SoftwareX 30 (2025) 102170

Contents lists available at ScienceDirect

SoftwareX

journal homepage: www.elsevier.com/locate/softx

Software Update

Update 2.0 to Coastal dynamics analyzer (CDA): A QGIS plugin for transect and area based analysis of coastal erosion

Pietro Scala [a], Giorgio Manno [a,*], Carlo Lo Re [b], Giuseppe Ciraolo [a]

[a] Department of Engineering (DI), University of Palermo, Viale delle Scienze, Building 8 90128 Palermo, Italy
[b] ISPRA, Italian Institute for Environmental Protection and Research, Via V. Brancati 48 00144 Rome, Italy

ARTICLE INFO

Keywords
Shoreline evolution
Free GIS tool
Area-based analysis
Coastal monitoring
Tool update

ABSTRACT

The Coastal Dynamics Analyzer (CDA) v.2.0 is an enhanced version of the existing QGIS plugin, CDA v.1.0, which was originally developed for transect-based analysis (TBA) in coastal erosion assessment. This new release introduces the Area-Based Analysis (ABA), a new methodology useful for analyzing irregular or dynamic shorelines. By integrating ABA, CDA v.2.0 enables users to evaluate broader coastal dynamics and changes, providing a more comprehensive toolkit for researchers and professionals engaged in coastal monitoring and management. The plugin maintains its user-friendly interface and compatibility with QGIS, ensuring seamless integration into existing workflows.

Metadata

Current code version	2.0.0
Permanent link to code/repository used for this code version	https://github.com/PietroScalaUnipa/CDA-v2.0/tree/main
Permanent link to Reproducible Capsule	–
Legal Code License	-
Code versioning system used	Git
Software code languages, tools, and services used	Python/PyQGIS
Compilation requirements, operating environments & dependencies	Python 3 on Linux, OSX or Windows. QGIS (min version 3) Dependencies listed in CDA_algorithm.py in code repository and user manual
If available Link to developer documentation/manual	https://github.com/user-attachments/files/19162605/CDA_User_Manual_v2_0_0.pdf
Support email for questions	

1. Introduction

Shoreline analysis is a crucial element in the study of coastal dynamics [1–3], with important implications for land management, environmental planning and natural hazard mitigation [4–7]. In recent years, this type of analysis has gained increasing popularity among researchers and practitioners [8–11]. In this context, the CDA plugin [12] was developed as an open-source tool to perform TBA (Transect-Based Analysis) analyses directly in the QGIS environment, exploiting the PyQGIS language. The plugin is designed to be user friendly, with a simple and intuitive graphical interface that makes it easy to use even for non-experts.

The TBA approach, based on the analysis of shoreline variations along transects perpendicular to a baseline, is effective for assessing the linear displacement of shorelines [13,14]. However, it has some significant limitations, particularly in the presence of fragmented shorelines or those characterised by irregular geometries [15,16]. In such cases, the linear approach may be less accurate and adaptable, reducing the reliability of data interpretation.

To overcome these limitations, we have introduced a useful extension to the CDA plugin, which now includes ABA (Area-Based Analysis). This approach provides a more comprehensive spatial view by calculating areal variations between successive shorelines. ABA not only enables the assessment of global or micro-scale areal variations (between two consecutive transects) but also allows for the estimation of average shoreline displacement by dividing the change in beach area by the length of the considered coastal segment (i.e., the distance between two transects). This method is particularly useful in coastal stretches with complex geometries or anthropogenic structures, where the TBA approach could be less efficient than ABA [15].

Several studies have compared the two approaches [15,17–20],

DOI of original article: https://doi.org/10.1016/j.softx.2024.101894.
Refers toCoastal dynamics analyzer (CDA): A QGIS plugin for transect based analysis of coastal erosionhttps://doi.org/10.1016/j.softx.2024.101894
* Corresponding author.

https://doi.org/10.1016/j.softx.2025.102170
Received 19 March 2025; Received in revised form 8 April 2025; Accepted 15 April 2025
Available online 30 April 2025

showing that the results of TBA and ABA are highly correlated on sectors up to 100 m in length [15]. However, in the presence of irregular shorelines, this correlation decreases significantly over longer lengths, suggesting that ABA may offer more accurate assessments in such contexts. The integration of both approaches provides a more comprehensive understanding of coastal dynamics: TBA provides point details on linear displacements, while ABA offers a global assessment of areal variations.

The implementation of ABA analysis in the CDA plugin represents a major step forward, extending the capabilities of the tool and improving its flexibility and adaptability to a wide range of application contexts. Furthermore, in the case of a beach, if topographical data such as the slope and boundary of the backshore are known, ABA data can allow the calculation of sediment volume in terms of gains or losses.

