 doi:10.20944/preprints202101.0082.v1

Article

End Point Rate Tool for QGIS (EPR4Q): Validation using DSAS and AMBUR

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Abstract: This paper presents the validation of the End Point Rate (EPR) tool for QGIS (EPR4Q), a tool built-in QGIS Graphical Modeler to calculate the shoreline change by End Point Rate method. The EPR4Q tries to fill the gap of user-friendly and free open-source tool for shoreline analysis in Geographic Information System environment, since the most used software - Digital Shoreline Analysis System (DSAS) - although is a free extension, is suited for commercial software. Besides, the best free open-source option to calculate EPR called Analyzing Moving Boundaries Using R (AMBUR), since it is a robust and powerful tool, the complexity and heavy processes can restrict the accessibility and simple usage. The validation methodology consists of applying the EPR4Q, DSAS, and AMBUR on different examples of shorelines found in nature, extracted from the U.S. Geological Survey Open-File. The obtained results of each tool were compared with Pearson correlation coefficient. The validation results indicate that the EPR4Q tool created acquired high correlation values with DSAS and AMBUR, reaching a coefficient of 0.98 to 1.00 on linear, extensive, and non-extensive shorelines, guarantying that the EPR4Q tool is ready to be freely used by the academic, scientific, engineering, and coastal managers communities worldwide.

Keywords: Shoreline Evolution; Open-Source Software; GIS; Modeling

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1. Introduction

The sandy beaches occupy more than a third of the global coastline [1]. Because of the high socio-economic value of these environments, in the last 40 years, there has been a substantial increase in the coastal population [2]. The shoreline is defined straightforwardly as the line that overlaps the physical land-water boundary [3]. Several factors influence their dynamics (e.g., waves, tides, human activities), which make them one of the most important features in coastal planning [4]. The observed shoreline changes along the centuries are related to oscillations of sea-level and river sediment discharge whereas those changes in the short timescale (annual to decade) are mainly linked to hydrodynamic processes, local sediment budgets, and/or anthropogenic activities (e.g., coastal engineering works such as nourishment operations) (e.g., [5–8]). Its advance towards the continent can cause damage to the coastal zone, such as change in the beach dynamics and wear and tear on civil constructions, in addition to also resulting in socioeconomic impacts by reaching some activities inherent to the littoral [9]. Therefore, the knowledge about the rate of shoreline changes and possible predictions in the future based on previous trends is of capital importance for the development of coastal morphodynamic models, budget of sediments and erosion/accretion analysis, identification of hazard areas, policy and coastal management [10].

Nowadays, there is a serious growing concern about climate change problems [11,12], and the expected increase of extreme events as bigger hurricanes and storms over coastal littorals [13–15]. Therefore, the information about shoreline changes increases the capability to manage erosion, overwash, and flooding risks and protect the population living in coastal areas [5]. These issues increase the necessity to have a quick application to detect and to compute shoreline variation rates. Currently, many studies have used change detection tools interconnected to GIS environment, to determine changes in the shoreline position, as well as to forecast future positioning trends. This study aims to develop an alternative tool (EPR4Q) to End Point Rate statistical analysis running in QGIS Software, which is commonly used by Digital Shoreline Analysis System (DSAS) and Analyzing Moving Boundaries Using R (AMBUR).

1.1. DSAS

The Digital Shoreline Analysis System (DSAS) is a tool whose purpose is to calculate the change position rates for a time series of historical shoreline vector data. Developed by the U.S. Geological Survey, the DSAS is a free extension tool of ArcGIS ESRI (Environmental Systems Research Institute) [16], and uses the measurement baseline method to calculate the shoreline velocity or change at user-specified intervals along the shoreline [17].

One advantage of using DSAS in coastal change analysis is that it can calculate the rate of change of shoreline time series, evaluating and resolving the nature of shoreline dynamics and changing trends [18]. Besides, DSAS has numerous applications in studies of coastal behavior and shoreline dynamics as historical trend analysis [19–23], and the expected future shoreline morphology (e.g.,[24,25]).

Indeed, the DSAS allows studying the shoreline behavior worldwide. However, many countries and small management agencies have a low budget to work with commercial software such as ArcGIS. Other options as SCARPS (Simple Change Analysis of Retreating and

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Prograding Systems) [26] and BeachTools [27,28] also uses the ArcGIS to run. To settle this, a free and open alternative of DSAS was created in R language called Moving Boundaries Using R (AMBUR) [29].

1.2. AMBUR

The AMBUR package for R software environment is based on another shoreline change analysis tool named SCARPS designed by AMBUR's author [29]. Numerous works using AMBUR can be found in the literature with examples of studies about shoreline changes at different timescales [30–35].

However, AMBUR has the disadvantage to be complex to install and configure the parameters, with the necessity to edit baselines and shorelines on geographic information systems, like QGIS or ArcGIS software. These problems, combined with no user-support, are not attractive for the end-users to adopt the AMBUR as a free-open, and source option for shoreline analysis in a GIS environment. Therefore, the implementation of a tool directly on QGIS [36], one of the most importantly free and open-source software for GIS, seems to be the most reasonable solution to ease the access of a fast shoreline trends analysis.

1.3. QGIS

The QGIS is a free and open-source GIS application that allows users to explore, control, evaluate, edit data, georeferencing images, composing, and exporting graphical maps. QGIS supports vector data (point, line, or polygon features) and numerous formats of raster images. Furthermore, integrates other open-source GIS packages as GRASS GIS, MapServer, and PostGIS [36], has a significant number of developers, and it is supported by most operating systems [37].

The QGIS frequently releases new versions and continuous updates that provide a better user experience, which creates a vast community around it. Likewise, it has a significant number of developers, and it is supported by most operating systems [37], also spreading for mobile phones through the Android App. Keeping in mind the described scenario, it is effortless to understand how useful is the existence of a shoreline analysis tool that operates directly in QGIS software.

The first tool for QGIS to perform shoreline analysis was created by the authors in 2017 [38] a Python Plugin for QGIS (not registered in the official repository) to calculate a simple shoreline movement. However, this project was discontinued from a plugin to focus on creating a tool on QGIS graphical modeler called EPR4Q that includes a future prediction of the shoreline position by End Point Rate Method.

1.4. End Point Rate (EPR)

There are numerous examples of methods to calculate the short- and long-term shoreline trend. These methods can be focused on shoreline distances such as Shoreline Change Envelope - which reports the distance between the farthest shoreline from baseline and the closest one at each transect, or Net Shoreline Movement – which estimates the distance between the oldest and the youngest shorelines for each transect; or they can be centered on rates such as Linear Regression Rate - a linear regression rate-of-change statistic; or Weighted Linear Regression - that shows the weight towards determining a best-fit line; among others [16].

The method selected to create the tool was the End Point Rate (EPR) [39], a fast and effective technique that has the great advantage of using only two shorelines to estimate changes and/or to generate predictions. Nevertheless, it has the disadvantage of the EPR when there are several shorelines available since this method only uses the oldest and the newest shoreline. Therefore, changes in magnitude or periodic trends might be omitted [40].

The main goal of this study is to develop an alternative tool for End Point Rate analysis running in QGIS Software. The new tool named End Point Rate for QGIS (EPR4Q) is subjected to a validation process by statistical comparison with well-known software such as AMBUR and DSAS.

2. Study Area

This study only aims the validation to allow the use of EPR4Q globally. To reach this purpose, it was necessary to find a shoreline database that expressed most examples of coastal characteristics found in the worldwide shorelines, which requires acceptable quality and a reliable source. The excellent open available data of vectorized shorelines with errors and accuracy well reported, combined with the usage of technologies of LIDAR and Aerial photography of U.S. Geological Survey [41–44] complete all the requirements to validate the EPR4Q for worldwide use. The shorelines chose to apply and to validate the EPR4Q are located on the west and east coast of the United States of America. The coastal stretches analyzed are i) Arlight and Concepcion in Santa Barbara County – California State; ii) Hampton in Rockingham County - New Hampshire State, and iii) Rockport, Essex County - Massachusetts State (Figure 1). The sites were chosen due to the different morphological characteristics, straight and embayed coasts, orientation, and ocean exposition. These features allow to test examples of linear shorelines (Concepcion and Hampton) and indented shorelines (Arlight and Rockport), and examples with different exposition (Concepcion coast with the ocean on the east side, Rockport coast exposed to the ocean located to the north, Hampton coast with the ocean on the west side and Arlight coast with the ocean situated in the south), and extensive (extension >1 Km, Arlight and Concepcion) and non-extensive (extension ≤1 Km, Hampton, and Rockport) shorelines.

