A MULTISCALE ANALYSIS OF THE MORPHOLOGICAL SETTING ALONG THE SUSCEPTIBLE COASTAL AREA OF THE AGRI RIVER (SOUTHERN ITALY)

Angela Rizzo, Giuseppe Corrado, Gianluigi Di Paola, Antonio Minervino Amodio, Dario Gioia

Abstract: Assessment of coastal vulnerability to physical and anthropic processes is a crucial step in coastal risk management, especially in climate change scenarios characterized by sea level rise and increasing human pressure. The application of geomorphological-based indices is a consolidated approach to estimate the degree of vulnerability to erosion processes of low-relief coasts at a regional/wide scale. Such a method is based on the combination of physical variables such as shoreline changes, dune and beach geometry, vegetation, and coastal infrastructures, which are statistically or arbitrarily ranked to extract a vulnerability classification. Recent advances in the availability of UAV platforms with higher performance in terms of flight duration, sensor availability, and mapping resolution provide a unique opportunity for a comparison between high-resolution DEMs and the results that can be obtained from the application of a Coastal Index (CI). In this study, short- and medium-term comparison (i.e. about ten years) of high-resolution DEMs (derived by LiDAR) was performed in one of the sectors of the Ionian coastal belt, providing new insights about the geomorphological evolution of a highly vulnerable sector along a retreating coast. Such a comparison was tested along a sector of the coastal areas of the Basilicata region, southern Italy, that includes the Agri River mouth. The study area is featured by a strong human impact and environmental factors that have promoted in the last years the occurrence of remarkable shoreline retreat and coastal erosion.

Keywords: Coastal erosion, susceptibility index, monitoring techniques, Ionian coast

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Introduction

Assessment of coastal vulnerability to physical and anthropogenic processes is a crucial step in coastal risk management, especially in scenarios promoted by sea level rise, climate change, and increasing human pressure [14, 24, 29]. The application of geomorphological susceptibility indices is a consolidated approach to estimate the proneness to erosion processes of low-lying coasts at the regional/wide scale [28]. Such a method is based on the combination of physical variables such as shoreline changes, dune and beach geometry, vegetation, and coastal infrastructures, which are statistically or arbitrarily ranked to extract a coastal vulnerability classification [15, 22].

Recent advances in the availability of Unmanned aerial systems (UAS) platforms with higher performance in terms of flight duration, sensor availability, and mapping resolution provide a unique opportunity to compare high-resolution point clouds or DEMs with the results that are obtained from the application of a Coastal Index (CI) [3]. UAS technology has recently advanced, allowing for the development of an alternative coastal monitoring method that effectively captures the spatial and temporal requirements across a wide variety of environmental applications [9, 16, 25, 27].

In this study, a methodological approach aimed at the reconstruction of the short-term evolution of a highly vulnerable coastal sector based on the integrated analysis of CI and multitemporal LIDAR surveys is proposed. The analysis has been tested along the Ionion sector of the Basilicata region, southern Italy (Figure 1) [8, 11]. In this sector, several environmental factors as well as a strong human impact have favoured severe shoreline retreat and coastal erosion [5]. The present-day shore is characterized by a low-gradient sandy beach that is limited landward by several diachronic dune ridges. Fine marshy deposits can be observed between these different generations of dunes. The application of an already tested coastal susceptibility index [1, 20] has allowed the identification of erosion hot-spots (i.e., the areas that can be considered more susceptible to erosion) along an approximately 7 km coastal strip that includes the Agri river mouth. More detailed investigations based on the exploitation of UAS derived-data were performed for the hot-spot areas. In particular, short-term comparison (i.e., about ten years) of high-resolution LIDAR DEMs was performed. To this aim, two types of LiDAR-derived data were used: 1) raw point clouds obtained from a LiDAR survey from aircraft carried out in 2013 at the regional scale; 2) point clouds obtained from a UAS survey carried out for this study in December 2023 with a LiDAR sensor. The comparison of the two high-resolution surveys allowed us to observe and quantify both the 2-D and volumetric changes occurring in the hot-spot areas, previously identified by the application of the coastal susceptibility index. Our data can be useful to 1) verify the usefulness of the methodology for the precise and effective delineation of coastal areas at risk of erosion due to recent sea levels; 2) provide valuable information regarding the degree of coastal susceptibility along the coasts.

