentages %	33 e 71	59	60 e 44	41 e 58	31, 20, 22 e 26	36 e 45

5 Problems Related to the Univocity of the Data: Section of Coast of the Geological Map 1: 50.000 Ugento

The Official Geological Cartography of Italy, surveyed at the scale of 1: 25,000, provides for a coverage of the entire national territory and is drawn up by the Geological Service of Italy (SGI).

Since the late 1980s, state resources have been made available such as to allow the launch of the "CARG Project" for the creation and computerization of the new official geological map of Italy. The surface of the national territory has been divided according to the framework of union IGMI at scale of 1: 50,000; scale of cartographic restitution of printed geological sheets.

The Project is characterized using national technical regulations, specially drafted by the SGI with the collaboration of experts and published in the Geological Service Notebooks series. They constitute the reference guidelines for the survey, cartographic representation, and computerization of both geological and geothematic sheets, allowing them to be homogeneous at national level.

The geological data collected are computerized and constitute the ISPRA geological database (Palombella 2010).

In the Puglia region, the CARG Project was interrupted due to a lack of funding and resumed at the end of 2020 thanks to the Budget Law no. 160/2019, with the funding of Sheet no. 493 "Taranto" of which the detection and computerization of both the emerged and the submerged area is envisaged. Four years are foreseen for the realization of the Sheet. Therefore, out of 54 Sheets needed to cover the entire Apulian territory, 39 Sheets have not yet been funded (Fig. 5).

In this study, the geometric elements of the coastline digitized on the Orthophotos of 2017 and compared with the Hydrogeomorphological map of 2011, were compared also with that of the database of the Sheet "Ugento" Geological of the CARG Project (Fig. 6).

The information level "coastline", of the geological Sheet "536 Ugento", digitized on topographic base at a scale of 1: 25,000 published in the years 1947–1948 by I.G.M.I., it was overlapping to the digitized one on Orthophoto of 2017 (Fig. 7).

The coastal stretches were examined on screen and a good coincidence appeared between them, considering the limits of digitization and the objective errors deriving from the transformations of the Reference Systems.

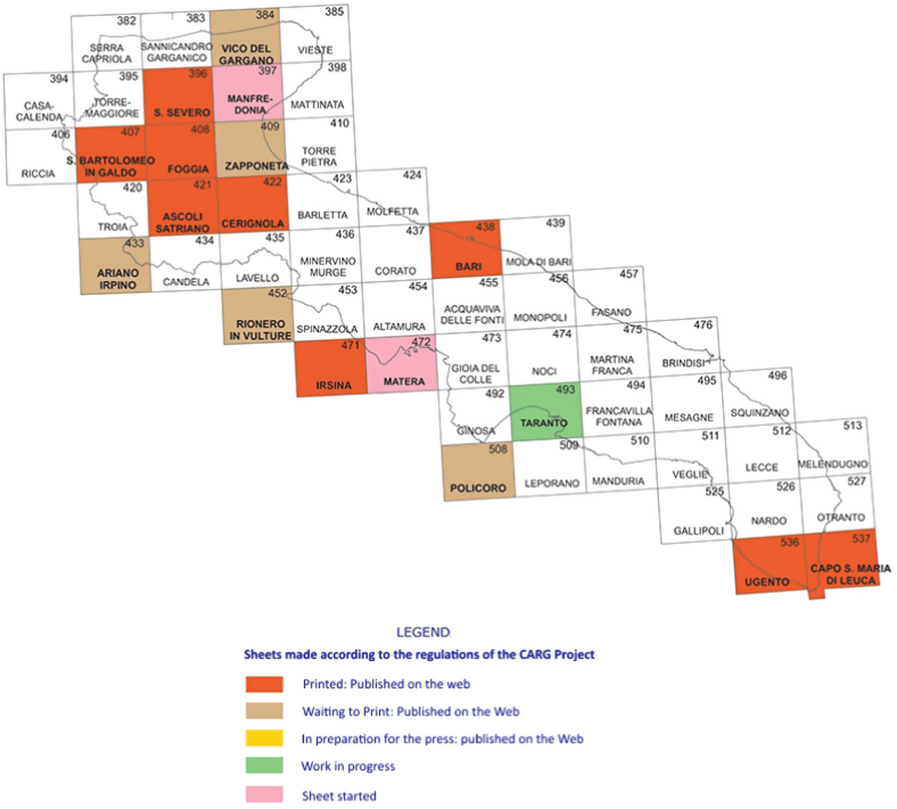

Fig. 5. Implementation status of the CARG Project in the Puglia Region (https://www.isprambiente.gov.it/Media/carg/puglia.html)