In this paper, we describe the new functionality of the updated plugin, analysing the rationale behind the introduction of ABA analysis, the technical improvements implemented and the potential benefits for the scientific community.

2. Version 1.0 summary

The Coastal Dynamics Analyzer (CDA) plugin for QGIS was designed to facilitate the analysis of coastal evolution, taking advantage of a process divided into five main steps.

- Step 1: Creation of the baseline, which connects some Ground Control Points (GCP) and generates an interpolated baseline, using the Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) method taking into account all the shorelines to analyze. This allows to adapt the baseline to the morphological characteristics of the coast.
- Step 2: Calculation of transects for the analysis of coastal changes. Using the generated baseline, the plugin creates perpendicular transects and calculates intersections between transects and shorelines.
- Step 3: Correction of transects. Incorrect or inconsistent transects (for example, those crossing sandbars or coastal bends) are automatically identified and corrected, ensuring the validity of the data.
- Step 4: Calculation of change metrics, such as Shoreline Change Envelope (SCE) and Linear Regression Rate (LRR), which provide information on the maximum distance of the shoreline change and the trend of change over time.
- Step 5: Calculation of the parameters Net Shoreline Movement (NSM) and End Point Rate (EPR), which describe the net change in the shoreline and the rate of change between two dates respectively.

The plugin offers an intuitive GUI to guide you through each step and supports exporting results into CSV and shapefile formats.

This first version supports the analysis of advance or retreat rates in linear transect-scale form. For this reason, the new version allows users to have information on increases or decreases also for areas between transects.

3. Upgrade description

The CDA plugin v2.0 can be easily installed using the QGIS Plugin Manager, either by downloading it directly from the metadata table or by installing it as an external plugin from a ZIP file. Additionally, it can also be run as a Python script using the QGIS Processing Script Editor. Based on QGIS algorithms and scientific libraries such as NumPy and QGIS Processing (see supplementary material and user guide for details), the plugin provides a comprehensive and user-friendly environment for coastal analysis, ensuring both flexibility and accuracy. The ABA approach built into the plugin uses as input a *linestring* shapefile connecting ground control points (GCPs) to define a polynomial baseline in accordance with CDA v1.0.0). From the baseline, the plugin automatically generates micro-areas between consecutive transects, calculating key areal metrics for analysing coastal variation. Each shoreline to be analysed must be provided as a separate shapefile.

As defined by Manno et al. [21] ABA metrics include:

- **A-SCE (Area Shoreline Change Envelope)**: represents the greatest change in area between all the shorelines analysed.
- **A-NSM (Area Net Shoreline Movement)**: measures the net change in area between oldest and the youngest shorelines.
- **A-EPR (Area End Point Rate)**: calculates the areal variation between two shorelines over a given period of time. A-EPR = *A*-NSM/ the time between the oldest and the most recent shoreline).
- **A-LRR (Area Linear Regression Rate)**: uses a linear regression to estimate the rate of areal change over time considering all the shorelines.

These areal parameters, expressed in *square* metres (m^2) for A-SCE and A-NSM and $m^2/time$ for A-EPR and A-LRR, offer a spatially integrated view of coastal changes compared to classical linear approaches. A graphical representation of the metrics is shown in Fig. 1.

Based on the date of shoreline acquisition, which is one of the inputs to the plugin, the tool calculates any advance or retreat in terms of area by performing areal differences as shown in Fig. 2.

In particular, Fig. 2 illustrates a graphical representation of the shoreline evolution between two distinct time moments, denoted as t_1 and t_2, where $t_2 > t_1$. The figure highlights the interaction between the PCHIP (Piecewise Cubic Hermite Interpolating Polynomial) baseline (in red), the shorelines at the two-time instants (t_1 in green and t_2 in orange), and a series of transects perpendicular to the baseline.

The areas of accretion and retreat are clearly demarcated on the seaward and beachward sides, respectively. The t_1 area is represented by a green grid plot in areal terms. In contrast, the retreat area is indicated with an orange diagonal grid plot. The condition of accretion and retreat is met when $At_2 > At_1$.

The figure uses transects as a reference to calculate and visualize the spatial variation of the shoreline in relation to the PCHIP baseline. These transects are equidistant and intersect both shorelines, highlighting points of contact that allow changes in areas between the two-time instants to be estimated.

To obtain linear rates using the ABA approach, the average shoreline displacement is calculated by dividing the area bounded by the transects, shoreline and baseline, by the length of the shoreline between two different transects. This simple geometric ratio is then used to calculate by the plug-in further linear average rates of shoreline change, including M-NSM [m], M-SCE [m], M-EPR [m/time] and M-LRR [m/time].