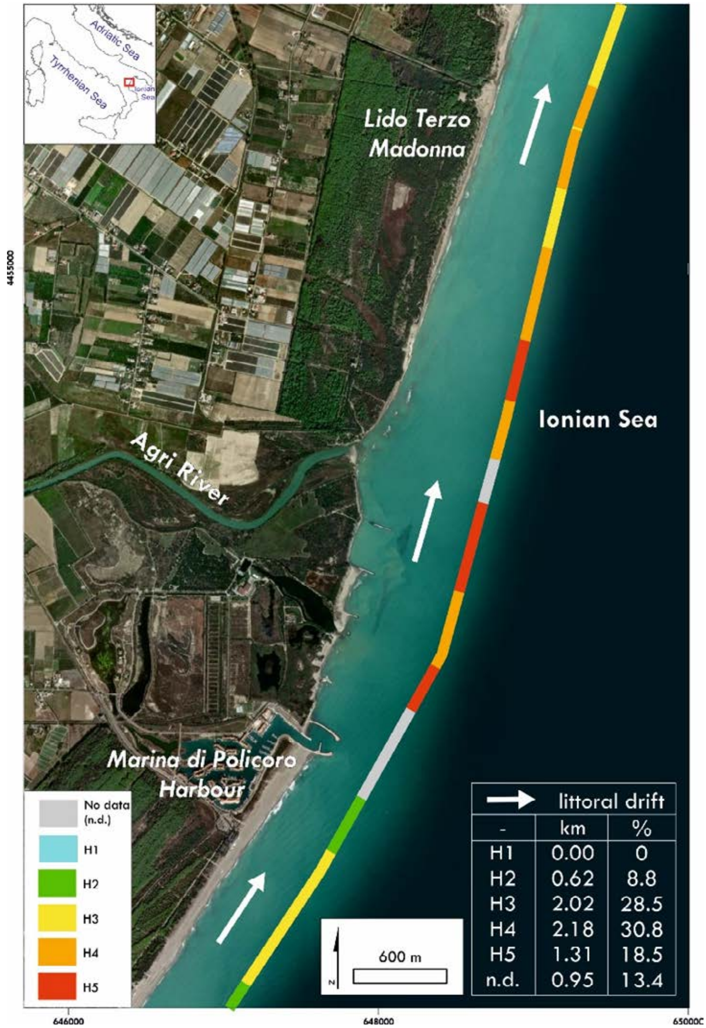

Figure 1 – Geographical location of the study area and graphical representation of the CESI results. On the right corner, quantitative CESI results are also provided, expressed both as kilometers and as percentage values.

Study area

The study area is located along the Ionian coastal belt of the Basilicata region, southern Italy (Fig. 1). It belongs to the southernmost and youngest outcropping sector of the Bradano Foredeep, which experimented a progressive stage of emersion since the Middle Pleistocene [7, 11, 12] as a consequence of the interplay between tectonic uplift and eustatic sea-level cycles. Moreover, it is characterized by a continental shelf developed for about 3÷4 km with a dip lower than 1°, and the break is located at a depth of about 40÷50 m b.s.l. [23].

The landscape is dominated by the presence of several well-preserved orders of marine terraces, which are deeply incised by a fluvial net with an angular pattern [3, 6, 10, 26]. The present-day shore is featured by a low-gradient sandy beach that is limited landward by several meters-thick dunes, striking mainly parallel to the shoreline [8, 18, 23]. Fine marshy deposits accumulated between these different generations of dunes. Lower altitudes sectors of the Metaponto coastal plain were characterized by wide outcrops of limno-palustrine deposits, which have been affected by land reclamation during the first decades of the 1900s. The plain is now featured by sandy and silty meandering fluvial systems with several artificial channels. These areas of the coastal plain are still affected by occasional flooding events during extreme rainfall events [18].