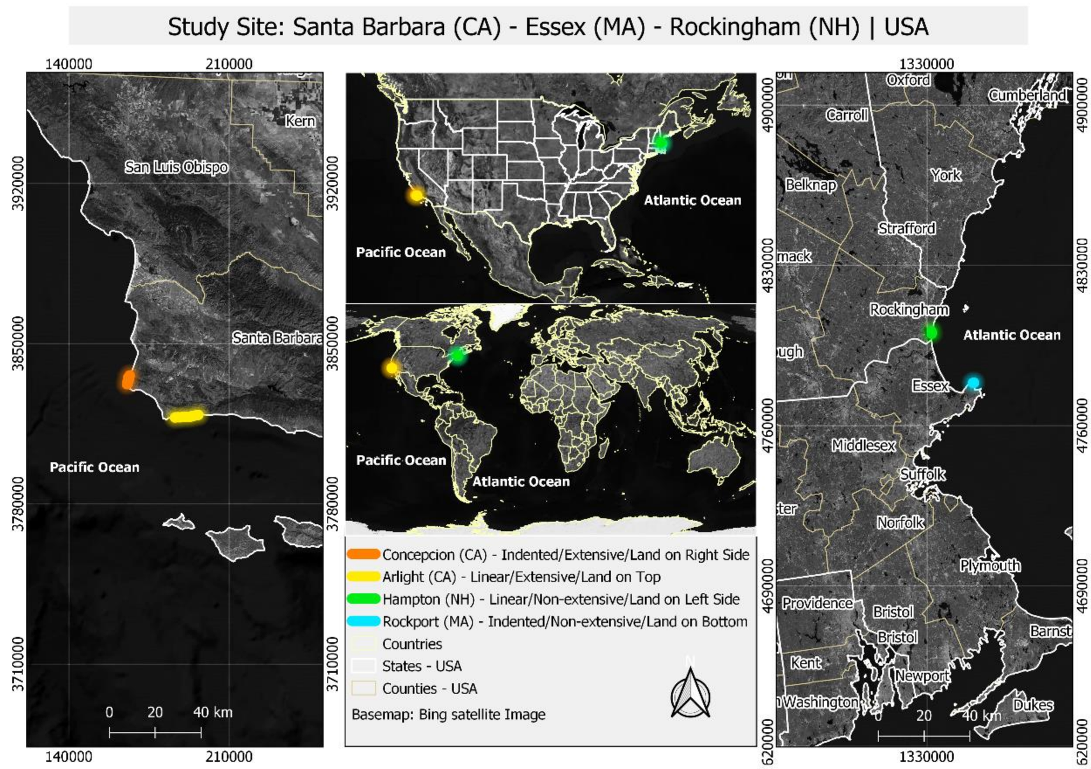

Figure 1. General location and study coastal stretches: Concepcion and Arlight shorelines - Santa Barbara (CA); Hampton shoreline - Rockingham (NH); Rockport shoreline - Essex (MA).

3. Materials and Methods

3.1. EPR4Q Tool Creation

The EPR4Q tool was created on Graphical Modeler QGIS Desktop version 3.4 - Madeira using existing tools of Processing Extension (Appendix A). To this study, the analysis needs two shorelines to be assessed, also is mandatory the creation of two baselines: a straight vector line on both sides of the shorelines (Figure 2 – a). The first step consists in the transformation of the baselines into points by using the v.to.points tool (Figure 2 – b).

The second step consisted of creating perpendicular transects between the baselines and the shorelines with the Distance of nearest hub tool (Figure 2 – b). It was also developed an alternative for the One Side Buffer or Single-Sided Buffer tool since these tools did not result in correct geometries for the purpose. This method is called in this paper by Alternative One Side Buffer (Figure 2 – c, d, e). It consists of creating a buffer on the vector line and applying the algorithm Extend Lines at the extremities of the vector line to cross this buffer and allowing to split it into two parts with the Split with Line tool.

The selection of only one side of the buffer was created as a point in the center of the vector line with the Point on Surface tool and shift the location of this point by the Project Points tool to locate the point on the surface of the buffer polygon to allow the extraction with the Extract by Location tool. This procedure gives to the model two buffer polygons from the baseline to the newest and the oldest shorelines ready to cut the transect lines created at the beginning. The third step consisted in calculating the distances between them with the Field Calculator tool (Figure 2-f).

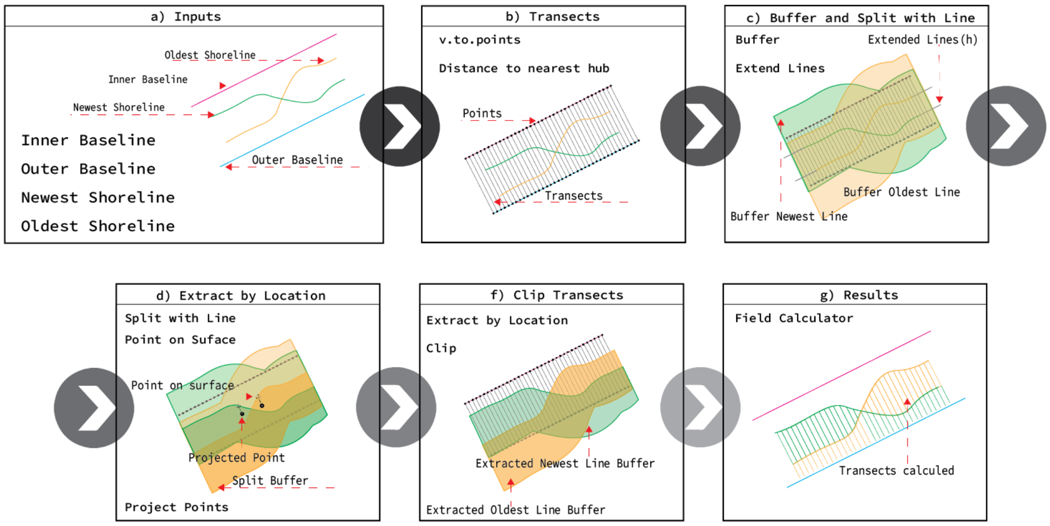

Figure 2. Graphical illustration of EPR4Q tool.

The tool generates two shapefiles of transect lines with the shape of the advance and retreat movement of the shoreline in the analyzed period. The Field Calculator tool was used to calculate the variations and the rates with the End Point Rate method.

3.1.1. EPR Method

The End Point Rate (EPR) method define the shoreline position by a straight-line equation (Eq.1):

$$\text{Shoreline Position}=\text{Rate}*\text{Date}+\text{Intercept} \qquad (1)$$

The projection of the shoreline position for a specified date is expected by the subsequent slope and Y-intercept. The EPR method uses a line selected from the two end points, the earliest and the latest positions. Using Y to represent the shoreline position, B for the intercept, X for the date, and m for the shoreline movement rate, the previous equation becomes (2):

$$Y=m*X+B \qquad (2)$$

Assuming N samples, numbered in ascending order by date, the end point rate calculation can be rewritten (3):

$$Y=(Y_N-Y_1)/(X_N-X_1) \qquad (3)$$

moreover, the EPR intercept is (4):

$$B_{EPR}=Y_1-m_{EPR}*X_1$$
$$=Y_N-m_{EPR}*X_N \qquad (4)$$

The endpoint line that passes beyond the most recent point (X, Y) N' equation can be rewritten by using the position (YN) and the elapsed time $(X - XN)$ as (5):

$$B_{EPR}=m_{EPR}*(X-X_n)+Y_n \quad (5)$$

3.1.2. EPR Projection and Visualization

For the graphical representation of EPR results in EPR4Q, it was used the v.to.points tool in the vector lines of transects results to get the values of EPR and to allow the application of the next tools (Figure 3 – a, b). After this procedure, diamond shapes were created in these points with the size of EPR projection through the Rectangles, Ovals, and Diamonds tool (Figure 3 – b), expressing the position of the new shoreline in the future at the tip of the diamond shape. The location of the baseline was shifted with the v.parallel tool, and applied again the Alternative One Side Buffer method to cover and extract the area of diamond shapes with EPR result (Figure 3 – c). The buffers from the parallel baseline were united with the divided buffer of the newest line created at the beginning of the model construction (Figure 3 - d). This procedure generated a polygon with the shape of the parallel buffer and the buffer of the newest shoreline, which extracted the positive and negatives values of EPR results (Figure 3 - e). The last process applies the color ramps by the Set Style for Vector Layer tool (Figure 3 - f).