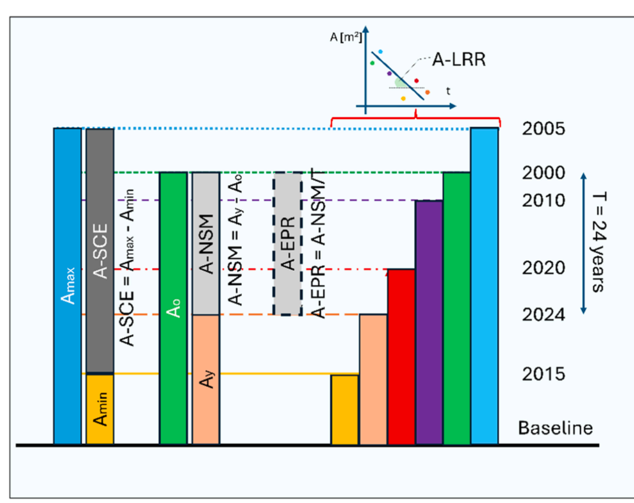

Fig. 1. Graphical explanation of A-SCE, A-NSM, A-EPR and A-LRR. The area below the baseline represent land, while the area above sea.

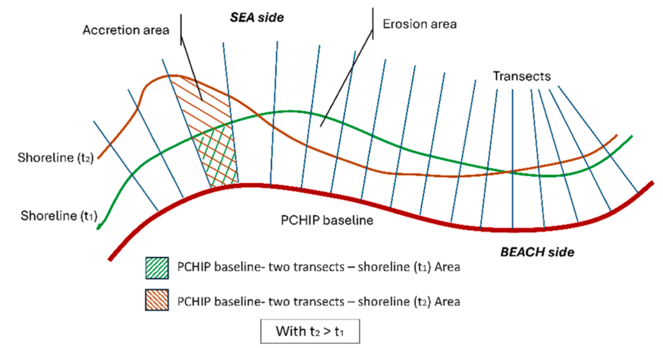

Fig. 2. Schematic diagram of the representation of areas between two transects and two shorelines. Indication on areas of retreat and accretion is also provided in the figure.

4. Update functionalities

Similar to version 1.0, the update is designed to guide the user through the various steps required to analyse coastal dynamics, using a structured workflow and automated functionality. Below is a summary of the main steps and implemented functionalities:

Step 1: Main plugin interface

- The execution of the plugin starts with the import of the required libraries and the configuration of a *Main Dialog Box*. This window (Fig. 3) allows the user to choose whether to perform TBA or ABA analysis. In the first case (TBA), the following window is the same as the one discussed in Scala et al. [12]. In the second case, a new GUI will be displayed to perform the analyses being updated. The GUI guides the user through the analysis steps, allowing selection of ABA operations, management of the required inputs (baselines and shorelines) and start of the calculations.

Step 2: Configuring the ABA Interface

- **User Interface:** The *NumberInputDialog* class is implemented, which configures the plugin's main graphical user interface (GUI) (Fig. 4). The ABA GUI allows users to select the ABA approach and set the necessary parameters, such as the choice of shorelines and the definition of a custom polynomial baseline.

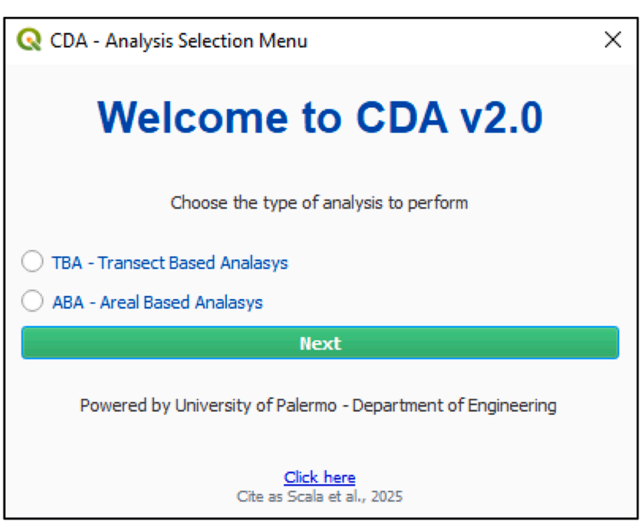

Fig. 3. CDA v.2.0 main GUI. The window allows users to choose which type of analysis to perform (TBA or ABA).