The maximum fetch reaches about 500 km and derives from the SE-oriented quadrant and the surface circulation is anticyclonic in the winter season while, in the summer season, it is cyclonic, according to the application of the Marine Rapid Environmental Assessment (MREA) method [19]. This opposite circulation pattern is probably connected to the different Western Adriatic Coastal Current [13, 19]. Anemological climate acquired in a wind station located in the proximity of the Agri River mouth (Terra Montonata station, ARPAB, Agenzia Regionale per la Protezione dell'Ambiente in Basilicata) identified average wind speed values of about 9 m/s, with dominant SE winds. Such data, coupled with the sedimentological and mineralogical studies carried out on a wider coastal sector, allow the identification of a main direction of sediment transport (littoral drift) toward NE [2, 23].

In 2006 and 2012, two inland tourist ports, each protected by jetties, were built on both the left sides of Agri and Basento river mouths. Starting from their construction, the breakwaters modified the sediment distribution by the longshore currents, principally directed from SW to NE, accentuating the deposition in the southernmost part and increasing the erosion in the other part of the coast [17]. Such disturbance in the sediment distribution affects also other coastal areas, near the mouths of the Basento and Bradano rivers, due to the construction of two inland tourist ports [17].

Materials and Methods

The proposed multiscale procedure is based on the exploitation of an already available coastal susceptibility index [1, 20], i.e. the Coastal Erosion Susceptibility Index (CESI), which is here adopted to analyze the proneness to erosion of the littoral sector extending along the Agri River month (7 km long). The applied index is a linear combination of weighted variables covering site-specific geomorpho-dynamic aspects. CESI results are then ranked into five classes ranging from null/very low susceptibility (Class H1) to very high susceptibility (Class H5). Based on CESI results, erosion hot-spot areas were identified. In these areas, a LiDAR survey was performed using a Dji Zenmuse L1 3-echo laser scanner, equipped with a GNSS RTK positioning system, used as a payload on a DJI Matrice 300 drone. LiDAR acquisition covered an area of about 60 ha. Flights were carried out at 120 m AGL, at a constant speed of 3.5 m/s, in a double acquisition grid pattern.

The LiDAR used has the following specifications: (i) 3-echo, (ii) 70° of FOV (Field of View), and (iii) 480 000 measurements per second. The LiDAR data provide a DEM of the study area and an orthophoto. The latter is provided by the coloring of the point cloud thanks to an RGB camera. DEMs relative to the years 2023 (created for this study) and 2013 (provided by the regional authorities) are used to extract 250 m spaced transects and to assess the main morphological variations that occurred in the last 10 years in the investigated coastal stretch. These analyses have been performed exploiting GIS-based tools (in particular, the QGIS "profile tool" was used for the transect extraction).

Results and Discussion

The results of the CESI application are graphically shown in Figure 1, from which it emerges that the investigated coastal sector is characterized by a susceptibility level ranging from "low" – in green, to "very high" – in red. Grey sectors identify areas in which the CSEI values are not available due to the lack of suitable data.

The quantitative analysis highlighted that less than 10 % of the investigated area has a low susceptibility level and that approximately 28 % of the investigated area has a medium level of susceptibility. High and very high susceptibility levels characterize 30.8 % and 18.5 % of the investigated area, respectively. Finally, a coastal stretch 1 km long was excluded from the CESI calculation due to the presence of a permanent anthropogenic structure (i.e., the Marina di Policoro harbor) and the Agri River mouth. CESI results allowed the identification of hot-spot erosion areas to be investigated in greater detail, which occupy a surface of 3.5 km (almost 50 % of the total investigated area). They are located mostly around the river mouth and towards the northernmost part of the study area. Conversely, the low susceptibility sector is located on the breakwater pier, highlighting the influence of the hard structure on the overall coastal dynamic. Starting from the point clouds derived by the photogrammetric acquisition performed in 2013 (aircraft) and 2023 (UAV), orthophotos and DEMs were generated with a resolution of 10 cm (Figure 2).