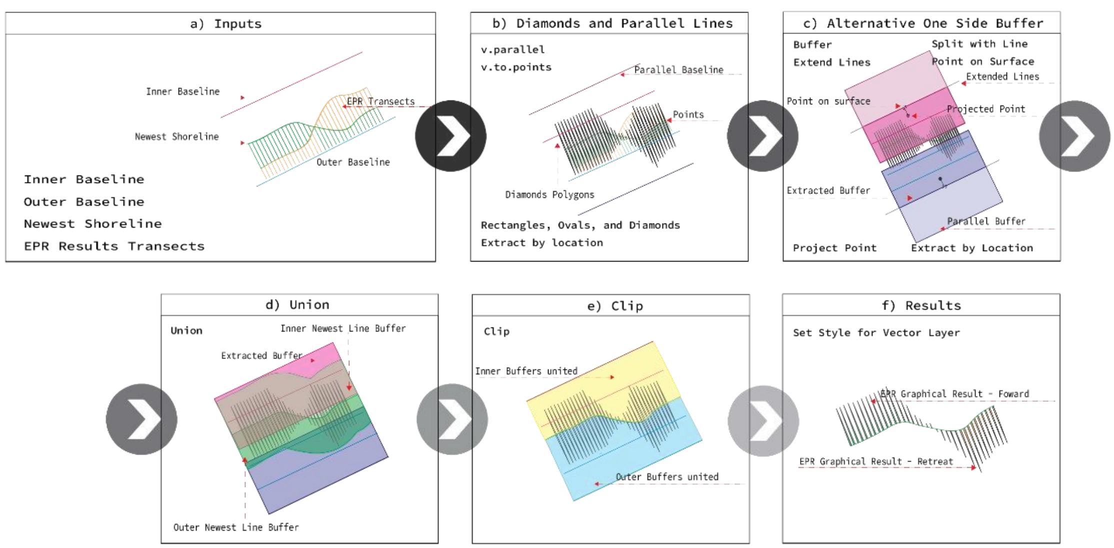

Figure 3. Graphical visualization process of EPR4Q tool.

3.2. Validation Process

3.2.1. Shorelines Data

The Hampton and Rockport shoreline vector have a total shoreline position uncertainty of 5.5 meters (Himmelstoss et al., 2010), and the total shoreline position uncertainty for Concepcion and Arlight is 10.1 meters [43], both including the errors of georeferencing, digitalizing, air photo, and uncertainty of the high water line.

The shoreline analysis with AMBUR (version 1.1.27), DSAS (version 5.0), and EPR4Q (version 1.0) was applied in two types of shorelines: indented or non-linear (i.e., with irregular morphology), and linear. Furthermore, the analysis included extensive (>1 Km) and non-extensive (≤1 Km) coastal stretches. Finally, the shoreline orientation was also assessed (Table 1).

Table 1. General characteristics of shorelines used in the validation process.

Shoreline	Location	Type	Extension	Orientation	Date
Concepcion	Santa Barbara	Linear	Extensive (11 Km)	Ocean to the south	Mar 1976 – Sep 1993
Arlight	Santa Barbara	Non-Linear	Extensive (4 Km)	Ocean to the west	Mar 1976 - Nov 1993
Hampton	Rockingham	Linear	Non-extensive (1 Km)	Ocean to the east	Jul 1953 – Sep 2000
Rockport	Essex	Non-Linear	Non-extensive (<1Km)	Ocean to the north	Oct 1951 – Oct 1994

3.2.2. Transects selection and statistical analysis

The transects with a spacing of 1.0 m were generated in the three tools in the shorelines considered. The perpendicular transects of AMBUR and DSAS were smoothed with the default values suggested by the models (i.e.: DSAS – Smoothing Distance: 500 m; AMBUR - Windows Size: 5) because the selection of better transects induce a bias in analysis when favoring the result that reached the best filtering. Otherwise, using any filtering process can disfavor the tools that allow this procedure. To balance this was chosen the default values of smooth distance (DSAS) and windows size (AMBUR) since the results of default parameters seem adequate. The selection of these values is more detailed in the discussion section.

The AMBUR transects were selected in QGIS to use as a reference and thus, to allow the statistical analysis between AMBUR, EPR4Q, and DSAS results. A shapefile was created with one unique attribute table including the three EPR results with the same identification (ID). For this, a polygon buffer in AMBUR transects with a width of 0.6 m and the equal attribute table was created. The value 0.6 m was chosen to reach 0.3 m for each side and select the transects near this area and not cross the area of the surrounding transects. Next, the consecutive first matching transects of DSAS and EPR4Q that showed some spatial criteria (intersects, overlaps, contains, within, equals, crosses, and touches) associated with the buffer created in AMBUR were selected. This method also avoids the problem of comparing distinct transects, valuating only the transects close to the reference (i.e.: AMBUR transects).

The attribute table containing the EPR results of AMBUR, EPR4Q, and DSAS was extracted in order to analyze basic statistics parameters (mean, standard deviation, median, maximum, minimum) and to obtain matrix correlation using Pearson's coefficient. These analyses were performed in R language by running the libraries Pastec and PerformanceAnalytics, respectively.

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4. Results

4.1. Linear/Extensive/Ocean to the south – Concepcion (CA)

Concepcion shoreline is an example of an extensive (11 km length) and linear shoreline. The Pearson correlation coefficient between the three models reached the maximum value (1.00), showing that all the models present similar values. In the Frequency Curve is possible to observe the identical pattern of the distribution (Figure 4).

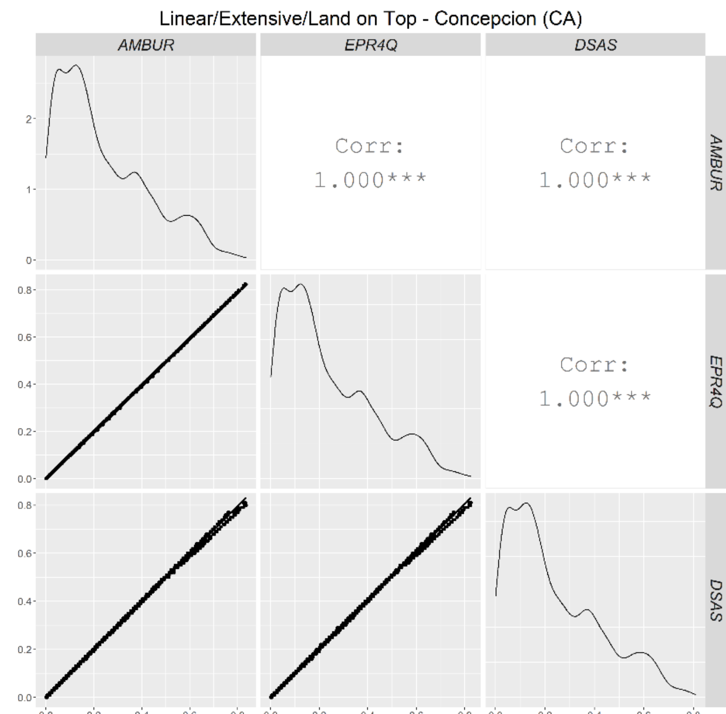

Figure 3. Matrix correlation of AMBUR, EPR4Q, and DSAS models on Linear/Extensive/Ocean to the south for Concepcion coast. p-value - Significance codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. The Matrix correlation shows the Frequency Curve of the Histogram of each model and the Scatter plot between the models (EPR4Q x DSAS, EPR4Q x AMBUR, AMBUR x DSAS).

Figure 5 shows the results according to AMBUR, EPR4Q, and DSAS tools although it is hard to distinguish the differences between the transects due to the extreme similarity. In this example, the models seem to provide suitable results in linear and extensive shorelines. All the models equally recognized the areas of accretion and erosion and the shoreline orientation did not affect the results.