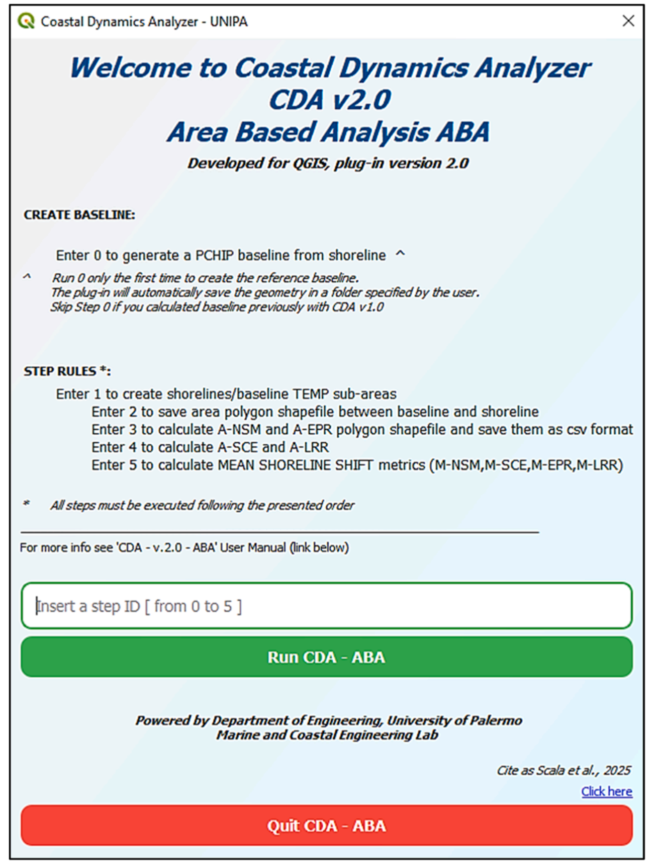

Fig. 4. ABA main GUI.

- **Event Handling:** A dedicated function handles user input and validates data before processing begins.
- **Clear instructions:** The interface provides detailed instructions for each step, guiding the user through the entire ABA analysis process in an intuitive manner.

Step 3: Automation of the ABA Analysis Steps (AA Step)

Step AA = 0: Creation of the PCHIP Baseline

This step, discussed in the article by Scala et al. [12] and in the documentation of the previous version of the plugin, is dedicated to the generation of the baseline using a PCHIP interpolation. The baseline represents the reference curve for subsequent analyses and is automatically created from shoreline geometries and ground control points. This step is performed only once, and the results can be re-used in further analyses. For more information on the process refer to Scala et al. [12].

Step AA = 1: Calculation and Vectorisation of Areas

Step AA = 1 calculates and vectorizes the areas between the baseline and the shorelines, generating shapefiles representing the areas subtended by the curves. This process can be run in batches to automatically analyse multiple shorelines in a single operation, making the analysis particularly efficient.

Step AA = 2: Calculation of Area Differences

Step AA = 2 uses the shapefiles generated in the previous step to calculate the difference between baseline and shoreline areas. The result represent spatial variations between the baseline and different shoreline positions. This step also supports batch processing.

Step AA = 3: Calculation of A-NSM and A-EPR Metrics

During step AA = 3, the metrics A-NSM (Areal Net Shoreline Movement) and A-EPR (Areal End Point Rate) are calculated. These values are automatically stored in shapefile and CSV files in a user-specified folder. At this stage, it is necessary to define the spacing of the transects, which allows the calculation of the metrics on the areas delimited by the baseline, shoreline and transects themselves. Each area analysed is given a unique ID to ensure data traceability.

Step AA = 4: Calculation of A-SCE and A-LRR Metrics

Step AA = 4 calculates the areal change metrics A-SCE (Shoreline Change Envelope) and A-LRR (Linear Regression Rate). Again, the process can be automated for batch processing, allowing for fast and efficient analysis of large datasets.

Step AA = 5: Calculation of Mean Shoreline Shift Metrics

Finally, step AA = 5 calculates average shoreline variation metrics, including M-NSM, M-SCE, M-EPR, M-LRR and others. These metrics summarise linear and areal shoreline variations, providing a comprehensive view of coastal dynamics.

For a step-by-step guide on how to execute each phase of the process, along with detailed explanations of every calculation algorithm used, please refer to the supplementary materials or consult the GitHub repository, where the complete user manual is available.