From the DEMs, six topographical profiles (T1-T6) were extracted and analyzed (Figure 3). In detail, along each profile, the following morphological parameters were evaluated for both investigated years (2013 and 2023): height of the ordinary berm, width of the backshore, mean slope of the backshore, and slope of the foreshore. The estimated values are synthesized in Figure 4. For T2, these parameters were calculated only for the year 2013, since the beach has been completely replaced by a hard structure. For what concern the slope of the backshore, it increased in the case of T1 (passing from 1.4 % to 7 %) while in the remaining profiles (T4, T5, and T6) it decreased by 39.6 %, 91.7 %, and 100 %. In the case of the foreshore, the slope is decreased in all the profiles, except for the T6 profile, for which the backshore slope has increased by 240.8 %.

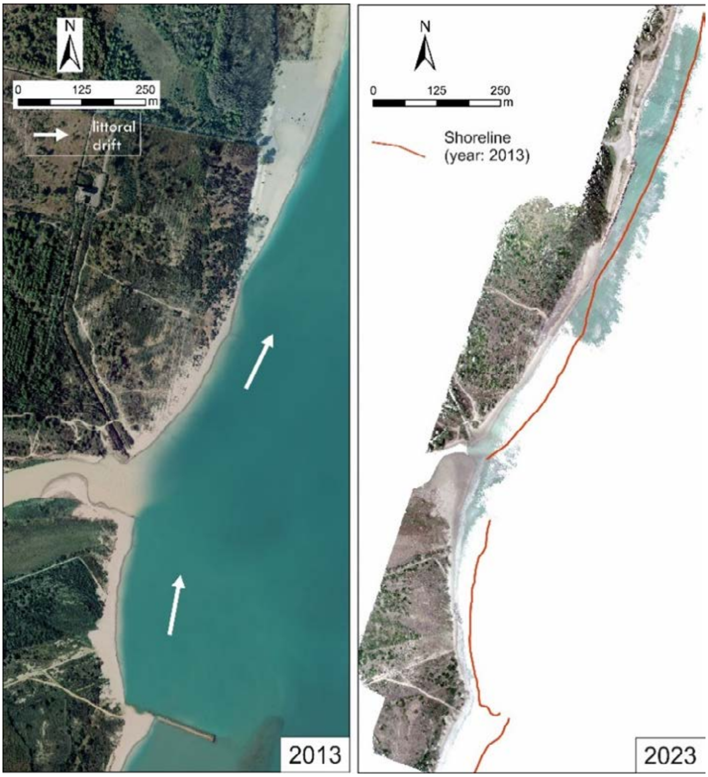

Figure 2 – Comparison between the two ortophotos of the surveyed area. The shoreline derived from the 2013 survey was drawn on the 2023 image to highlight the severe coastal retreat that occurred in the last 10 years.

Figure 3 – Location of the topographical profiles (T1-T6) extracted from DEMs and differences in topographical height estimated from the comparison between DEMs relative to the years 2023 and 2013.

