Western Lefkada Shoreline Displacement Rates Based on Photogrammetric Processing of Remote Sensing Datasets from Various Sources

A. Roufi[1], Emm. Vassilakis[1], S. Poulos[1]

(1) Faculty of Geology & Geo-environment, NKUA, Panepistimioupolis, Zographou, 15784, Greece, amaliaroufi@gmail.com

The aim of this study is to calculate the displacement rates of the coastline at the western part of the island, which is characterized of the escarpment coast. The shape of this coastal zone is caused mainly by tectonism which is very frequent in this wider area (Valkaniotis *et al.*, 2018). The western coast of the island from Cape Agios Ioannis (NW) to the southernmost point of the peninsula, Cape Doukato is steep and precipitous, as a result of the high seismicity of the Ionian Sea area (Bornovas, 1964). Along this side of the island, several landslides and rock falls are observed. The situation changes only at the northern part of the island, with a distinctive coastal landform over the narrow zone called "Zostiras" (Leivaditis & Verikiou - Papaspyridakou, 1986).

This work was conducted using two different types of data. Historical analogue panchromatic aerial images of high resolution (Zuidam and Van Zuidam-Cancelado, 1979) and contemporary digital high resolution multi-spectral satellite images were combined for extracting the coastline at the time period of acquisition. The acquisition of the aerial photographs took place during 1945 and 2010, while the satellite images where acquired during 2016, 2017 and 2018 (Figure 1). In all cases the images were digitally processed and optically optimized in order to produce a highly accurate representation of the shoreline at each time period. All the data were imported in a Geographic Information System platform, where they were subjected into comparison and geo-statistical analysis (Tsokos *et al.*, 2018). Several transects were drawn normally to the coast and the distance between them was set at every 200 m as the relative displacement of the coastline was calculated for each one of them.

In a way to achieve this, an extension of the ESRI ArcGIS v.10.6.1 software was employed as published by USGS and named Digital Shoreline Analysis System v.5 (DSAS). The DSAS extension (Thieler *et al.*, 2009) lets the user define a constant straight line in a specific distance from the shoreline and take transects perpendicular to it among the evolving coastlines. The measurements give quantitative information on the change of the position of the shoreline, as well as more useful statistical data. Even if this seems to be an arbitrary value, it worked rather sufficiently at this almost 12 km long segment of the shoreline as it can be characterized as rather curvy and either a smaller value would result an oversampled area with transects intersect each other mixing the calculations or a larger value would result quite sparse transect locations without any representative outcome.

Spatial classification of the calculated displacement rate

According to the geostatistical analysis results, the entire 42km shoreline was segmented into 8 areas, regarding the overall evolution of the coast throughout the studied time period. The basement rocks seem to play a very important role and therefore the dominant rock type for each segment is also mentioned below.

1. *Ag. Giannis:* The area is eroded from 0.11 to 1.06 m/yr. The geology of the area consists of contemporary coastal formations (Holocene) and limestone Pantokrator (L. Triassic).
2. *Ag. Nikitas:* There is a progradation of 0.02 to 0.27 m/yr in the Pantokrator limestones that crop out at the area, which seems to have been affected by the recent earthquakes of 2003 and 2015.
3. *Kathisma - Avali:* Erosion of the order of 0.01 to 0.54 m/yr is observed in contemporary coastal formations (Holocene) and Vigla limestones (E. Senonian)
4. *Chortata - Komilio:* At this area the progradation is larger as it reaches 0.52 m/yr. The outcrops consist of carbonates (Jurassic to Paleocene limestones). The earthquake of 2003 caused several falls of boulder size rocks from the existing terraces, forming a wider coastal zone.
5. *Dragano – Athani:* At this area there we observed also erosion (0.01 to 0.26 m/yr) and deposition (0.04 to 0.37 m/yr). In both cases the basement consists of limestones (L. Jurassic), whilst the eroded zone is covered by talus scree (Pleistocene) forming a slope of 65°-70°.
6. *Egremnoi:* We observed erosion varying from 0.02 to 0.29 m/yr simultaneously with deposition of 0.06 to 0.59 m/yr. The eroded formations are contemporary coastal deposits (Holocene) or limestones (L. Cretaceous). During the earthquakes of 2003 and 2015 massive rock falls were observed along the steep slopes. This fact is repeated after every major earthquake in these areas, due to the high elevation and steep slopes.
7. *Porto-Katsiki:* The L. Cretaceous limestones that crop out in this area are eroded with a rate from 0.04 to 0.49 m/yr.
8. *Krimnoi:* Coastal erosion reaching 0.66 m/yr was calculated along this shoreline segment.

