COMPREHENSIVE LECTURE NOTES AND TUTORIAL

on

Shoreline Change Analysis using the Digital Shoreline Analysis System (DSAS)

(Theory, Methodology, and Step-by-Step Workflow)

Prepared by Dr. Aran Castro

https://draran.online

For PhD Scholars and Researchers

April 2026

Table of Contents

PART I: THEORETICAL FOUNDATION OF SHORELINE CHANGE ANALYSIS

1. Introduction to Shoreline Change Science

Shoreline change analysis constitutes a fundamental component of coastal geomorphology and coastal zone management. Shorelines are inherently dynamic boundaries that respond to a complex interplay of natural processes—including wave action, tidal forces, longshore drift, sediment transport, sea-level fluctuations, and storm surges—as well as anthropogenic interventions such as coastal engineering structures, land reclamation, and sand mining. Quantifying the rate and magnitude of shoreline change over time is essential for understanding coastal evolution, assessing erosion and accretion patterns, and informing evidence-based coastal management policies.

Remote sensing and Geographic Information Systems (GIS) have revolutionised the capacity to monitor and analyse shoreline dynamics at multiple spatial and temporal scales. The integration of historical maps, aerial photographs, and multi-temporal satellite imagery within a GIS framework enables the extraction of shoreline positions spanning several decades. Once these historical shoreline vectors are compiled, statistical software can be employed to compute rates of change, providing quantitative metrics that underpin coastal hazard assessments, environmental impact studies, and infrastructure planning.

2. Historical Context and Significance

Systematic shoreline monitoring has been conducted since the mid-twentieth century, initially relying upon ground-based survey techniques and topographic sheets (T-sheets) prepared by agencies such as the National Oceanic and Atmospheric Administration (NOAA) in the United States and the Survey of India. The advent of aerial photography in the 1930s–1960s provided the first synoptic views of coastal change, whilst the launch of the Landsat programme in 1972 marked the beginning of continuous, moderate-resolution satellite observation of the global coastline.

The development of standardised, repeatable, and automated methods for computing shoreline change rates became a priority for the United States Geological Survey (USGS) in the early 1990s. This effort culminated in the creation of the Digital Shoreline Analysis System (DSAS), which has since become the most widely adopted software tool for shoreline change computation worldwide. DSAS has been cited in over 800 peer-reviewed publications and has been employed by national and state governments across the globe in support of resource management and critical coastal decision-making (Himmelstoss et al., 2021).

3. The Digital Shoreline Analysis System (DSAS)

The Digital Shoreline Analysis System (DSAS) is a freely available software application developed by the USGS Woods Hole Coastal and Marine Science Center. DSAS calculates rate-of-change statistics from multiple historical shoreline positions represented as vector data within a GIS environment. The software provides an automated method for establishing measurement transects, performs rate calculations, and generates the statistical data necessary to assess the reliability of the computed results (Himmelstoss et al., 2021).

Although originally designed for shoreline change, DSAS is suitable for any application that calculates positional change over time, including glacier limit assessment, river edge boundary migration, and land-cover change delineation.

3.1 Evolution of DSAS Versions

Version	Year	Platform	Key Features
DSAS 1.0	1992	MapGrafix / ArcInfo	First release; written in C and awk programming languages
DSAS 2.0	Late 1990s	ArcView 3.x	Rewritten in Avenue scripting language
DSAS 3.x	Early 2000s	ArcGIS 9	Migrated to ArcGIS platform
DSAS 4.2–4.4	2008–2016	ArcGIS 9.2–10.5	Added WLR, proxy-datum bias correction; widely adopted
DSAS 5.0–5.1	2018–2021	ArcGIS 10.4–10.x	ArcGIS Add-In; improved user interface and statistics
DSAS 6.0	2024	Standalone	Standalone application; GIS-independent; GeoPackage support
DSAS 6.1	Feb 2026	Standalone	Current version; accepts onshore, offshore, midshore, and combination baselines; exports to shapefile, GeoJSON, CSV, and GeoPackage