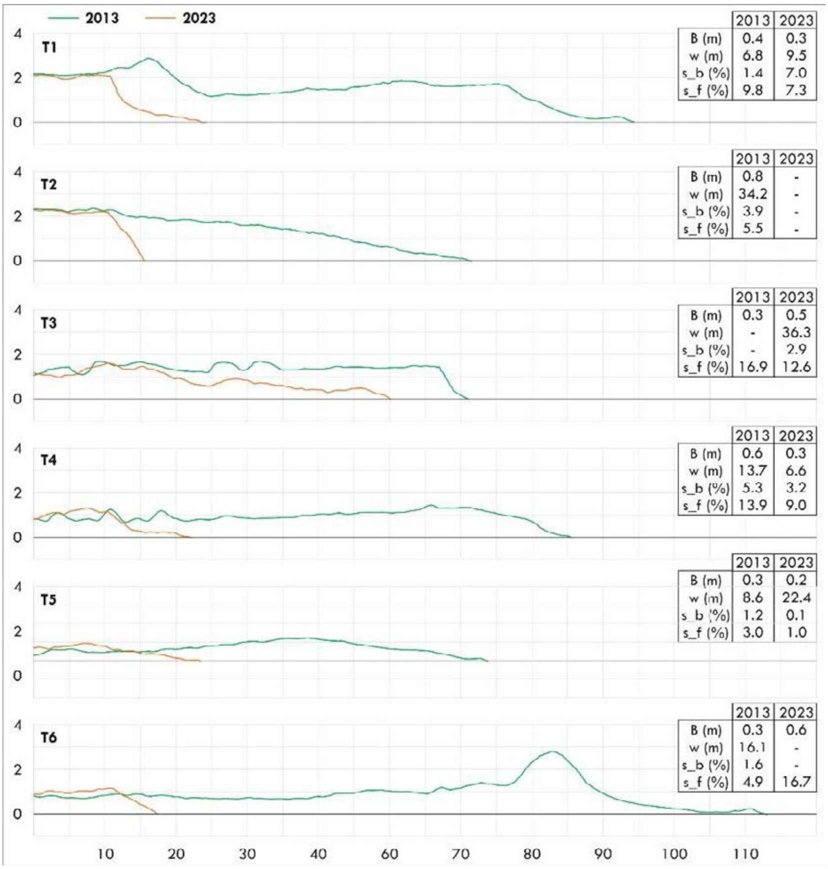

Figure 4 – Beach topographical profiles (T1-T6) along the study area. In the tables, the values of the main morphological parameters calculated along each profile are indicated. Legend: B (m) = berm height, w = width beach; s_b (%) = backshore slope, s_f (%) = foreshore slope.

Despite the general erosion trend that characterizes the investigated coastal sector, profiles T1, T3, and showed an increase in backshore width, with values of 2.7 m, 36.3 m, and 13.8 m, respectively. This latter aspect is related to the substantial naturalness of these areas, with systems free to move inland.

Overall, the qualitative analysis of the T1–T6 profiles (Figure 4) highlights the following trends:

- T1: the sector shows a strong coastal retreat, with the total damage of the dune system which is nowadays completely absent;
- T2: the beach has been completely eroded and an adherent structure (revetment) has been placed to protect the inland coastal zone;
- T3: the sector shows a prevailing coastal retreat, with the formation of a beach probably as a consequence of the dune demolition;
- T4: the sector shows strong coastal retreat with rates up to 5 m/year;

- T5: the sector shows complete erosion that affects also the dune system; T6: the sector shows a complete beach erosion with has caused the demolition; of the groin clearly recognizable on the 2013 orthophoto.

The DEM of Difference (DoD, see Figure 3) between the two high-resolution DEMs (with a spatial resolution of 0.1 m) provides additional quantitative information on the short-term geomorphological evolution of the study area. Quantitative analysis of the DoD allowed us to quantitatively detect the remarkable volume changes that occurred along the surveyed coast. Negative and positive values of the DoD map show erosion and deposition, respectively (Figure 5). Values ranging from -0.1 to 0.1 m were considered as thresholds for the stable areas. Statistical analysis of the pixel distribution of the DoD map highlights the large erosion trend of the study area, with a net eroded volume of about 250 000 m^3 (Figure 5b). By considering the 2013 beach as a reference surface, the eroded volume is about 29 000 m^3 (Figure 5c).