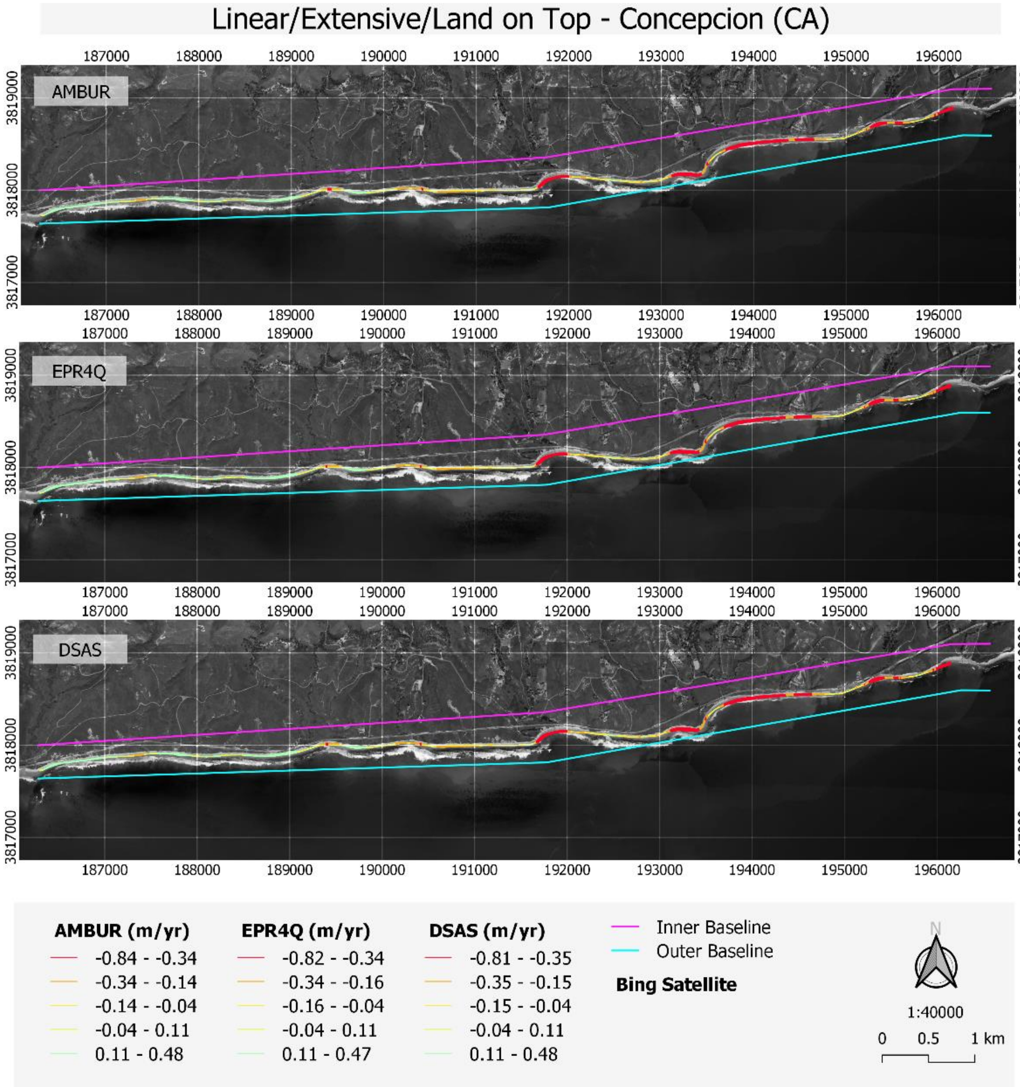

Figure 4. Shoreline changes in Concepcion using the AMBUR, EPR4Q and DSAS tools.

The values of statistical parameters are quite similar for the three tools (Table 2). The results revealed an advance of the shoreline between 1976 and 1993, with a mean value of -0.12 m yr-1 and a median value of -0.08 or -0.09 m yr-1 depending on the model used. The identical mean is a good indicator that the results are uniform for all models. The highest retreat rates (-0.84 m yr-1) were observed on the west side and the highest advance rates (0.48 m yr-1) were reported on the northeast of the map (Figure 5).

Table 2. Statistical parameters between the different tools applied to the Concepcion shoreline.

Parameter	AMBUR	EPR4Q	DSAS

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Minimum (m.yr-1)	-0.84	-0.82	-0.81
Maximum (m.yr-1)	0.47	0.47	0.48
Mean (m.yr-1)	-0.12	-0.12	-0.12
Median (m.yr-1)	-0.08	-0.09	-0.08
Standard deviation (m.yr-1)	0.25	0.25	0.26

4.2. Non-linear/Extensive/Ocean to the west - Arlight (CA)

The Arlight (CA) coast is characterized by an extensive shoreline of about 4km length, an irregular outline, and the continent is set on the west side (Figure 1). The correlation matrix showed high Pearson correlation coefficients between EPR4Q and AMBUR (0.946), and EPR4Q and DSAS (0.940). However, the AMBUR and DSAS calculation methods revealed the highest similarity with a correlation coefficient of 0.995 (Figure 6).

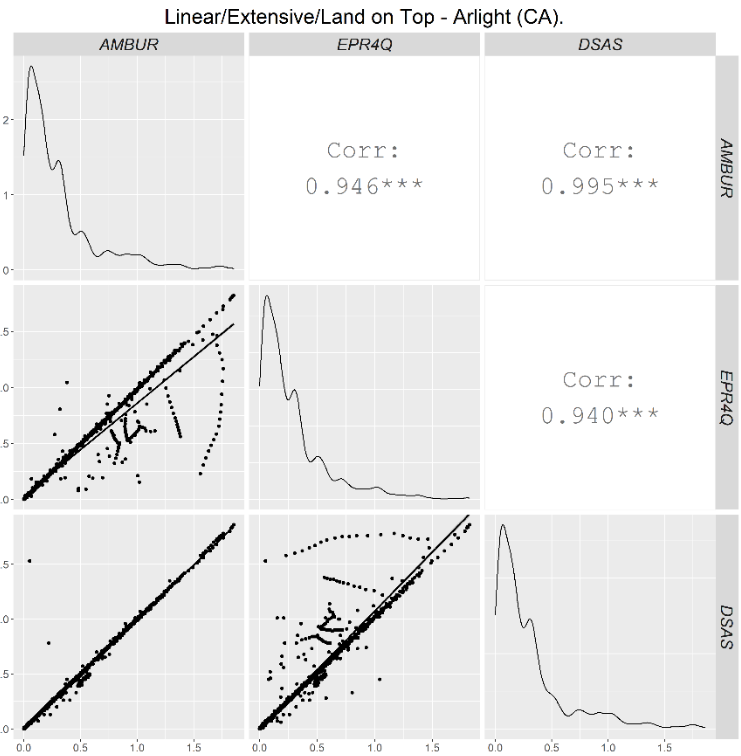


Figure 5. Matrix correlation of AMBUR, EPR4Q, and DSAS models on Indented/Extensive/Ocean to the east – Arlight shoreline. p-value - Significance

codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. The Matrix correlation shows the Frequency Curve of the Histogram of each model and the Scatter plot between the models (EPR4Q x DSAS, EPR4Q x AMBUR, AMBUR x DSAS).

In linear stretches, observed in the center and in the extreme north of the sector, it can be observed great similarity between outcomes. Anyway, there are some differences between models in the stretches with an embayment configuration (Figure 7).

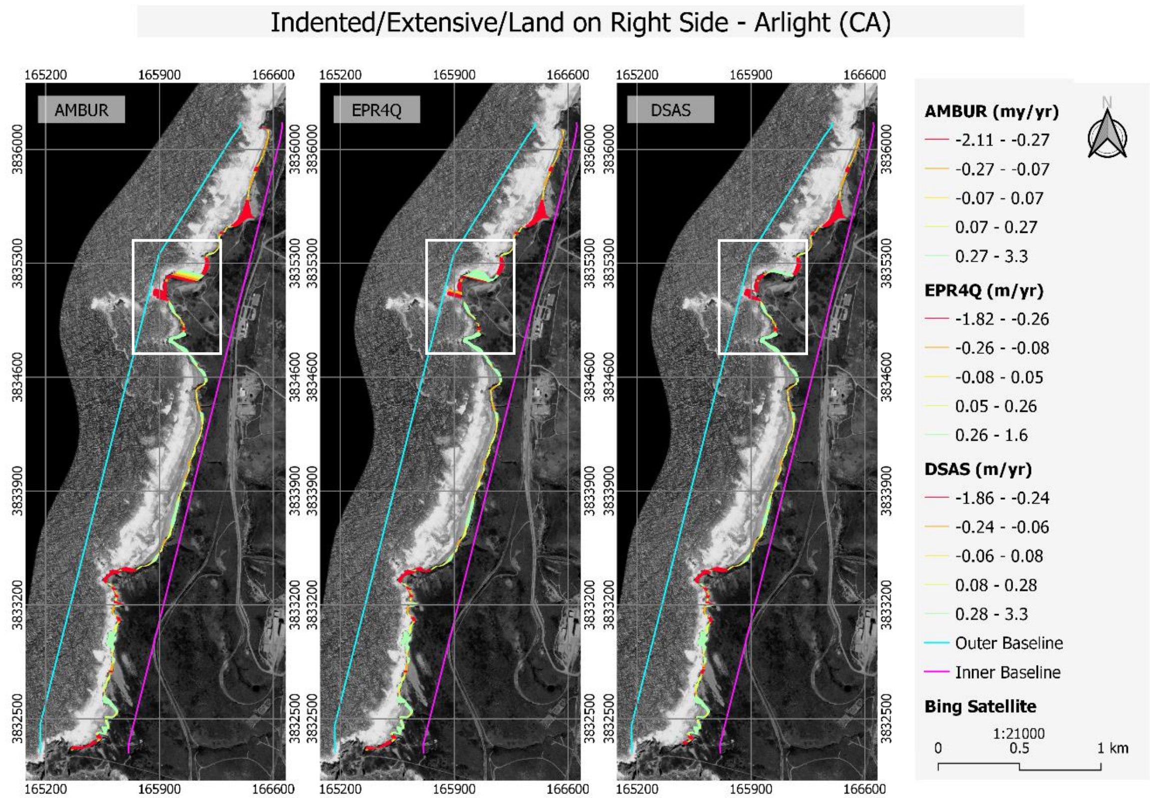


Figure 7. Shoreline changes in Arlight coast using the AMBUR, EPR4Q and DSAS tools.