3.2 DSAS Version 6.1: Current Release

DSAS version 6.1, released in February 2026, is a standalone desktop application that operates alongside any GIS of the user's choice (e.g., ArcGIS Pro, QGIS). Baseline and shoreline data are prepared in a GIS and then uploaded to DSAS in either shapefile or GeoJSON format. Once uploaded, data are stored in a GeoPackage (.gpkg)—an open, standards-based, platform-independent, SQLite database file capable of containing multiple datasets of geographic features (Henderson et al., 2026).

Key features of DSAS v6.1 include:

- Accepts baselines that are onshore, offshore, midshore, or any combination thereof.
- Stores all data layers (baselines, shorelines, transects, results) within a single GeoPackage.
- Exports data as shapefiles, GeoJSON, CSV, or GeoPackage formats.
- Generates a summary report (.txt) of the calculation.
- Provides basic editing tools within the application; extensive editing is recommended in a GIS.

Note: The USGS End-of-Life (EOL) date for ArcMap was 1 February 2024. As of August 2025, the USGS can no longer provide comprehensive support for Esri-dependent DSAS versions (v5.1 and earlier). Users are advised to adopt DSAS v6.1 for all new analyses.

4. Fundamental Concepts and Terminology

4.1 Shoreline Indicators

A shoreline indicator is the feature used to represent the shoreline position. Common indicators include the High Water Line (HWL), the Mean High Water (MHW) datum-based shoreline, the wet/dry line visible on aerial photographs or satellite imagery, and the vegetation line. The choice of indicator affects the positional uncertainty assigned to each shoreline and may introduce a proxy-datum bias when different indicator types are combined within a single analysis (Himmelstoss et al., 2021).

4.2 Reference Baseline

The reference baseline is a user-constructed line feature from which measurement transects originate. DSAS generates transects that are cast perpendicular to the baseline to intersect the historical shoreline positions. In DSAS v6.1, the baseline may be placed onshore (landward of all shorelines), offshore (seaward of all shorelines), midshore (between shoreline positions), or as a combination. The orientation of the baseline with respect to land must be accurately identified so that DSAS computes rates with the correct sign: positive values indicating accretion and negative values indicating erosion.

4.3 Transect Casting

Transects are straight-line features cast perpendicular to the reference baseline at a user-specified spacing along the shore. Each transect intersects the historical shoreline positions, and DSAS measures the distance from the baseline to each intersection point. Key transect parameters include:

- **Search Distance:** The maximum distance a transect extends to search for shoreline intersections.
- **Transect Spacing:** The alongshore interval (in metres) between successive transects.
- **Smoothing Distance:** A distance parameter used to generalise the baseline geometry, reducing the influence of local irregularities on transect orientation.

4.4 Shoreline Intersection Points

At each transect, DSAS records the intersection point with every shoreline and stores the distance from the baseline, the date of the shoreline, and the associated positional uncertainty. When a transect intersects a shoreline at more than one point (common along curved or embayed coasts), the user may choose the intersection point by distance (farthest or closest to baseline) or by placement (seaward or landward).

5. Statistical Methods in DSAS

DSAS computes both distance-based measurements and rate-of-change statistics from the transect–shoreline intersection data. The following subsections detail each metric.

5.1 Distance Measurements: SCE and NSM

Shoreline Change Envelope (SCE)

SCE reports the greatest distance (in metres) among all shoreline positions that intersect a given transect. It represents the total range of shoreline movement irrespective of direction or chronological order. All SCE values are positive.

Formula: $SCE = Distance(farthest\ shoreline) - Distance(closest\ shoreline)$

Net Shoreline Movement (NSM)

NSM reports the distance (in metres) between the oldest and the youngest (most recent) shoreline positions for each transect. Positive NSM values indicate net accretion, whilst negative values indicate net erosion.