Subsequently, some numerical considerations were made. The length of the coastline included in the limit of Sheet 536 Ugento has been calculated:

– Coastline Length of the Sheet 536 Ugento: **46.724,85 mt.**
– Same stretch digitized on 2017 orthophoto: **56.196,23 mt.**

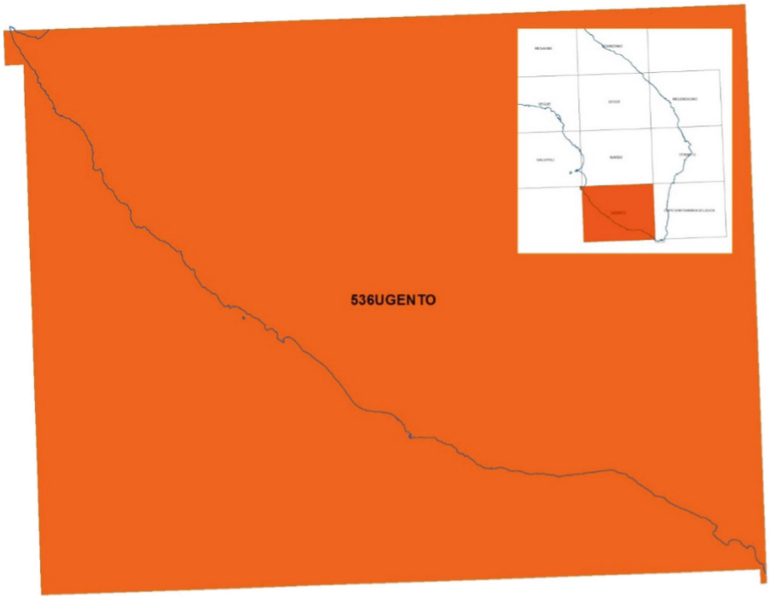

Fig. 6. Coastline extracted from the database of 536 Ugento (CARG Project).

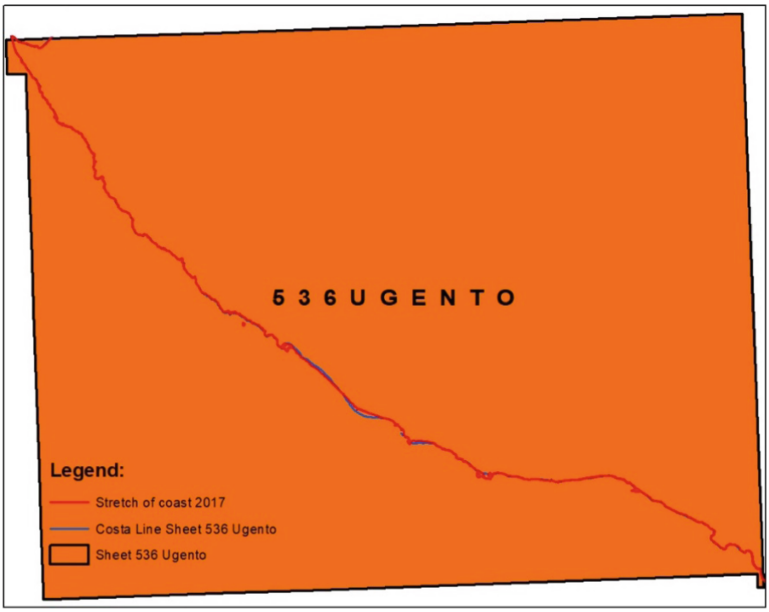

Fig. 7. Overlap of the coastal line information level extracted from the database of Geological 536 Ugento (CARG Project) on the one digitized on the 2017 orthophoto**.**

These differences are also attributable to the digitization scale of the shoreline of the Geological Data Sheet (1: 25,000).

Along the coast between Torre San Giovanni and Torre Pali there are some sections in erosion and others in accretion, as shown in Fig. 8.

The erosion areas in this stretch of coast were measured in 259,268.65 m^2 (Fig. 9).

The accretion areas were measured in 234,746.68 m^2.

Using the hydrogeomorphological map as a basis, the lithologies were mapped as follows:

1. Primarily calcareous or dolomitic unit.
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In some points, the erosion can be calculated in more than 150 m of eroded coastline, as shown in the Fig. 10 detail.