5. Case study

The developed plugin was applied to the beach of Eraclea Minoa, a logarithmic spiral beach located on the south-west coast of Sicily, Italy. The coast (about 6 km long and 20 m wide), can be identified as a dissipative (slope of the submerged beach is about 5 degrees) logarithmic beach. This beach, known as Eraclea Minoa Beach (37°23′39'' N – 13°17′29'' E), is a wild stretch of coastline located on the southern coast of Sicily, near the ancient ruins of the Greek city of Eraclea Minoa. The beach is located between the promontory of Capo Bianco to the north and that of Torre Salsa to the south. The morphodynamic characteristics of the beach are influenced both by the refraction of the waves that occurs to the north due to the promontory, and by the sediment transport along the coast, which has a north-west-south-east direction. The northern part of the coast, near to the headland of Capo Bianco, is characterised by a small beach (about 600 m long and 3 m wide) which was formed by the erosion of a marl cliff. Here the beach has sediments with a variable granulometry from arenitic to ruditic grain size. Moving southward from this small beach at the foot of the promontory begins the beach of Eraclea Minoa where the sediment consists of fine sand with a grain size of about 0.6 mm. Behind the beach, a low-lying dune system has developed, partially stabilised by Mediterranean vegetation and a coastal pine forest, which helps to reduce aeolian transport. The tidal range in this coastal area is relatively small, and it is classified as microtidal. A few years ago, in order to protect the beach from coastal erosion, three groins made of cyclopean stones were built. These structures are designed to intercept sediment coming from the north, thereby limiting erosion. For more information see Manno et al. [21] and Scala et al. [12].

The beach of Heraclea Minoa has been subject to erosion phenomena for years, with the rate of retreat increasing in the last decade. This phenomenon is mainly due to two factors:

1. **Natural beach behaviour in a logarithmic spiral**, influenced by wave action and refraction phenomena [22].
2. **Reduced sediment supply from upstream rivers**, which has limited the sediment balance needed to counter retreat.

The new version of the plugin was performed using the update to the ABA analysis, taking as input data of shorelines and baselines the same used by Scala et al. [12]. All the shorelines have been identified using the wet/dry proxy [23]. The shorelines used in the analysis correspond to the years 1989, 1997, 1998, 2005, 2010, 2019 and 2020, extracted from aerial photographs in black and white and color as well as satellite images, with resolutions between 0.5 and 3 m using the model presented by Scala et al. [11]. 515 transects with an average spacing of 10 m (corresponding to an irregularity of 0.11) were generated for each shoreline. Each transect has as its start point a point belonging to the baseline and as its end point the intersection of the transect with the generic shoreline. Each sub-area corresponds to the area intercepted by the intersections of the shoreline, the baseline and the transects.

Fig. 5 analyses the coastal dynamics along the stretch of shoreline from Eraclea Minoa beach to Bovo Marina beach, providing an integrated view through two main columns. The left column contains three subplots describing the evolution of coastal metrics along the transects, while the right column shows two thematic maps (subplot A and B) illustrating the spatial distribution of A-NSM and A-EPR, respectively.

Subplot A of Fig. 5 shows the comparison between the mean net linear shoreline change (M-NSM) and the maximum linear shoreline change (M-SCE). The data show that in the initial transects, between 1 and 100, the value of M-NSM drops rapidly to around −150 m, indicating strong retreat, while M-SCE remains close to zero. In the intermediate portion, between transects 100 and 250, an increase in M-SCE is observed up to about 50 m, with M-NSM remaining consistently negative around −100 m. Finally, in the transects between 250 and 500, both parameters stabilise, with M-SCE progressively approaching zero and M-NSM remaining in negative territory.

In the second subplot (B) in the left column of Fig. 5, the mean linear rate of change (M-EPR) and the mean linear trend of change (M-LRR) are compared. In the first 50 transects, both parameters show significant negative values, with M-EPR reaching peaks of −2 m/yr and M-LRR following a similar trend but with less fluctuation. In the intermediate and final portions of the shoreline, starting from transect 200, a tendency towards stabilisation is noted, with both parameters approaching values close to zero, indicating an equilibrium in coastal dynamics.

The last subplot in the left column (subplot C) of Fig. 5, analyses the cumulative areas of change, showing a comparison between the cumulative area of change (A-SCE) and the change over time of beach area derived from the linear trend (A-LRR). In the first transects, from 1 to 100, A-SCE increases rapidly to a maximum peak of about 5000 m^2, showing significant changes in the coastal area. In contrast, A-LRR shows a more regular and less marked trend, reaching a maximum of around 2000 m^2 between transects 200 and 300. After this phase, both parameters tend to stabilise, with A-SCE showing slight fluctuations and A-LRR remaining at lower values than in the initial phase.