The statistical analysis applied to the Arlight coast explains the differences detected in the results. The AMBUR minimum value (-2.11 m.yr-1) show a significant alteration when compared with the other models (-1.82 m.yr-1 and -1.86 m.yr-1). The maximum value (3.3 m.yr-1) is comparable with the DSAS method but very different from that obtained with EPR4Q (Table 3). Nevertheless, the median and mean values found with the three methods are quite similar.

Table 3. Statistical parameters between the different tools applied to the Arlight shoreline.

Parameter	AMBUR	EPR4Q	DSAS
Minimum (m.yr^{-1})	-2.11	-1.82	-1.86

Maximum ($m.yr^{-1}$)	3.3	1.6	3.3
Mean ($m.yr^{-1}$)	0	0	0.01
Median ($m.yr^{-1}$)	-0.03	-0.03	-0.01
Standard deviation ($m.yr^{-1}$)	0.47	0.40	0.46

4.3.Linear/Non-extensive/Ocean to the East - Hampton (NH)

In Hampton example, the EPR analysis of AMBUR, EPR4Q, and DSAS focused on a short length and linear shoreline, exposed to the ocean situated to the east. The statistics between parameters show a high correlation coefficient (0.998) between EPR4Q and AMBUR, and 0.980 between EPR4Q and DSAS (Figure 8).

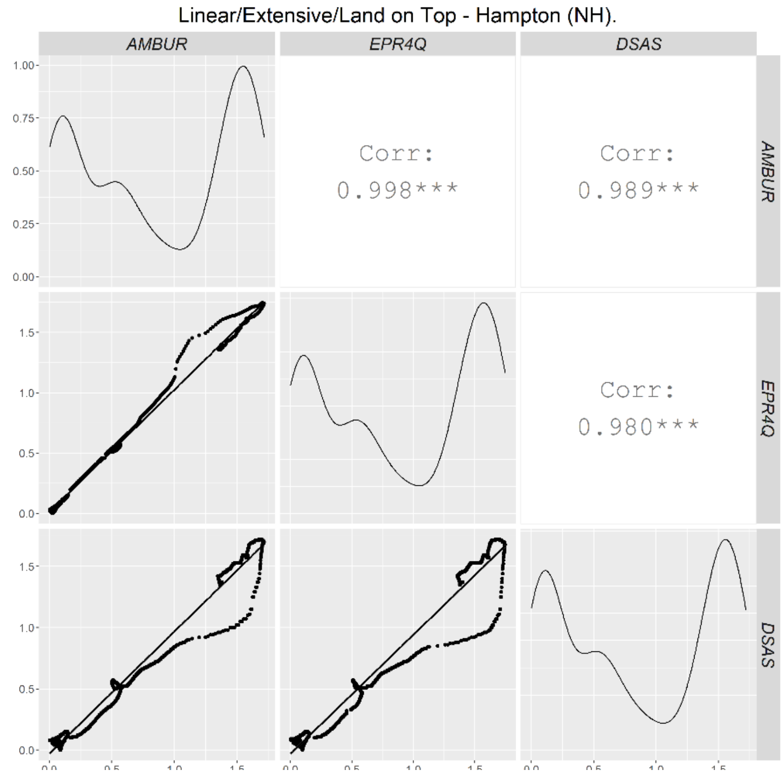
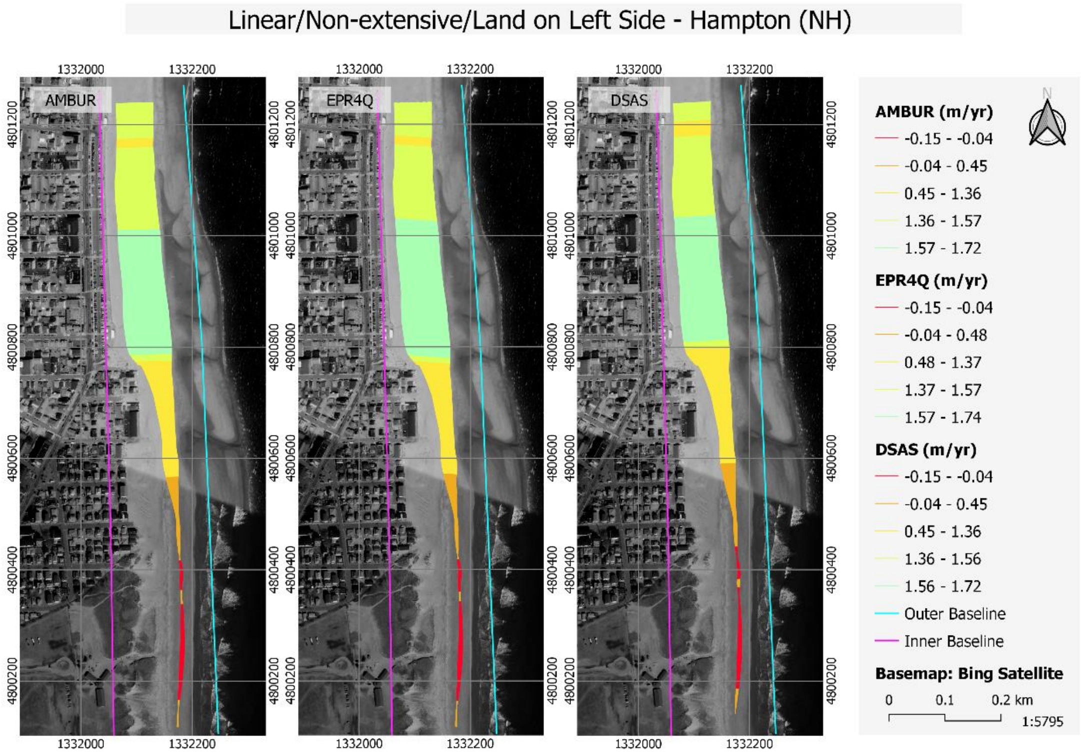


Figure 8. Matrix correlation of AMBUR, EPR4Q, and DSAS models for Hampton coast. p-value - Significance codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. The Matrix correlation shows the Frequency Curve of the Histogram of each model and the Scatter plot between the models (EPR4Q x DSAS, EPR4Q x AMBUR, AMBUR x DSAS).

The results show a displacement in the DSAS transects of 23 meters when compared with AMBUR and EPR4Q results. It is also possible to see a difference in the angle (7º) of the transects on EPR4Q



in comparison with the others (Figure 9).

Figure 9. Shoreline changes in Hampton using the AMBUR, EPR4Q, and DSAS tools.

Basic statistics applied to AMBUR and DSAS results show the same values (Table 4). Regarding EPR4Q the values are quite similar to those obtained with the other models. The mean shoreline retreat was about -0.76 / -0.78 m yr-1 between 1953 and 2000, depending on the model considered.

Table 4. Statistical parameters between the different methods applied to the Hampton shoreline.

Parameter	AMBUR	EPR4Q	DSAS
Minimum (m.yr^{-1})	-0.15	-0.15	-0.15
Maximum (m.yr^{-1})	1.72	1.73	1.72
Mean (m.yr^{-1})	0.76	0.78	0.76
Median (m.yr^{-1})	0.62	0.58	0.62

Standard deviation ($m.yr^{-1}$)	0.71	0.71	0.71

4.4. Non-linear/Non-extensive/Ocean to the north - Rockport (MA)

The shoreline of Rockport is irregular and less than 1 km in length; the continent is situated to the north. This case presents a weak correlation coefficient of DSAS when comparing with AMBUR (correlation coefficient = 0.116) and EPR4Q (correlation coefficient = 0.149) (Figure 10).