It is evident that in the stretch of coast between Torre San Giovanni and Torre Pali there has been a real rebalancing of the coastal dynamics.

Comparing the reference stretch IGM with the 2017 Orthophotos, the most evident anthropogenic transformations occurred in the following points (Figs. 11 and 12).

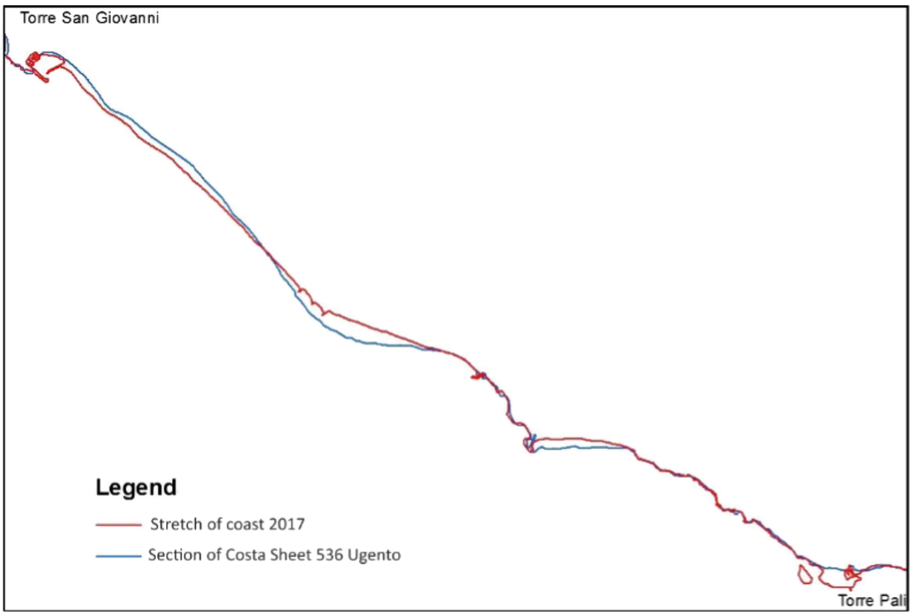

Fig. 8. Stretch of coast between Torre San Giovanni and Torre Pali

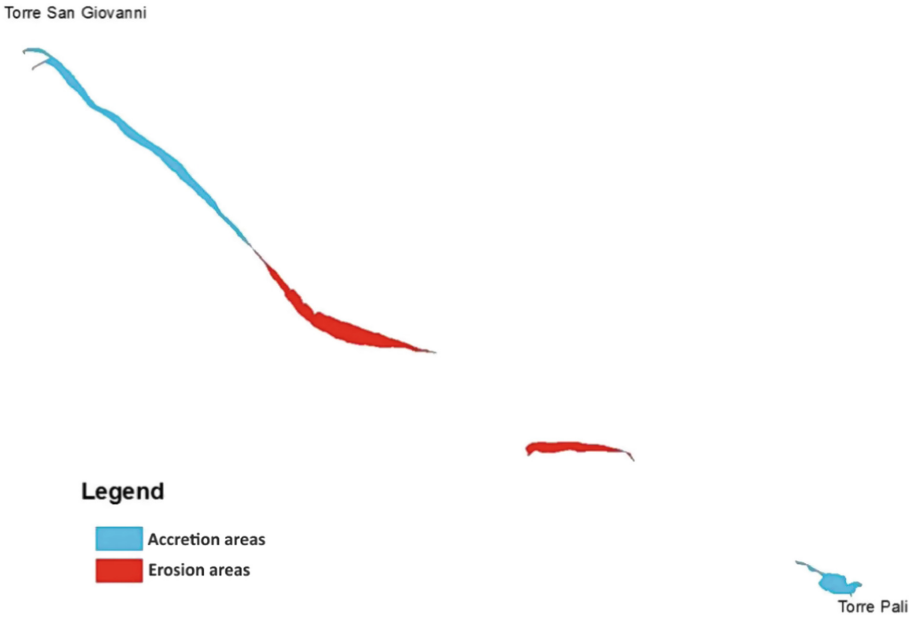

Fig. 9. Areas in erosion and growth in the stretch of coast between the localities of Torre San Giovanni and Torre Pali

