INVESTIGATION OF EROSION MANAGEMENT ALTERNATIVES BY AREA-BASED ANALYSIS METHOD

Giorgio Manno, University of Palermo, giorgio.manno@unipa.it
Carlo Lo Re, ISPRA, carlo.lore@isprambiente.it
Gabriele Nardone ISPRA, gabriele.nardone@isprambiente.it
Giuseppe Ciraolo, University of Palermo, giuseppe.ciraolo@unipa.it

INTRODUCTION

Coastlines are in a perpetual state of transformation, undergoing continuous modifications as a result of natural processes, such as erosion and accretion, driven by the forces of waves, currents, and tides (Davidson, 2021). These alterations hold significant implications across various scientific domains. Precisely determining the position of shorelines is of paramount importance for effective coastal management and the investigation of morphodynamics. A comprehensive grasp of shoreline evolution is crucial for the analysis of erosion patterns (Bergillos et al., 2017) and for evaluating the effects of coastal structures, nourishment practices, and energy farms. As human activities and coastal developments surge, there is a growing need for specialized studies on shoreline stability (Manno et al., 2017; Molina et al., 2020). While natural shoreline shifts persist, coastal development often necessitates structural interventions. Intense storms, flooding, erosive processes, and rising sea levels heighten coastal risks, which are shaped by both local and regional factors. The employment of precise methodologies to determine shoreline positions becomes increasingly critical. Shoreline Change Analysis (SCA) is a widely adopted tool for quantifying alterations in shoreline positions (Davidson et al., 2021). The management of erosion relies heavily on SCA parameters, which are indispensable for the formulation of comprehensive beach management plans. To enhance the SCA methodology, it is imperative to incorporate error and uncertainty assessments and explore innovative approaches.In the process of conducting SCA, shoreline markers are employed to ascertain shoreline positions, often through Transect-Based Analysis (TBA). Conversely, the less utilized Area-Based Analysis (ABA) lacks adequate tools for a comprehensive analysis. This study specifically centers on shoreline analysis, with a focus on sandy beaches, renowned for their dynamic nature influenced by physical phenomena such as waves and tides. Shoreline change analysis stands as one of several tools that can be employed to assess coastal erosion. Furthermore, there is an increasing need for dedicated investigations into coastal stability, prompted by the growing human presence in coastal regions and the development of buildings and infrastructure.
This research represents a preliminary study that utilized an aerial-based approach for shoreline change analysis to evaluate the rates of coastal transformation.

METHOD

A major advantage for shoreline analysis is the widespread availability of aerial and satellite imagery, combined with its cost effectiveness and ability to analyse large coastal areas. This has led to the utilization of various analytical methods over many decades to precisely monitor changes in shoreline positions over time.
In our research, we employed an innovative SCA tool developed in MATLAB® and seamlessly integrated it with GIS software (Manno et al. 2022). This methodology incorporates both the Transect-Based Analysis (TBA) and Area-Based Analysis (ABA) approaches (Fig.1), featuring significant enhancements and innovations. In detail, the main primary innovation was introduced within the framework of the ABA approach, with only a few improvements applied to the TBA method.

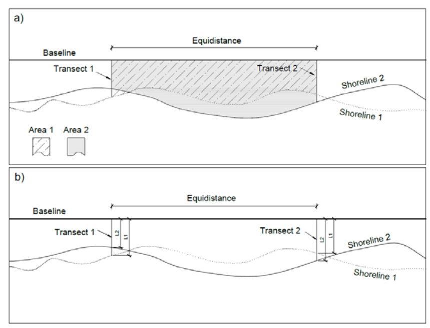

Figure 1 - Differences between the aerial based analysis (a) and the transect based analysis (b).

To address the challenges associated with implementing transect-based analysis, various authors (Emam & Soliman, Quadrado et al., 2021, etc.) have explored alternative approaches based on areal analysis. When utilizing the Area-Based Analysis (ABA) approach, one of the most complex steps involves calculating the average shoreline shift over a specific time interval between two shorelines. In this study, we used a novel method (ciatre)for computing the mean shoreline shift, encompassing the following key improvements: *i*) area calculations are performed using a cubic polynomial baseline (PCHIP), *ii*) equally spaced transects are employed to calculate areas, *iii*) shoreline rates of change (measured in meters per year) are determined using all available shoreline lines, *iv*) Areal rates of change (measured in square meters per year) are computed using data from all shorelines, and *v*) this approach offers a more robust and comprehensive methodology for ABA, aiming to enhance the accuracy and reliability of shoreline shift calculations. Figure 2 illustrates the flowchart of the utilized method. The parameter associated with predicting future erosion impact is called the Coastal Retreat Velocity (R_V). It is calculated by multiplying the Longshore Recession Rate (LRR) in meters per year by the projected number of years and then dividing this value by the beach

width. The beach width is measured from the backshore to the most recently formed shoreline.
Coastal Retreat Velocity is categorized into three ranges: high, moderate, and low based on specific thresholds. Other parameters, including Longshore Sediment Transport (L_t), Tidal Fluctuations (T_f), and Morphological Instability (M_f), are considered. Lt assesses the direction of sediment transport and has five categories. T_f evaluates tidal fluctuations, categorized as micro, meso, and macro.Morphological instability (Mf) is assessed by considering water motions and changes in topography. These parameters were calculated for the Lido Signorino beach to provide valuable information for coastal management procedures.