Formula: $NSM = Distance(oldest\ shoreline) - Distance(newest\ shoreline)$

5.2 Rate-of-Change Statistics: End Point Rate (EPR)

The End Point Rate (EPR) is calculated by dividing the Net Shoreline Movement by the time elapsed (in years) between the oldest and the most recent shoreline. EPR is expressed in metres per year (m/yr). EPR requires only two shoreline positions; however, it provides no information about shoreline behaviour during intervening years even if multiple shoreline positions are available.

Formula: $EPR = NSM / (Year\_newest - Year\_oldest)$

Uncertainty of End Point Rate (EPRunc)

The uncertainty of the EPR is computed from the positional uncertainties of the two shorelines:

Formula: $EPRunc = \sqrt{(uncyA^2 + uncyB^2)} / (yearA - yearB)$

Where uncyA and uncyB are the positional uncertainties of the youngest and oldest shorelines, respectively.

5.3 Linear Regression Rate (LRR)

For analyses involving three or more shoreline positions, the Linear Regression Rate (LRR) provides a more robust rate-of-change estimate. LRR is determined by fitting a least-squares regression line to all shoreline intersection points along a transect. The slope of the regression line represents the rate of change in metres per year.

Formula: $LRR = \Sigma[(x_i - \bar{x})(y_i - \bar{y})] / \Sigma[(x_i - \bar{x})^2]$

Where x_i = year of the i^{th} shoreline; y_i = distance of the i^{th} shoreline from the baseline; $\bar{x}$ = mean of years; $\bar{y}$ = mean of distances; n = number of shoreline positions.

5.4 Weighted Linear Regression Rate (WLR)

The Weighted Linear Regression Rate (WLR) is similar to LRR, but assigns greater weight to shoreline positions with smaller positional uncertainty. The weight (w) is defined as the inverse of the variance of the measurement uncertainty:

Formula: $w = 1 / e^2$

Where e is the positional uncertainty of a given shoreline. The weighted regression slope then becomes the WLR.

Formula: $WLR = \Sigma[(x_i - \bar{x}w)(y_i - \bar{y}w) \times w_i] / \Sigma[(x_i - \bar{x}w)^2 \times w_i]$

Where $\bar{x}w$ and $\bar{y}w$ are the weighted means of years and distances, respectively.

5.5 Supplementary Statistics and Uncertainty Metrics

Statistic	Abbreviation	Description
R-squared (Linear Regression)	LR2	Coefficient of determination; indicates the proportion of variance in shoreline position explained by the linear model
Standard Error of Estimate (LRR)	LSE	Standard error of the linear regression estimate: $\sqrt{[\Sigma(y_i - \hat{y}_i)^2 / (n - 2)]}$
Confidence Interval (LRR)	LCI	Confidence interval of the regression rate, computed using the Student's t-distribution at a user-specified confidence level (default: 99.7%)
R-squared (Weighted Regression)	WR2	Coefficient of determination for the weighted linear regression
Standard Error of Estimate (WLR)	WSE	Standard error of the weighted regression estimate
Confidence Interval (WLR)	WCI	Confidence interval of the weighted regression rate

6. Data Sources for Shoreline Change Analysis

Historical shoreline data may be derived from a variety of sources. The following table summarises common data sources, their typical temporal coverage, and the associated positional uncertainties as reported in the literature.

Data Source	Typical Period	Spatial Resolution / Accuracy	Uncertainty (m)
Topographic Sheets (T-sheets)	1850s–1980s	Varies (~1:20,000)	±5 to ±10
Aerial Photographs	1930s–present	0.1–1.0 m (depends on	±3 to ±8

		scale)	
Landsat Imagery (TM/OLI)	1984–present	30 m (multispectral)	±15 to ±30
Sentinel-2 Imagery	2015–present	10 m (visible/NIR)	±5 to ±15
High-Resolution Satellite (e.g., Pléiades, WorldView)	2000s–present	0.3–0.5 m (panchromatic)	±1 to ±3
LiDAR / UAV Surveys	2000s–present	0.01–0.5 m	±0.5 to ±2
GPS Ground Surveys	1990s–present	Sub-metre (RTK-GPS)	±0.1 to ±1

PART II: STEP-BY-STEP DSAS WORKFLOW

7. Data Acquisition and Preparation

7.1 Obtaining Historical Shoreline Data

The first step in any DSAS analysis is the compilation of multi-temporal shoreline positions. Shorelines may be obtained from existing published datasets or digitised from remote sensing imagery.