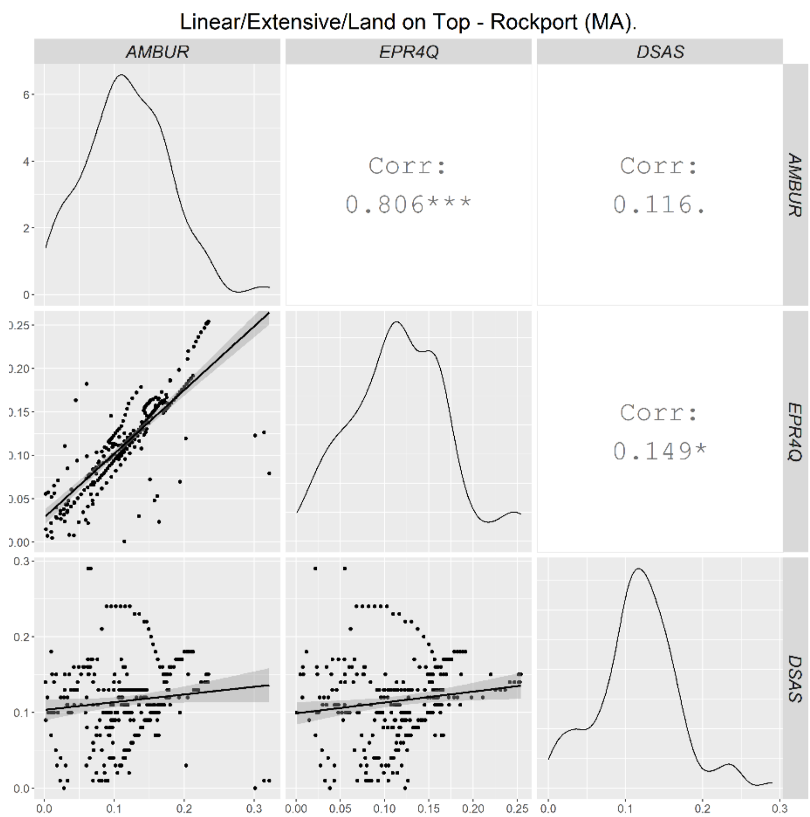


Figure 10. Matrix correlation of AMBUR, EPR4Q, and DSAS models on Rockport coast. p-value - Significance codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. The Matrix correlation shows the Frequency Curve of the Histogram of each model and the Scatter plot between the models (EPR4Q x DSAS, EPR4Q x AMBUR, AMBUR x DSAS).

The angle of DSAS transects shows a deviation of about 5º when compared with the AMBUR and EPR4Q models, which may be a reason for the low performance of the correlation coefficients. Additionally, all models have different results when the indentation of the embayment is more irregular (white rectangle in Figure 11).

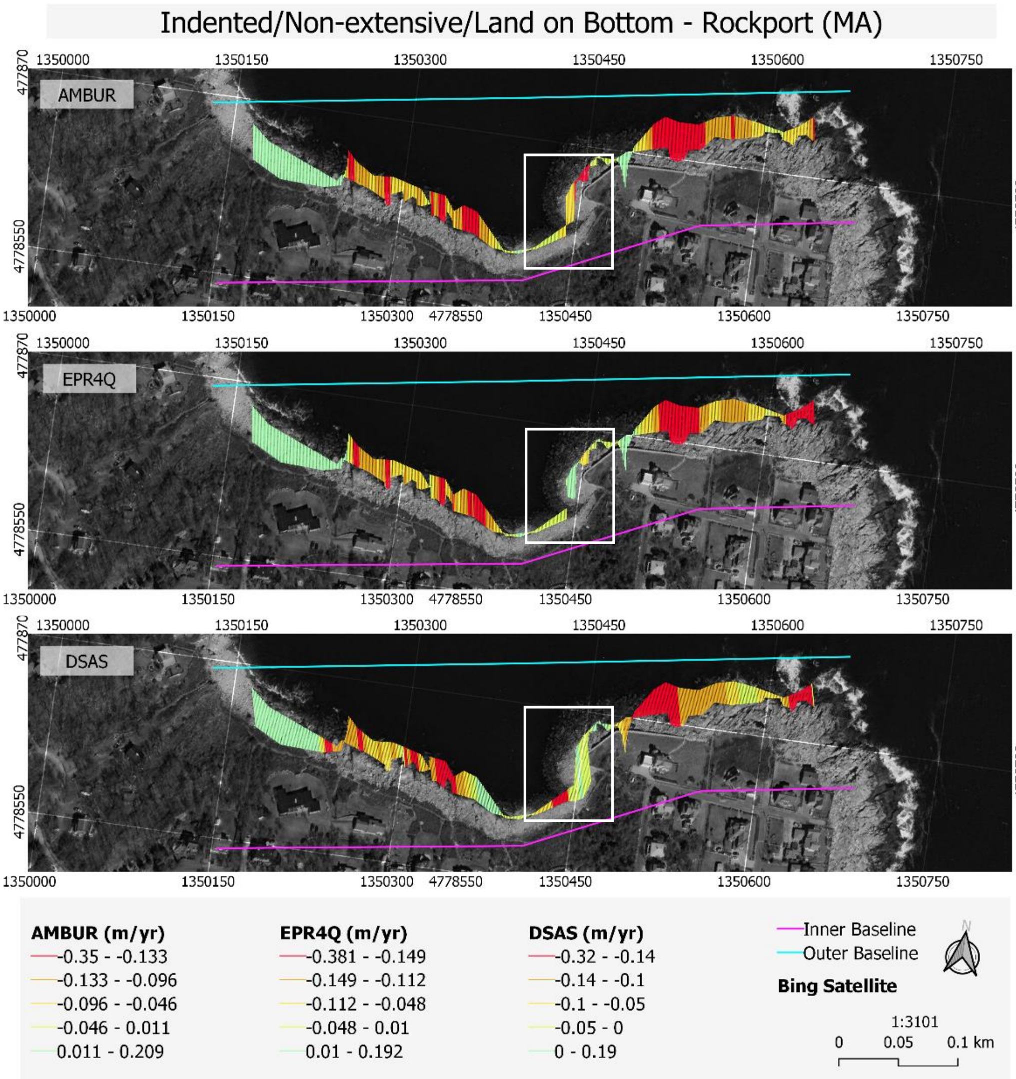


Figure 11. Shoreline changes in Rockport using the AMBUR, EPR4Q, and DSAS tools.

The statistical parameters indicate a similar standard deviation for all models (Table 5). The maximum values obtained with AMBUR and EPR4Q models are analogous whereas those obtained with DSAS are twice the maximum value found with EPR4Q. The mean value of -0.07 or 0.05 m. yr-1 depending of the model, suggest slight changes in shoreline position in 1994. The maximum changes in the shoreline position were observed in the areas with more wave exposition and the minimum in the embayed coast.

Table 5. Statistical parameters between the different methods applied to the Rockport shoreline analysis.

Parameters	AMBUR	EPR4Q	DSAS
Minimum (m.yr^{-1})	-0.21	-0.19	-0.32

Maximum (m.yr^{-1})	0.35	0.38	0.19
Mean (m.yr^{-1})	0.05	0.07	-0.07
Median (m.yr^{-1})	0.07	0.09	-0.08
Standard deviation (m.yr^{-1})	0.11	0.1	0.1

5. Discussion

The results obtained in the coastal areas with linear shorelines showed the highest correlation coefficients while in irregular and embayed shorelines presented the lowest values. This reveals that AMBUR, EPR4Q, and DSAS could not produce suitable transects for indented (non-linear) shorelines considering the scale used in the study cases (transects with 1.0 m spacing). The problems with transects in embayed shorelines had already been reported by Jackson et al. [29] who suggested the use of 'near' and 'filtered' transect methods to adjust transects to curved shoreline segments. Nevertheless, the authors recognize that these solutions might be not enough in highly irregular shorelines. Himmelstoss et al. [45] proposed the smoothing distance to avoid transects intersection in the case of DSAS methodology. They also recommended that the distance would be longer than the width of the bends in the shoreline, but they advise that using high smoothing values originate transects that are overly smoothed and undesirably oriented parallel or nearly parallel to the baseline. However, Anfuso et al. [46] affirm that transects can be representative for a coastal sector, but their position does not necessarily fall in the most representative point of it, especially when the shoreline is not linear.

The transects are, according to Anfuso et al. [46], generally defined keeping in mind the scale of the project and the spatial resolution used. The DSAS and AMBUR work intending to generate transects but the used spatial resolution can be influenced to differentiate the actual shoreline and possible noises. For this study, as the transects had a distance of 1 m, these residues were not noticeable for example for Arlight and Concepcion beaches.