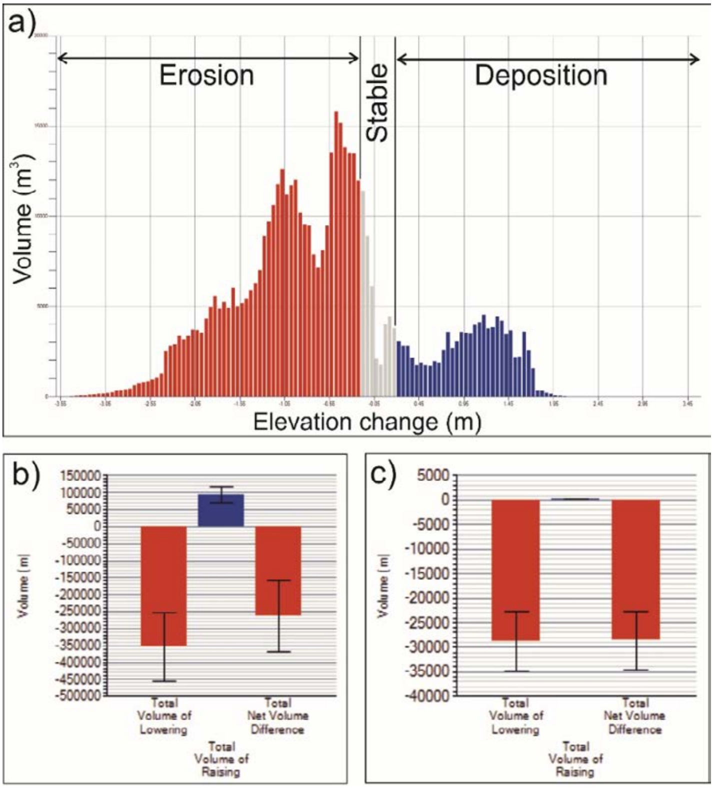

Figure 5 – Graphs showing the volumetric changes estimated by DoD mapderived from the multitemporal analysis of the study area. a) Histogram of the volumetric changes estimated by the statistical analysis of the DoD map; b) plot showing the positive (deposition) and negative (erosion) volumes for the entire area; c) plot depicting the volumetric change for the beach sector reconstructed from the 2013 survey.

These changes can either become part of a persistent trend or simply show reversible fluctuations. Furthermore, as shown in Figure 2, the availability of high-resolution topographic data is crucial for characterizing and monitoring the coastline and also for assessing coastal flooding scenarios. To assess morphological variations at a lower temporal scale (i.e., months), further activities will be focused on performing UAV surveys with a lower temporal interval and considering the occurrence of extreme weather events (i.e., storm surges). In this way, the comparison will be based on DEM acquired with the same survey's parameters, ensuring a higher spatial accuracy.

Conclusion

In this paper, a multiscale approach aimed at the reconstruction of the short medium-term evolution of a highly vulnerable coastal sector based on the integrated analysis of CI and multitemporal LIDAR surveys was tested. Such a comparison was performed along the Ionian coastal sector of the Basilicata, southern Italy, which includes the Agri River mouth where several environmental factors as well as a strong human impact have favoured the severe occurrence of shoreline retreat and coastal erosion.

According to the obtained results, 30.8 % and 18.5 % of the investigated areas are characterized by high and very high susceptibility levels, respectively. Conversely, the low susceptibility sector is located on the breakwater pier, highlighting the influence of the hard structure on the overall coastal dynamic. Despite the general erosion trend that characterizes the investigated coastal sector, some profiles showed an increase in the backshore width of up to 36 meters (T5). This latter aspect is related to the substantial naturalness of these areas, with systems able to move inland.

Quantitative analysis of the DoD allowed us to provide an overall quantification of the volume changes occurring along the surveyed coastal stretch. This aspect highlights the large erosion trend of the study area, with a net eroded volume of about 250 000 m^3. By considering the 2013 beach as a reference surface, the eroded volume reached a value of about 29 000 m^3.

This study shows how susceptibility indices are very useful for the qualitative identification of areas subjected to main changes in beach systems, but they need to be integrated by high-resolution and repeated monitoring campaigns over large areas, which can represent effective data to both a finer reconstruction of the geomorphological evolution of wide sectors of vulnerable coasts. The obtained results demonstrate that the susceptibility to erosion can experience significant short-medium term changes, even from year to year, as also evidenced by other studies conducted in similar coastal contexts [9,16]. Finally, in compliance with the guidelines proposed for the integrated geo-environmental characterization of coastal sites [21], this study highlighted the remarkable role of high-resolution surveys in coastal monitoring programs.

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