Step 7.1.1: Identify Data Sources

Consult national coastal mapping agencies, the NOAA Shoreline Website (https://shoreline.noaa.gov/), the USGS Coastal Change Hazards portal, or regional survey departments for pre-existing shoreline vectors. For satellite-derived shorelines, download imagery from USGS EarthExplorer (https://earthexplorer.usgs.gov/) or the Copernicus Open Access Hub (https://dataspace.copernicus.eu/).

Step 7.1.2: Select Temporal Range

Choose a temporal range that captures meaningful coastal change (typically 20–50 years for long-term rates). Include a minimum of two shoreline dates for EPR/NSM, or three or more dates for LRR/WLR analyses.

7.2 Shoreline Digitisation from Satellite Imagery

Step 7.2.1: Band Combination and Enhancement

In ArcGIS Pro or ArcMap, load the satellite imagery. For Landsat 8/9 OLI, a false-colour composite using Bands 5 (NIR), 6 (SWIR 1), and 4 (Red) or the NDWI (Normalised Difference Water Index) provides strong land-water contrast. For Sentinel-2, use Bands 8 (NIR), 11 (SWIR), and 4 (Red).

Step 7.2.2: Digitise the Shoreline

Create a new polyline feature class within a projected coordinate system (metre units). Digitise the shoreline by tracing the wet/dry boundary, high-water line, or the instantaneous waterline, maintaining consistency in the chosen shoreline indicator across all dates.

Step 7.2.3: Assign Uncertainty

Assign a positional uncertainty value (in metres) to each shoreline based on the data source, georeferencing error, digitisation precision, and tidal influence. This value is critical for EPRunc and WLR calculations.

7.3 Attribute Field Requirements for Shorelines

All shoreline feature classes must contain the following attribute fields for DSAS to function correctly. The field names shown below follow the DSAS v5.1/v6.1 conventions.

Field Name	Data Type	Status	Description
OBJECTID	Object ID	Auto-generated	Unique feature identifier
SHAPE	Geometry	Auto-generated	Polyline geometry
SHAPE_Length	Double	Auto-generated	Length of the feature
DATE_ (or DSAS_date)	Text	Required	Date of the shoreline (format: MM/DD/YYYY)
UNCERTAINTY (or DSAS_uncy)	Numeric	Required	Positional uncertainty in metres
SHORELINE_TYPE (or DSAS_type)	Text	Optional	Indicator type (e.g., HWL, MHW); required if using proxy-datum bias correction

7.4 Attribute Field Requirements for Baselines

The baseline feature class must contain a unique identifier field (ID). The baseline must be in the same projected coordinate system and reside in the same geodatabase or GeoPackage as the shoreline data.

Field Name	Data Type	Status	Description
OBJECTID	Object ID	Auto-generated	Unique feature identifier
SHAPE	Geometry	Auto-generated	Polyline geometry
ID	Integer/Long	Required	Unique segment identifier for the baseline

8. Setting Up the GIS Environment

8.1 Coordinate System Configuration

Step 8.1.1:

All DSAS input data must be in a projected coordinate system using metre units. The recommended system is the Universal Transverse Mercator (UTM) projection corresponding to the study area's UTM zone (e.g., WGS 1984 UTM Zone 44N for the southern coast of India).

Step 8.1.2:

In ArcGIS Pro: Right-click the Map in the Contents pane → Properties → Coordinate Systems. Set the coordinate system to the appropriate UTM zone. In QGIS: Project → Properties → CRS.