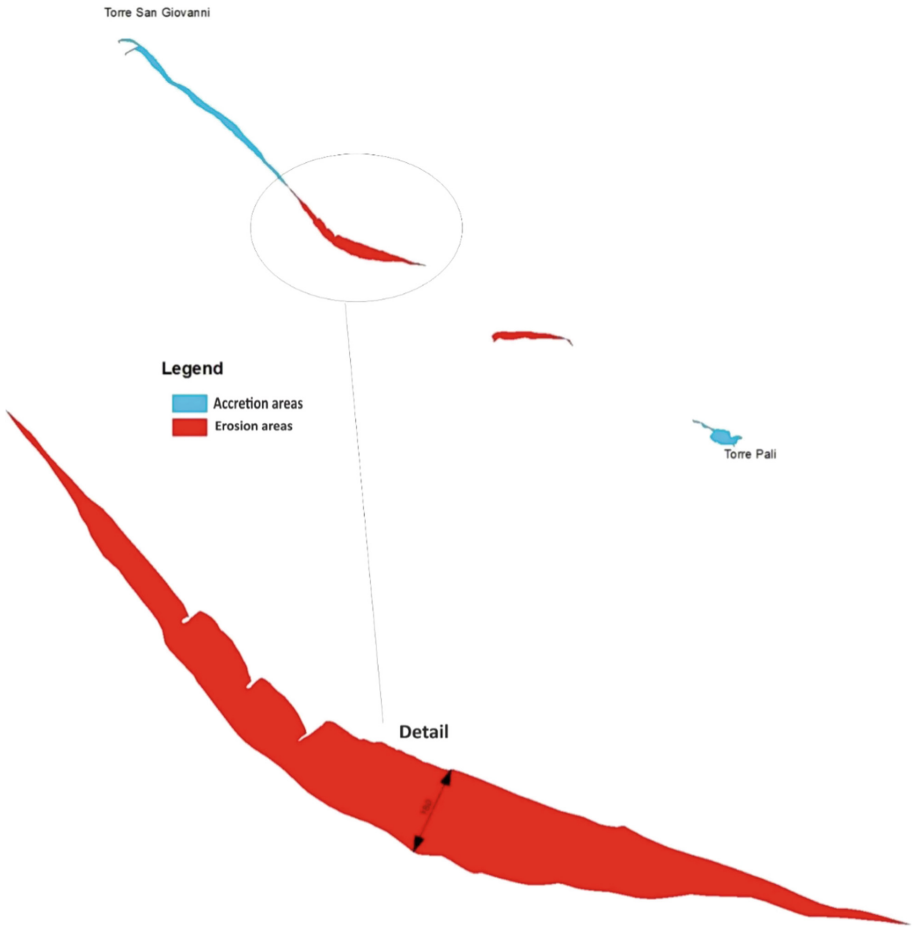

Fig. 10. Detail of the eroding areas in the Paduli area.