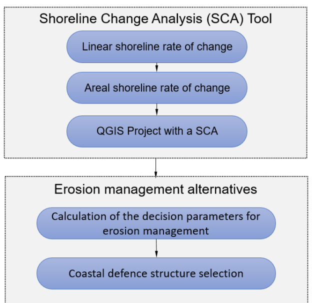

Figure 2 - Flowchart of the approach used

PRACTICAL IMPLEMENTATINS AND ITS OUTCOME
A sandy beach was selected for testing the proposed method. The chosen beach, Lido Signorino, is situated within Sicilian Physiographic Unit 14 (a region along the coast where sediment movement is confined within its boundaries). Lido Signorino is located in the southern part of the town of Marsala, Trapani. It stretches for approximately 3 kilometers and lies between two headlands that are home to two ancient towers (1600). This beach is situated within a larger coastal plain, characterized by relatively flat terrain with a gentle slope ranging from a few meters above sea level along the coast to approximately 250 meters in the inland hills. A series of distinct marine terraces, reaching heights of up to 170 meters above sea level, can be easily identified due to the presence of stepped, erosion-leveled morphology.
Lido Signorino is categorized as a dissipative sandy beach, with its sediments primarily resulting from coastal erosion and seabed deposits. Geologically, these sediments are classified as Marsala sandstone (Pleistocene). Over the past few decades, human activities have significantly altered the beach’s natural features.

CONCLUSIONS
A novel approach streamlines shoreline change analysis for beach erosion management, providing speed, precision and direct parameters for strategies. It combines Transect-Based Analysis (TBA) and Area-Based Analysis (ABA) to study shoreline evolution. A case study of a Mediterranean beach with coastal structures was carried out.
The new tool automates baseline and transect tracing using PCHIP curves for baselines and optimal spacing based on irregularity and roughness indices for transects. It preserves shoreline geometry and improves analysis accuracy. ABA provides more detailed results, especially for complex scenarios and varying beach characteristics.
The speed and efficiency of the tool enables regional studies of shoreline variation and complements in-situ measurements for short stretches of coastline. In a case study on Lido Signorino beach, it helped to assess the best erosion management strategy based on SCA parameters. Future work will include further validation through in-situ measurements and various real beach applications, improvement of tool performance and functionality, refinement of change rate definitions and assessment of precautionary measures.

Figure 3 - Example of shorelines identified and analyzed related to Lido Signorino beach (Marsala - Sicily).

REFERENCES
Bergillos, Masselink, Ortega-Sánchez, (2017): Coupling cross-shore and longshore sediment transport to model storm response along a mixed sand-gravel coast under varying wave directions. Coast. Eng. vol. 129, 93-104.
Davidson, Hesp, Miot da Silva, (2021): Rapid shoreline erosion and dunefield Change, Salmon Hole, South Australia. Sci. Total Environ. vol. 767, 145406.
Emam, Soliman, (2020). Applying geospatial technology in quantifying spatiotemporal shoreline dynamics along Marina El-Alamein Resort, Egypt. Environ. Monit. Assess. vol. 192 (7), 459.
Manno, Lo Re, Basile, Ciraolo (2022): A new shoreline change assessment approach for erosion management strategies, ELSEVIER, vol. 225, 106226.
Manno, Lo Re, Ciraolo, 2017. Uncertainties in shoreline position analysis the role of run-up and tide in a gentle slope beach. Ocean Sci. vol.13 (5), 661-671.
Molina, Manno, Lo Re, Anfuso, Ciraolo, (2020): A methodological approach to determine sound response modalities to coastal erosion processes in Mediterranean Andalusia (Spain). J. Mar. Sci. Eng. vol. 8(3), 154.
Quadrado, Dillenburg, Goulart, Barboza, (2021). Historical and geological assessment of shoreline changes at an urbanized embayed sandy system in Garopaba, Southern Brazil. Reg. Stud. Mar. Sci. 42, 101622.

ACKNOWLEDGEMENTS
This study was carried out within the RETURN Extended Partnership and received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan - NRRP, Mission 4, Component 2, Investment 1.3 - D.D. 1243 2/8/2022, PE0000005).