8.2 Organising the Geodatabase / GeoPackage

For DSAS v5.1 (ArcMap): All shoreline and baseline feature classes must reside within the same personal geodatabase (.mdb) or file geodatabase (.gdb).

For DSAS v6.1 (Standalone): Prepare shoreline and baseline data in your GIS and export as shapefiles or GeoJSON files. Upload these to the DSAS application, where they will be stored within a GeoPackage (.gpkg).

9. Creating the Reference Baseline

9.1 Baseline Placement Strategies

The baseline can be placed in one of the following positions:

- **Onshore Baseline:** Placed landward of all shoreline positions. This is the most common approach.
- **Offshore Baseline:** Placed seaward of all shoreline positions.
- **Midshore Baseline:** Placed between shoreline positions. Requires accurate identification of land orientation.
- **Combination:** A combination of onshore, offshore, and midshore segments (supported in DSAS v6.1).

9.2 Drawing the Baseline

There are three primary methods for creating a baseline:

Method A: Manual Creation

Create a new polyline feature class in ArcCatalog or ArcGIS Pro. Using the Editor toolbar, manually draw a smooth line that follows the general trend of the coast, positioned onshore (or offshore) of all historical shoreline positions.

Method B: Buffer an Existing Shoreline

Select a representative shoreline, create a buffer at a suitable distance (e.g., 50–100 m landward), and convert the buffer polygon to a polyline. This method ensures the baseline follows the general coastal orientation.

Method C: Smooth an Existing Shoreline

Use the Smooth Line (Cartography) tool in ArcToolbox to generalise an existing shoreline, then manually offset the smoothed line landward or seaward.

10. Casting Transects in DSAS

10.1 Transect Parameters

Parameter	Description	Recommended Value
Transect Spacing	Alongshore distance between transects	50–100 m (site-dependent)
Search Distance	Maximum distance a transect extends to find shoreline intersections	Typically 500–2000 m
Smoothing Distance	Distance over which the baseline is generalised to smooth transect orientation	500 m (default in DSAS)

10.2 Generating and Editing Transects

Step 10.2.1: Cast Transects

In DSAS v5.1 (ArcMap): Use the DSAS toolbar → Cast Transects. Select the geodatabase, name the transect feature class, and set the spacing, search distance, and smoothing distance parameters.

In DSAS v6.1 (Standalone): Upload the baseline and shorelines. Configure the transect parameters in the application interface and generate transects.

Step 10.2.2: Review and Edit

Visually inspect all transects. Delete or modify transects that cross land features, intersect each other, or fail to intersect all shoreline positions. In DSAS v6.1, basic editing tools are available within the application; for extensive edits, export to a GIS, edit, and re-upload.

11. Computing Shoreline Change Statistics

11.1 Running the Calculation

Step 11.1.1:

In DSAS v5.1: From the DSAS toolbar, click Calculate Statistics. Select the desired statistics (SCE, NSM, EPR, LRR, WLR) and set the confidence interval (default: 99.7%).

Step 11.1.2:

In DSAS v6.1: After transects have been generated, initiate the rate calculation from the application interface. DSAS computes all metrics and stores results in the GeoPackage as a rates layer and an intersects file.

11.2 Interpreting the Output

The output attribute table contains the computed statistics for each transect. The following table summarises the interpretation of key metrics.

Metric	Unit	Positive Value	Negative Value	Interpretation
NSM	metres (m)	Accretion	Erosion	Net displacement of the shoreline
EPR	m/yr	Accretion	Erosion	Rate of change based on two endpoints
LRR	m/yr	Accretion	Erosion	Rate of change from linear regression (≥3 shorelines)
WLR	m/yr	Accretion	Erosion	Uncertainty-weighted rate of change
SCE	metres (m)	—	—	Maximum envelope of change (always positive)

12. Cartographic Presentation of Results

12.1 Symbology and Classification

Apply a graduated colour symbology to the transect layer based on EPR or LRR values. A diverging colour scheme (e.g., red for erosion, blue/green for accretion) is recommended.