Turning to the right column (Fig. 5), subplot D represents the spatial distribution of net shoreline change (A-NSM). The data are classified into five colour ranges from red, indicating strong retreat, to green, indicating significant accretion. Fig. 5 shows how the net area lost, as identified by A-NSM, shows a significant reduction, with slight local accretion in the area south of Bovo Beach. In particular, the stretch of shoreline between transects 50 and 150 shows the most negative values of A-NSM, with peaks as low as −1314 m, represented in deep red. In contrast, the areas marked in green, indicating accretion, are predominantly located between transects 400 and 500, with positive values of up to 366 m. This sharp transition between erosive and accretionary areas reflects a significant variability along the shoreline. In fact, the maximum area variation determined by A-SCE is quite high, exceeding the total sum of the accretion and retreat areas measured by A-NSM. This shows the presence of large shoreline fluctuations during the observation period.

Finally, subplot E (Fig. 5) shows the spatial distribution of the average areal rate of change (A-EPR), which is also classified chromatically. Areas with more negative values, reaching −42.4 m^2/yr, are evident in the first 150 transects and are represented in deep red. Areas with positive values, indicating accretion, are more sporadic and are concentrated in the final transects, with maximum values reaching 11.8 m^2/yr, highlighted in dark blue. The map provides a clear representation of the areas subject to greater coastal dynamics, with immediate identification of critical zones.

This integrated analysis highlights a clear dichotomy between areas subject to retreat and those characterised by accretion along the studied shoreline. In the initial transects, strong retreat is observed, with M-NSM values down to −150 m and A-NSM values down to −1314 m. In the final transects, on the other hand, there is a tendency towards accretion,