Processing and Results

The described methodology introduces a simple but very convenient way of combining a dataset containing all the available shoreline traces throughout a given time period, in order to quantify its displacement rate for certain segments and therefore evaluate the risk or vulnerability of a coastal zone. We suggest that all kinds of remote sensing data (with

similar spatial resolution) could be included in this change detection procedure and the objective difficulty should be how far back in time one could find reliable datasets and hence increase the reliability of the methodology. The most labored issue would be to make all the collected datasets free from distortions and consequently comparable to each other, combine them in a Geographic Information System platform and finally determine and quantify the shoreline displacement rate and especially the erosion rate at certain segments.

By employing the methodology described above, at the area of investigation we have calculated the displacement rate of the coastline position over the past 75 years. The rates of change that were calculated were not homogeneous along the full length of the coastline. Specifically, the average value of the rate of receding is 10 cm/year, while extreme values of order 1 m/year were also observed, increasing the riskiness of specific positions. In those positions it has been estimated that the shoreline has receded over 55 m in the last 75 years and is strongly affected by the earthquake activity along with the human intervention in some cases. In conclusion we calculated that the extreme coastline displacement values reach the 1.06 m/yr (erosion) and 0.59 m/yr (progradation). The combination of geological formations and intense seismicity seems to be the main factor leading to these results.
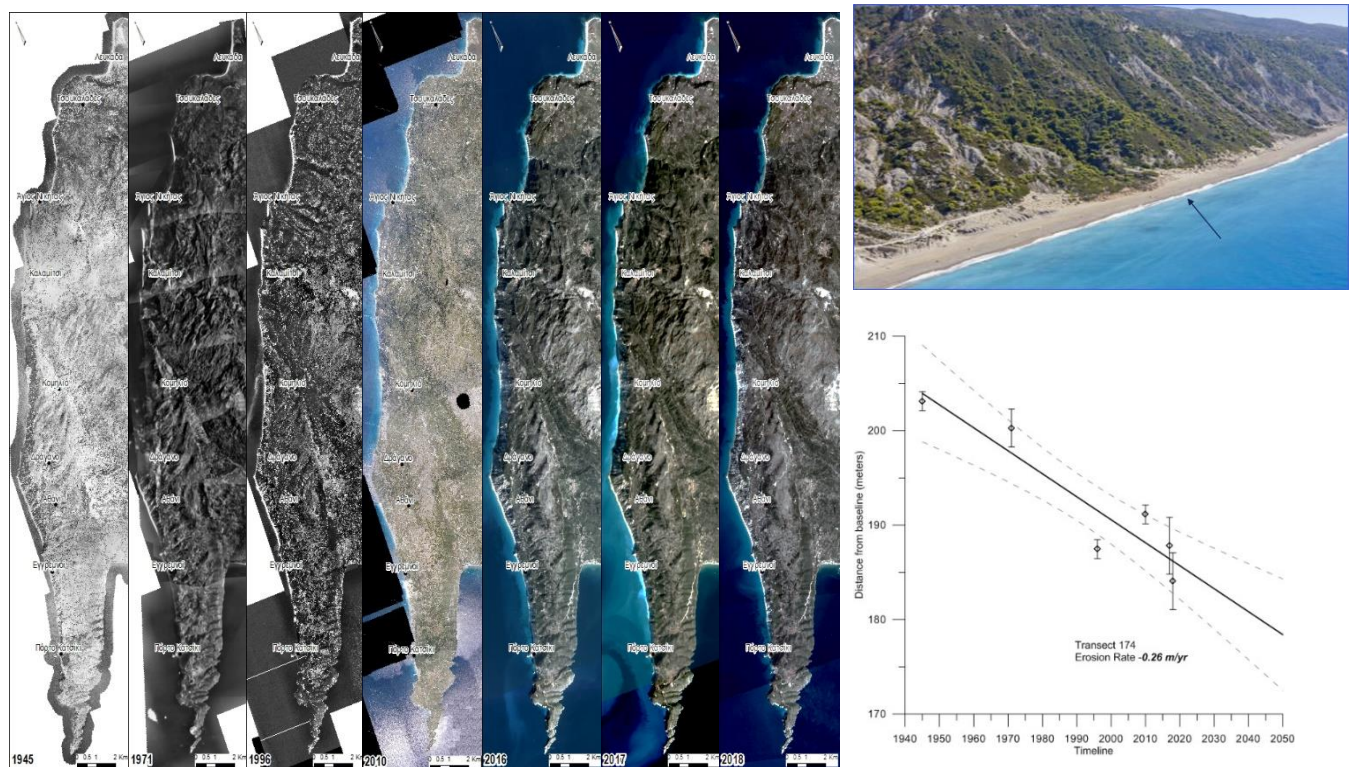

Figure 1. Datasets used for this study, representing the western part of Lefkada Isl. for the years 1945, 1971, 1996, 2010, 2016, 2017, 2018. The black arrow points at the location where section 174 corresponds (upper right) and below the coastline displacement rate diagram, calculating erosion of the order of 0.26 m/yr for the same section.

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