Class	EPR Range (m/yr)	Colour	Interpretation
Severe Erosion	< −2.0	Dark Red	Critical coastal retreat
Moderate Erosion	−2.0 to −1.0	Red	Significant erosion
Low Erosion	−1.0 to 0.0	Light Red / Orange	Minor erosion
Stable	0.0 ± uncertainty	Yellow	No significant change
Low Accretion	0.0 to +1.0	Light Green	Minor accretion
Moderate Accretion	+1.0 to +2.0	Green	Significant accretion
High Accretion	> +2.0	Dark Green	Substantial coastal progradation

12.2 Map Layout Design

Following the cartographic conventions consistent with academic publication standards:

- Title describing the study area, temporal range, and metric displayed.
- North arrow and scale bar (metric units).
- Legend clearly defining the colour classes and units.
- Inset/location map showing the regional context.
- Coordinate grid or graticule.
- Data credits and projection information.
- Export at 300 DPI in PDF, TIFF, or PNG format for publication.

PART III: APPLICATIONS, VALIDATION, AND REFERENCES

13. Applications of Shoreline Change Analysis

Application Domain	Description
Coastal Erosion Hazard Mapping	Identifying erosion-prone stretches for setback line delineation and coastal zone management plans
Coastal Engineering	Evaluating the efficacy of coastal protection structures (groynes, seawalls, breakwaters) by comparing pre- and post-construction shoreline change rates
Climate Change Impact Assessment	Quantifying the effects of sea-level rise and increased storm frequency on shoreline retreat
Sediment Budget Analysis	Integrating shoreline change rates with bathymetric and wave data to estimate sediment transport volumes
Environmental Impact Assessment (EIA)	Assessing the coastal impact of proposed infrastructure projects, ports, and industrial developments
Disaster Risk Reduction	Supporting post-event assessments of storm surge and tsunami impacts on coastal morphology
Urban and Land-Use Planning	Informing zoning regulations and infrastructure siting in coastal municipalities
Mangrove and Wetland Monitoring	Tracking the advance or retreat of vegetated shoreline boundaries

14. Common Errors and Troubleshooting

Error / Issue	Possible Cause	Solution
Transects not intersecting all shorelines	Search distance too short; baseline too far from shorelines	Increase the search distance parameter; reposition the baseline closer to the shoreline cluster
Transects crossing each other	Baseline has sharp bends or cusps	Increase the smoothing distance; manually simplify the baseline geometry
Incorrect sign (erosion shown as accretion)	Baseline placed on wrong side; incorrect land orientation setting	Verify baseline position relative to shorelines; in DSAS v6.1, correctly set the land orientation flag for midshore baselines
Missing statistics for some transects	Transect does not intersect the minimum required number of shorelines	Ensure all shoreline dates are correctly attributed; verify spatial overlap of transects and shorelines
Date field not recognised	Incorrect date format in shoreline attributes	Ensure date is in MM/DD/YYYY format (text field) as required by DSAS
Coordinate system mismatch	Shorelines and baseline in different projections	Reproject all data to the same projected coordinate system (metre units)
GeoPackage not loading in DSAS	Corrupted file or unsupported	Re-export data from GIS; ensure

v6.1	feature types	only polyline features are included

15. Key Academic References

Baig, M. R. I., Ahmad, I. A., Shahfahad, & Tayyab, M. (2020). Analysis of shoreline changes in Vishakhapatnam coastal tract of Andhra Pradesh, India: An application of digital shoreline analysis system (DSAS). Annals of GIS, 26(4), 361–375.

Crowell, M., Leatherman, S. P., & Buckley, M. K. (1991). Historical shoreline change: Error analysis and mapping accuracy. Journal of Coastal Research, 7(3), 839–852.