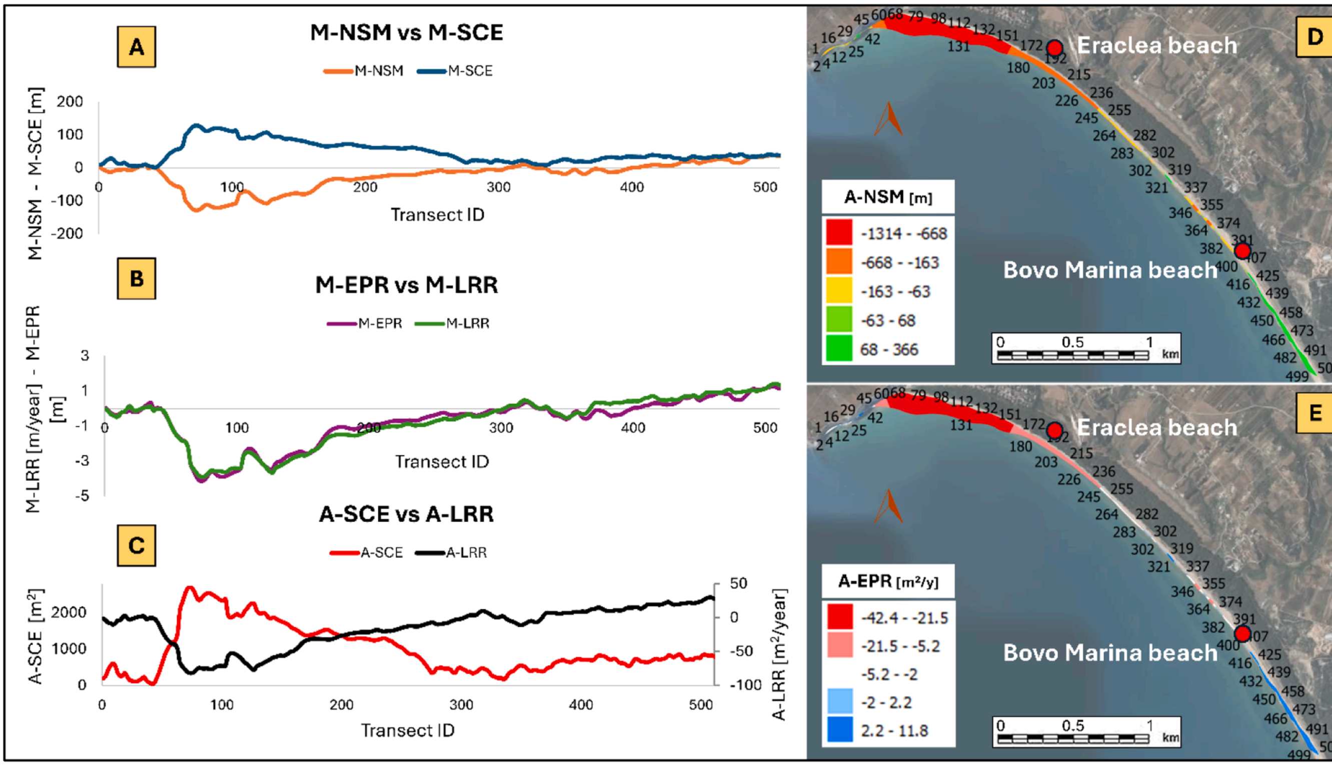

Fig. 5. Map showing the results of ABA of Eraclea Beach and Bovo Marina study area. In the left column, at A subplot, M-NSM and M-SCE plot is showed. In the middle (subplot B) M-EPR and M-LRR plots. A plot of A-SCE vs. A-LRR is shown at subplot C of the left column.. In the right column, subplot D displays the spatial distribution of net shoreline change area (A-NSM), while subplot E depicts the spatial distribution of the A-EPR metric. Reference System EPSG: 32,633.

with positive values of M-SCE, A-NSM and A-EPR, suggesting an accumulation of sediment but still much less than the eroded areas.

The results highlight not only the dramatic condition of the beach, which has lost a large area due to wave action and the lack of sediment in the area, but also the good accuracy of the proposed tool in identifying retreat dynamics when compared to the results obtained by Manno et al. [21]. These results confirm the high reliability of the proposed tool, which performs well even in a relatively linear coastal context. When compared with the outcomes of Scala et al. [11] (TBA) and Manno et al. [20], who applied both TBA and ABA analyses to the same logarithmic spiral beach, no significant differences in the shoreline change detection were observed. This is likely due to the linear nature of the studied shoreline, where the ABA's independence from transect spacing and the TBA's sensitivity to shoreline irregularity have a reduced impact. Therefore, while the joint use of ABA and TBA is particularly beneficial in complex settings, in this case both approaches yield consistent and accurate results.

6. Conclusions

The application on the beach of Heraclea Minoa demostrated both the abilities of the plugin to detect significant shoreline variations and its potential to support the understanding and mitigation of erosion phenomena. The results obtained are in line with those reported in the literature, confirming the reliability of the tool and its usefulness in addressing real issues related to coastal management.

With the integration of ABA, the CDA provides not only point metrics, but also offers a more comprehensive spatial view of coastal changes, allowing for the analysis of both large-scale global changes and more local changes on micro-areas. The ability to calculate metrics such as A-NSM, A-SCE and A-EPR provides an additional level of detail to monitor coastal evolution over time and identify areas at greatest risk of retreat or accretion.

Finally, the potential applications of the plug-in, ranging from coastal erosion monitoring to mitigation design and spatial planning, make it an extremely versatile tool. In a global context of increasing pressure on the coast due to climate change and human activities, tools such as CDA can make a crucial contribution to supporting science-based decisions and promoting sustainable management of coastal resources.

It will be important, in the future, to further expand the plugin's functionalities including, for example, the integration of three-dimensional topographic data for the calculation of sediment volumes and the improvement of predictive analysis capabilities. The adoption of the CDA by the scientific community and coastal professionals may accelerate the development of new solutions to address coastal dynamics challenges.

CRediT authorship contribution statement

Pietro Scala: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Giorgio Manno:** Writing – review & editing, Validation, Methodology, Investigation, Data curation, Conceptualization. **Carlo Lo Re:** Writing – review & editing, Software, Methodology, Conceptualization. **Giuseppe Ciraolo:** Writing – review & editing, Validation, Supervision, Resources, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was carried out within the RETURN Extended Partnership that 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).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.softx.2025.102170.

References

[1] Hunt E, Davidson M, Steele ECC, Amies JD, Scott T, Russell P. Shoreline modelling on timescales of days to decades. Camb Prisms Coast Futur 2023;1:e16. https://doi.org/10.1017/cft.2023.5.

[2] Rizzo A, Anfuso G. Coastal dynamic and evolution: case studies from different sites around the world. Water 2020;12:2829. https://doi.org/10.3390/w12102829.

[3] Aladwani NS. Shoreline change rate dynamics analysis and prediction of future positions using satellite imagery for the southern coast of Kuwait: a case study. Oceanologia 2022;64:417–32. https://doi.org/10.1016/j.oceano.2022.02.002.

[4] Adebisi N, Balogun A-L, Mahdianpari M, Min TH. Assessing the impacts of rising sea level on Coastal morpho-dynamics with automated high-frequency shoreline mapping using multi-sensor optical satellites. Remote Sens 2021;13:3587. https://doi.org/10.3390/rs13183587.

[5] Youssef YM, Gemail KS, Sugita M, AlBarqawy M, Teama MA, Koch M, et al. Natural and anthropogenic coastal environmental hazards: an integrated remote sensing, GIS, and geophysical-based approach. Surv Geophys 2021;42:1109–41. https://doi.org/10.1007/s10712-021-09660-6.