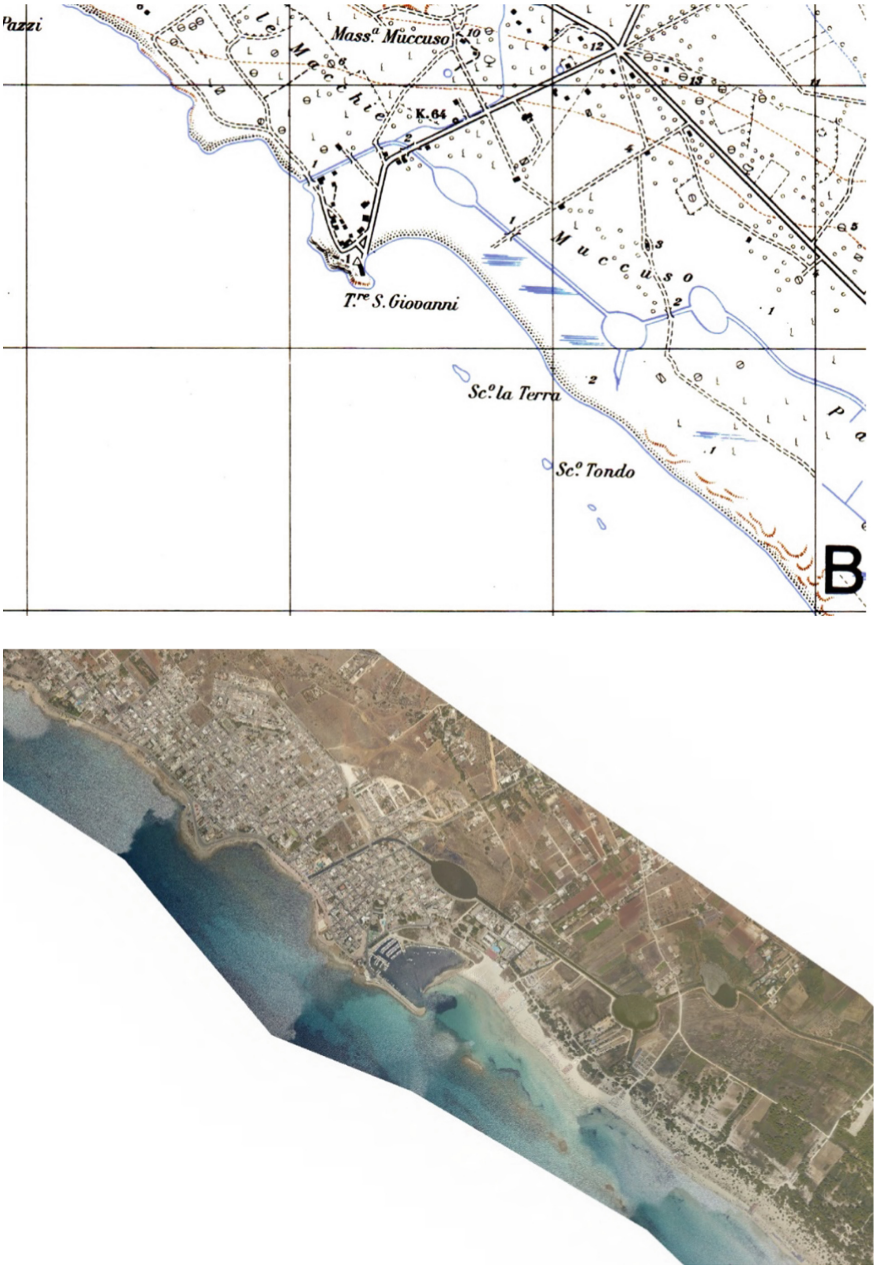

Fig. 11. Torre S. Giovanni: area comparison 1947–1948 excerpt of I.G.M.I. and orthophoto 2017.