Other approaches that aim to obtain the shoreline retraction have been working from the perspective of the coastal segment area [46–49]. From the generation of polygons, and their subsequent subtraction, was possible to generate significant information, especially in coastal segments that have a rhythmic morphology.

In the literature there are several studies that do not show the transects associated with the shoreline analysis (i.e.: [21,32,35]) or when included, is possible to identify some errors in its orientation (i.e.:[19,24,25]). Thieler and Danforth [17] have stated that the determination of variation rates in a certain coastal stretch may be obtained by different forms of interpretation of the distance among relative positions in different periods.

In the EPR4Q tool, some steps can be reconsidered with new versions of QGIS, in response to tools updates and improvements on Graphical Modeler. For example, the process of diamond shape went through a long process so it could be split with the newest shoreline and is not difficult to contemplate other theoretical easier solutions. However, the advantage of the EPR4Q tool, in addition to being designed for open-source software, is the facility into obtaining EPR results in a few minutes, without the necessity of switch software, analyze baseline orientations or create complex databases as it happens in DSAS and AMBUR tools.

6. Conclusion

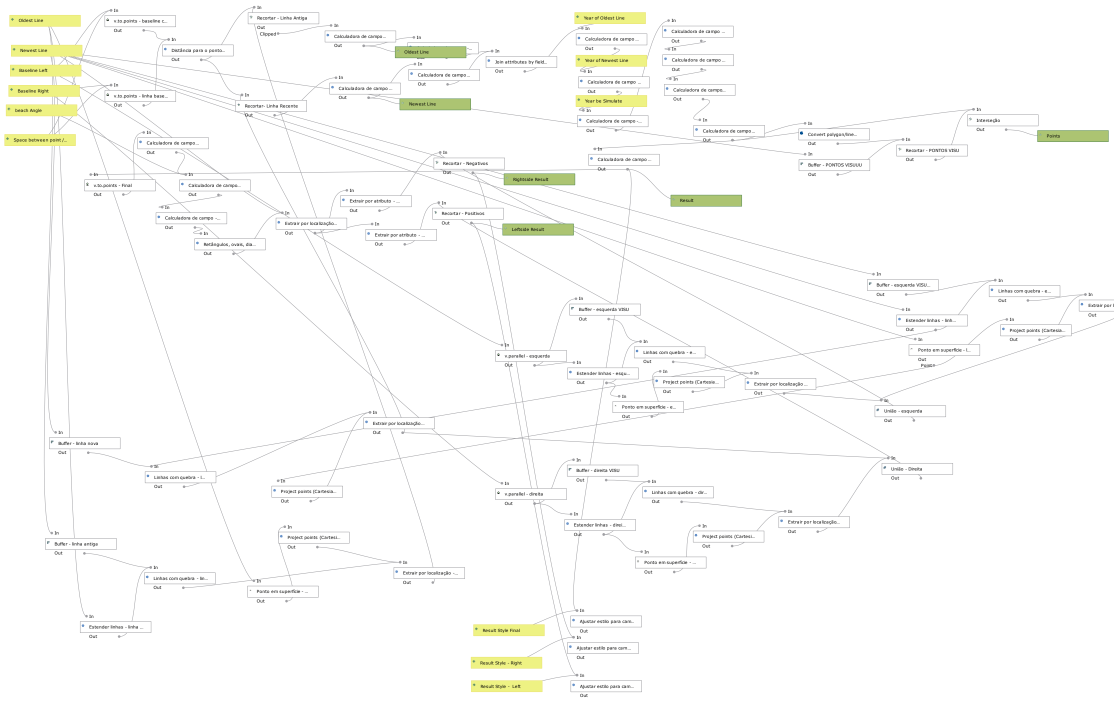
Although the tools used in this study have their adjectives and limitations for calculating the shoreline movement, the EPR4Q model, created in QGIS, returns acceptable results with similar values as AMBUR and DSAS software. The results of EPR4Q underscore high statistical correlation coefficients of 0.98, and 1.00 on linear, extensive, and non-extensive shorelines. Regarding embayed shorelines, the EPR4Q, as well the AMBUR and DSAS, required attention to generate specific transects and thus, to improve the obtained results.

This work constitutes a first step towards the creation of a tool that once free acquired can be edited for the scientific community for different purposes, such as adding more prediction analysis or rebuild it on a plugin. It is remarkable the potential of QGIS and Graphical Modeler to create functional tools. On the other hand, it was needed several tool adaptations (i.e., Alternative Side Buffer) to reach the results due to the limitations of the Graphical Modeler that increased the complexity of the EPR4Q.

Studies that consider the comparative approach between methods are of great importance for coastal managers, given that many coastal cities have presented serious problems related to the action of extreme events, for example. Finally, the EPR4Q tool is freely available to download (10.5281/zenodo.3378004) and it is accompanied by the guidelines to reproduce the analysis in different locations of the world.

Acknowledgments: L.T Lima is grateful to the Brazilian National Council for Scientific and Technological Development (CNPq) for the CSF's (Ciência sem Fronteiras) program doctoral fellowship granted (249636/2013-1). Thanks are due to FCT/MCTES for the financial support to CESAM (UIDP/50017/2020+UIDB/50017/2020), through national funds.

Appendix A



Appendix A. Graphical Modeler of EPR4Q created using QGIS 3.4 - Madeira.

References

1. Luijendijk, A.; Hagenaars, G.; Ranasinghe, R.; Baart, F.; Donchyts, G.; Aarninkhof, S. The State of the World's Beaches. Sci. Rep. 2018. 10.1038/s41598-018-24630-6.
2. Dritsas, S.E. The effect of sea level rise on coastal populations: The case of the Gironde (Estuaries of Gironde). Econ. Anal. Policy 2020, 66, 41–50. 10.1016/j.eap.2020.02.008.
3. Boak, E.H.; Turner, I.L. Shoreline definition and detection: A review. J. Coast. Res. 2005. 10.2112/03-0071.1.
4. Ardeshiri, A.; Swait, J.; Heagney, E.C.; Kovac, M. Willingness-to-pay for coastline protection in New South Wales: Beach preservation management and decision making. Ocean Coast. Manag. 2019. 10.1016/j.ocecoaman.2019.05.007.
5. Del Río, L.; Gracia, F.J.; Benavente, J. Shoreline change patterns in sandy coasts. A case study in SW Spain. Geomorphology 2013. 10.1016/j.geomorph.2012.07.027.
6. Castelle, B.; Guillot, B.; Marieu, V.; Chaumillon, E.; Hanquiez, V.; Bujan, S.; Poppeschi, C. Spatial and temporal patterns of shoreline change of a 280-km high-energy disrupted sandy coast from 1950 to 2014: SW France. Estuar. Coast. Shelf Sci. 2018. 10.1016/j.ecss.2017.11.005.
7. Oyedotun, T.D.T.; Ruiz-Luna, A.; Navarro-Hernández, A.G. Contemporary shoreline changes and consequences at a tropical coastal domain. Geol. Ecol. Landscapes 2018. 10.1080/24749508.2018.1452483.
8. Armstrong, S.B.; Lazarus, E.D. Masked Shoreline Erosion at Large Spatial Scales as a Collective Effect of Beach Nourishment. Earth's Futur. 2019. 10.1029/2018EF001070.
9. Xu, N. Detecting coastline change with all available landsat data over 1986-2015: A case study for the state of Texas, USA. Atmosphere (Basel). 2018. 10.3390/atmos9030107.
10. Hegde, A.V.; Akshaya, B.J. Shoreline Transformation Study of Karnataka Coast: Geospatial Approach. Aquat. Procedia 2015. 10.1016/j.aqpro.2015.02.021.