Dolan, R., Fenster, M. S., & Holme, S. J. (1991). Temporal analysis of shoreline recession and accretion. Journal of Coastal Research, 7(3), 723–744.

Henderson, R. E., Farris, A. S., Kratzmann, M. G., Bartlett, M. K., Ergul, A., McAndrews, J., Cibaj, R., Zichichi, J. L., Himmelstoss, E. A., & Thieler, E. R. (2026). Digital Shoreline Analysis System version 6.1. U.S. Geological Survey software release. https://doi.org/10.5066/P1NHMJNC.

Himmelstoss, E. A., Henderson, R. E., Kratzmann, M. G., & Farris, A. S. (2021). Digital Shoreline Analysis System (DSAS) version 5.1 user guide (Open-File Report 2021–1091). U.S. Geological Survey. https://doi.org/10.3133/ofr20211091.

Mahapatra, M., Ratheesh, R., & Rajawat, A. S. (2014). Shoreline change analysis along the coast of South Gujarat, India, using digital shoreline analysis system. Journal of the Indian Society of Remote Sensing, 42(4), 869–876.

Morton, R. A., Miller, T. L., & Moore, L. J. (2004). National assessment of shoreline change: Part 1—Historical shoreline changes and associated coastal land loss along the U.S. Gulf of Mexico (Open-File Report 2004–1043). U.S. Geological Survey.

Mutaqin, B. W. (2017). Shoreline changes analysis in Kuwaru Coastal Area, Yogyakarta, Indonesia: An application of the Digital Shoreline Analysis System (DSAS). International Journal of Sustainable Development and Planning, 12(7), 1203–1214.

Oyedotun, T. D. T. (2014). Shoreline geometry: DSAS as a tool for historical trend analysis. Geomorphological Techniques, 2(3), 1–12.

Thieler, E. R., & Danforth, W. W. (1994). Historical shoreline mapping (II): Application of the digital shoreline mapping and analysis systems (DSMS/DSAS) to shoreline change mapping in Puerto Rico. Journal of Coastal Research, 10(3), 600–620.

Thieler, E. R., Himmelstoss, E. A., Zichichi, J. L., & Ergul, A. (2009). The Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change (Open-File Report 2008–1278). U.S. Geological Survey.

Appendix: Complete Formula Reference Sheet

Step	Metric	Formula	Unit	Min. Shorelines Required
1	Shoreline Change Envelope (SCE)	SCE = Dist(farthest) − Dist(closest)	metres (m)	2
2	Net Shoreline Movement (NSM)	NSM = Dist(oldest) − Dist(newest)	metres (m)	2
3	End Point Rate (EPR)	EPR = NSM / (Year_newest − Year_oldest)	m/yr	2
4	EPR Uncertainty (EPRunc)	$EPRunc = \sqrt{(uncyA^2 + uncyB^2)} / (yearA - yearB)$	m/yr	2
5	Linear Regression Rate (LRR)	$LRR = \Sigma[(x_i-\bar{x})(y_i-\bar{y})] / \Sigma[(x_i-\bar{x})^2]$	m/yr	3
6	Weighted Linear Regression (WLR)	$WLR = \Sigma[(x_i-\bar{x}w)(y_i-\bar{y}w)\times w_i] / \Sigma[(x_i-\bar{x}w)^2\times w_i]$ $(w=1/e^2)$	m/yr	3
7	Standard Error (LSE / WSE)	$\sqrt{[\Sigma(y_i - \hat{y}_i)^2 / (n - 2)]}$	m	3
8	R-squared (LR2 / WR2)	$1 - [\Sigma(y_i-\hat{y}_i)^2 / \Sigma(y_i-\bar{y})^2]$	—	3
9	Confidence Interval (LCI / WCI)	$t\_inv(n-2, 1-\alpha/2) \times \sqrt{[SE^2 / \Sigma(x_i-\bar{x})^2]}$	m/yr	3