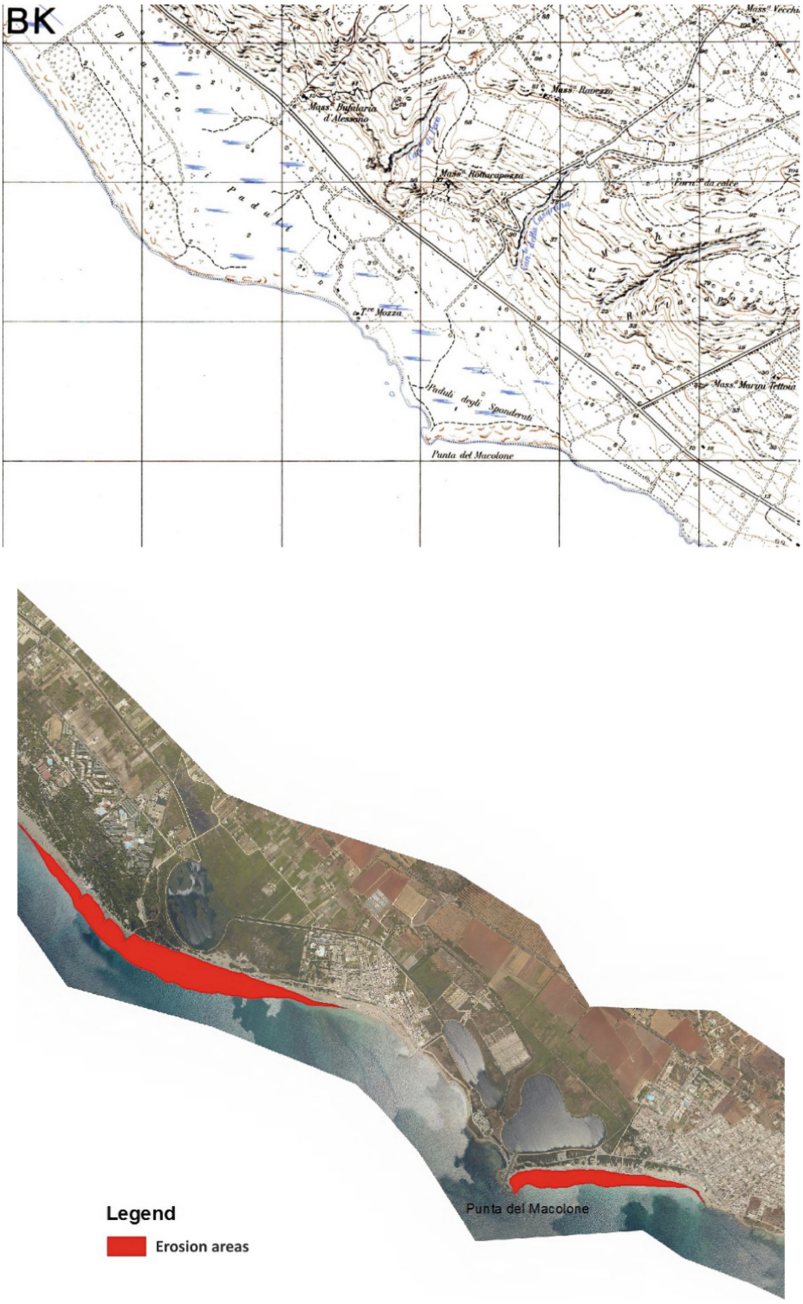

Fig. 12. The Paduli-Punta del Macalone: area comparison 1947–1948 excerpt of I.G.M.I. and Orthophoto 2017.

6 Analysis of the Results

The 2017 digitized coastline was used to carry out numerical and morphometric analyses. The analysis shows that the stretches of coast in 2017 with anthropogenic works (27%) have now equalled the type of natural coast prevalent in Puglia consisting of low rocky coasts. Sandy beaches constitute 24% of the length of the entire Apulian coast. The coastal development also includes the anthropic works on its overall length.

To continue to monitor the dynamism of the coastline, it appears necessary to continue the studies to develop automatic or semi-automatic methods for updating the coastline. This would allow to obtain better data with good spatial resolution that are comparable with the regional data available, considering the possibility of integrating information from different types of sensors and platforms (e.g., drones, aerial photos, high resolution satellite images). As a non-secondary objective, we also have returned the data on the coastline to the tolerance provided for cartographic rendering at the 1: 25,000 scale.

From the comparison of the digitized coastline on orthophotos of 2017 with the new geological cartography of the Geological Survey of Italy, we highlighted the strong coastal rebalancing taking place between Torre S. Giovanni and Torre Vado. The correlation appears clear between the anthropization of this stretch of coast and the coastal dynamics of the last seventy years. Hence, our results suggest there is a need to consider the problems associated with sedimentary inputs in the planning and management phase of coastal territories.

In Italy, the waterproofing process on coastal areas is a documented phenomenon: 19.4% of soils between 0 and 300 m from the sea are already sealed, and even 16% are sealed at between 300 and 1,000 m. However, the environmental effects of this phenomenon are poorly explored due to the extensive substitution of land use. It appears necessary to develop subsequent studies to explore the qualitative effects of the sealing process by considering changes in ecosystem services as a key factor for environmental assessment as well as to link these issues to the ongoing climate changes. The loss of biodiversity on coastal areas is one of the main problems for the sustainability of the urban development process.

Furthermore, it is necessary to ensure uniformity of data of reference maps, such as those of the CARG Project. The coastline present in the two cartographic databases analysed should be the same in order not to create confusion for the planner and the manager of the territory. They should be updated periodically and at the same time. In this way, starting from the common geometric element, the different specific databases would contain all the other peculiar informations. For example, the same geometric element "coastline" should be able to connect and dialogue with the information contained in the geomorphological cartography model approved and published by ISPRA in 2018 and the data of the Regional Coastal Plan of the Puglia Region (Reina et al. 2011).

Some strengths and criticalities existing in institutional geological cartography were analyzed. The problem of the uniqueness of the data should be analyzed in subsequent methodological studies, also with reference to other elements existing in the database of the Hydro geomorphological maps and useful in the analysis of integrated territorial planning and soil defense such as: forms of river modeling, slope forms, hydrography (the hydrographic network "le lame" and rivers).

The results obtained allowed, in sample areas, a more detailed and in-depth definition of some aspects of geological cartography and some elements of geohazard which deserve further study for a clearer reconstruction of the interaction mechanisms between the various processes responsible for their genesis and evolution.

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