11. Oppenheimer, M. Global warming and the stability of the West Antarctic ice sheet. Nature 1998. 10.1038/30661.
12. Hansen, J.; Sato, M.; Hearty, P.; Ruedy, R.; Kelley, M.; Masson-Delmotte, V.; Russell, G.; Tselioudis, G.; Cao, J.; Rignot, E.; et al. Ice melt, sea level rise and superstorms: Evidence from paleoclimate data, climate modeling, and modern observations that 2 °c global warming could be dangerous. Atmos. Chem. Phys. 2016. 10.5194/acp-16-3761-2016.
13. Holland, G.; Bruyère, C.L. Recent intense hurricane response to global climate change. Clim. Dyn. 2014. 10.1007/s00382-013-1713-0.
14. Collins, J.M.; Walsh, K. Hurricanes and Climate Change; 2017; ISBN 9783319475943. 10.1007/978-3-319-47594-3.
15. Mentaschi, L.; Vousdoukas, M.I.; Voukouvalas, E.; Dosio, A.; Feyen, L. Global changes of extreme coastal wave energy fluxes triggered by intensified teleconnection patterns. Geophys. Res. Lett. 2017. 10.1002/2016GL072488.
16. Thierler, E.R.; Himmelstoss, E..; Zichichi, J..; Ergul, A. DSAS 4.0 Installation Instructions and User Guide. U.S. Geol. Surv. Open-File Rep. 2008-1278 2009.
17. Thieler, E.R.; Danforth, W.W. Historical shoreline mapping (II): application of the digital shoreline mapping and analysis systems (DSMS/DSAS) to shoreline change mapping in Puerto Rico. J. Coast. Res. 1994.
18. Oyedotun, T.D.T. Shoreline Geometry: DSAS as a Tool for Historical Trend Analysis. Geomorphol. Tech. (online Ed. 2014.
19. Jabaloy-Sánchez, A.; Lobo, F.J.; Azor, A.; Martín-Rosales, W.; Pérez-Peña, J.V.; Bárcenas, P.; Macías, J.; Fernández-Salas, L.M.; Vázquez-Vílchez, M. Six thousand years of coastline evolution in the Guadalfeo deltaic system (southern Iberian Peninsula). Geomorphology 2014. 10.1016/j.geomorph.2013.08.037.
20. Kermani, S.; Boutiba, M.; Guendouz, M.; Guettouche, M.S.; Khelfani, D. Detection and analysis of shoreline changes using geospatial tools and automatic computation: Case of jijelian sandy coast (East Algeria). Ocean Coast. Manag. 2016. 10.1016/j.ocecoaman.2016.08.010.
21. Blue, B.; Kench, P.S. Multi-decadal shoreline change and beach connectivity in a high-energy sand system. New Zeal. J. Mar. Freshw. Res. 2017. 10.1080/00288330.2016.1259643.
22. Benkhattab, F.Z.; Hakkou, M.; Bagdanavičiūtė, I.; Mrini, A. El; Zagaoui, H.; Rhinane, H.; Maanan, M. Spatial–temporal analysis of the shoreline change rate using automatic computation and geospatial tools along the Tetouan coast in Morocco. Nat. Hazards 2020. 10.1007/s11069-020-04179-2.
23. Franco-Ochoa, C.; Zambrano-Medina, Y.; Plata-Rocha, W.; Monjardín-Armenta, S.; Rodríguez-Cueto, Y.; Escudero, M.; Mendoza, E. Long-Term Analysis of Wave Climate and Shoreline Change along the Gulf of California. Appl. Sci. 2020, 10, 8719. 10.3390/app10238719.
24. Esmail, M.; Mahmod, W.E.; Fath, H. Assessment and prediction of shoreline change using multi-temporal satellite images and statistics: Case study of Damietta coast, Egypt. Appl. Ocean Res. 2019. 10.1016/j.apor.2018.11.009.
25. Al-Zubieri, A.G.; Ghandour, I.M.; Bantan, R.A.; Basaham, A.S. Shoreline Evolution Between Al Lith and Ras Mahāsin on the Red Sea Coast, Saudi Arabia Using GIS and DSAS Techniques. J. Indian Soc. Remote Sens. 2020. 10.1007/s12524-020-01169-6.
26. Jackson, C.W. Quantitative shoreline change analysis of an inlet-influenced transgressive barrier system; Figure Eight Island, North Carolina. 2004, 86.
27. Hoeke, R.; Zarillo, G.; Synder, M. A GIS Based Tool for Extracting Shoreline Positions from Aerial Imagery (BeachTools). US Army Corps Eng. 2001.
28. Zarillo, G.A.; Kelley, J.; Larson, V. A GIS Based Tool for Extracting Shoreline Positions from Aerial Imagery (BeachTools) Revised. US Army Corps Eng. 2001.
29. Jackson, C.W.; Alexander, C.R.; Bush, D.M. Application of the AMBUR R package for spatio-temporal analysis of shoreline change: Jekyll Island, Georgia, USA. Comput. Geosci. 2012. 10.1016/j.cageo.2011.08.009.
30. Eulie, D.O.; Walsh, J.P.; Corbett, D.R. High-resolution analysis of shoreline change and application of balloon-based aerial photography, Albemarle-Pamlico estuarine system, North Carolina, USA. Limnol. Oceanogr. Methods 2013. 10.4319/lom.2013.11.151.
31. Addo, K.. Assessment of the Volta Delta Shoreline Change. J. Coast. Zo. Manag. 2015. 10.4172/2473-3350.1000408.
32. Wakefield, K.R. Georgia Southern Assessing Shoreline Change and Vegetation Cover Adjacent to Back-Barrier Shoreline Stabilization Structures in Georgia Estuaries. 2016.

33. Dennis, A.; Senthilnathan, L.; Machendiranathan, M.; Ranith, R. Shoreline demarcation on tirunelveli coast analysis moving boundaries using R (AMBUR) statistics. Ecol. Environ. Conserv. 2018.
34. Sankar, R.D.; Donoghue, J.F.; Kish, S.A. Mapping Shoreline Variability of Two Barrier Island Segments Along the Florida Coast. Estuaries and Coasts 2018. 10.1007/s12237-018-0426-3.
35. Sankar, R.D.; Murray, M.S.; Wells, P. Decadal scale patterns of shoreline variability in Paulatuk, N.W.T, Canada. Polar Geogr. 2019. 10.1080/1088937X.2019.1597395.
36. QGIS Development Team QGIS Geographic Information System. Open Source Geospatial Found. Proj. 2019. http://www.qgis.org/.
37. Criollo, R.; Velasco, V.; Nardi, A.; Manuel de Vries, L.; Riera, C.; Scheiber, L.; Jurado, A.; Brouyère, S.; Pujades, E.; Rossetto, R.; et al. AkvaGIS: An open source tool for water quantity and quality management. Comput. Geosci. 2019. 10.1016/j.cageo.2018.10.012.
38. de Lima, L.; Sá, M.; Bernardes, C. Shoreline Analyst QGIS Python Plugin. 2017. 10.5281/ZENODO.3378016.
39. Fenster, M.S.; Dolant, R.; Elder, J.F. A New Method for Predicting Shoreline Positions from Historical Data. J. Coast. Res. 1993, 9, 147–171.
40. Crowell, M.; Douglas, B.C.; Leatherman, S.P.; Crowell, M.; Douglas, B.C.; Leatherman, S.P. of Coastal Florida Fall On Forecasting Future U . S . Shoreline Positions : A Test of Algorithms. 2015, 13, 1245–1255.
41. Morton, R.A.; Miller, T.L.; Moore, L.J. National Assessment of shoreline Change: Part 1: Historical shoreline change and associated land loss along the U.S. Gulf of Mexico: U.S. Geological Survey Open-file Report 2004-1043; Santa Cruz, CA 95060, 2004;
42. Morton, R.A.; Miller, T.L. National Assessment of shoreline Change: Part 2: Historical shoreline change and associated land loss along the U.S. South East Atlantic Coast: U.S. Geological Survey Open-file Report 2005-1401; Santa Cruz, CA 95060, 2005;
43. Hapke, C.J.; Reid, D.; Richmond, B.M.; Ruggiero, P.; List, J. National Assessment of Shoreline Change: Part 3: Historical Shoreline Change and Associated Coastal Land Loss Along Sandy Shorelines of the California Coast: U.S. Geological Survey Open-file Report 2006-1219; Santa Cruz, CA 95060, 2006;
44. Himmelstoss, E.A., Kratzmann, M., Hapke, C., Thieler, E.R., and List, J. The national assessment of shoreline change: A GIS compilation of vector shorelines and associated shoreline change data for the New England and Mid-Atlantic Coasts: U.S. Geological Survey Open-File Report 2010–1119; 2010;
45. Himmelstoss, E.A.; Henderson, R.E.; Kratzmann, M.G.; Farris, A.S. Digital Shoreline Analysis System (DSAS) Version 5.0 User Guide. Open-File Rep. 2018-1179 2018.
46. 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. 10.1007/s10661-016-5571-1.
47. Smith, M.J.; Cromley, R.G. Measuring Historical Coastal Change using GIS and the Change Polygon Approach. Trans. GIS 2012. 10.1111/j.1467-9671.2011.01292.x.
48. 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. 10.2112/si65-289.1.
49. Leal, K.B.; de Oliveira, U.R.; de Almeida Espinoza, J.M. Beach dune limit variation on Mostardense, Mar Grosso, Cassino and Barra do Chuí beaches, in the south of Brazil between 2003-2015. Quat. Environ. Geosci. 2018.