[6] Nunez K, Rudnicky T, Mason P, Tombleson C, Berman M. A geospatial modeling approach to assess site suitability of living shorelines and emphasize best shoreline management practices. Ecol Eng 2022;179:106617. https://doi.org/10.1016/j.ecoleng.2022.106617.

[7] Scala P, Toimil A, Álvarez-Cuesta M, Manno G, Ciraolo G. Mapping decadal land cover dynamics in Sicily's coastal regions. Sci Rep 2024;14:22222. https://doi.org/10.1038/s41598-024-73085-5.

[8] Rahman MK, Crawford TW, Islam MS. Shoreline Change Analysis along Rivers and Deltas: a systematic review and bibliometric analysis of the Shoreline study literature from 2000 to 2021. Geosciences 2022;12:410. https://doi.org/10.3390/geosciences12110410.

[9] Ankrah J, Monteiro A, Madureira H. Bibliometric analysis of data sources and tools for shoreline change analysis and detection. Sustainability 2022;14:4895. https://doi.org/10.3390/su14094895.

[10] Yan D, Yao X, Li J, Qi L, Luan Z. Shoreline change detection and forecast along the Yancheng Coast using a digital Shoreline analysis system. Wetlands 2021;41:47. https://doi.org/10.1007/s13157-021-01444-3.

[11] Scala P, Manno G, Ciraolo G. Semantic segmentation of coastal aerial/satellite images using Deep Learning techniques: an application to shoreline detection. Comput Geosci 2024:105704.

[12] Scala P, Manno G, Ciraolo G. Coastal dynamics analyzer (CDA): a QGIS plugin for transect based analysis of coastal erosion. SoftwareX 2024;28:101894. https://doi.org/10.1016/j.softx.2024.101894.

[13] Quadrado GP, Dillenburg SR, Goulart ES, Barboza EG. Historical and geological assessment of shoreline changes at an urbanized embayed sandy system in Garopaba, Southern Brazil. Reg Stud Mar Sci 2021;42:101622. https://doi.org/10.1016/j.rsma.2021.101622.

[14] Santos CAG, do Nascimento TVM, Mishra M, da Silva RM. Analysis of long- and short-term shoreline change dynamics: a study case of João Pessoa city in Brazil. Sci Total Environ 2021;769:144889. https://doi.org/10.1016/j.scitotenv.2020.144889.

[15] Anfuso G, Bowman D, Danese C, Pranzini E. Transect based analysis versus area based analysis to quantify shoreline displacement: spatial resolution issues. Environ Monit Assess 2016;188:1–14.

[16] Del Río L, Gracia FJ, Benavente J. Shoreline change patterns in sandy coasts. A case study in SW Spain. Geomorphology 2013;196:252–66.

[17] Albuquerque M, Espinoza J, Teixeira P, De Oliveira A, Corrêa I, Calliari L. Erosion or coastal variability: an evaluation of the DSAS and the change polygon methods for the determination of erosive processes on Sandy beaches. J Coast Res 2013;165:1710–4. https://doi.org/10.2112/SI65-289.1.

[18] Emam WWM, Soliman KM. Applying geospatial technology in quantifying spatiotemporal shoreline dynamics along Marina El-Alamein Resort, Egypt. Environ Monit Assess 2020;192:459. https://doi.org/10.1007/s10661-020-08432-w.

[19] Emam WWM, Soliman KM. Quantitative analysis of shoreline dynamics along the Mediterranean Coastal Strip of Egypt. Case study: marina El-Alamein Resort. editors. In: Elbeih SF, Negm AM, Kostianoy A, editors. Environ. remote sens. Egypt, Cham: Springer International Publishing; 2020. p. 575–94. https://doi.org/10.1007/978-3-030-39593-3_18.

[20] Smith MJ, Cromley RG. Measuring historical coastal change using GIS and the Change Polygon approach. Trans GIS 2012;16:3–15. https://doi.org/10.1111/j.1467-9671.2011.01292.x.

[21] Manno G, Lo Re C, Basile M, Ciraolo G. A new shoreline change assessment approach for erosion management strategies. Ocean Coast Manag 2022;225:106226. https://doi.org/10.1016/j.ocecoaman.2022.106226.

[22] LeBlond PH. An explanation of the logarithmic spiral plan shape of headland-bay beaches. J Sediment Res 1979;49:1093–100.

[23] Boak EH, Turner IL. Shoreline definition and detection: a review. J Coast Res 2005;214:688–703. https://doi.org/10.2112/03-0071.1.