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Monitoring Coastal Erosion in Cyprus: An Analysis Utilizing Sentinel-1 SAR Data

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ABSTRACT

The maritime safety and security of coastal regions is a crucial concern impacted by the dynamic growth and erosion processes shaping these areas. Coastal erosion can pose a safety risk to people living or working in these areas and the tourism industry. Furthermore, erosion can include hazards to maritime infrastructure, such as piers, ports, and other facilities, as well as to shipping and navigation in the area. Problems that can be identified from coastal erosion and accretion are changes in water depth, unpredictable currents, displacement of buoys and markers, increased risk of vessel grounding as well as changes in shoreline characteristics that can affect the direction and intensity of wind and waves, making it difficult for ships and boats to navigate safely. This paper uses Sentinel 1 satellite data to monitor Coastal Erosion patterns along the Southeast Cyprus coastlines. The findings of this study could help manage coastal resources and improve maritime safety and security in Cyprus. This study thereby contributes to the broader body of knowledge concerning coastal erosion monitoring using satellite-based remote sensing data, explicitly emphasising the application of Sentinel-1 SAR imagery. The study's methodologies and findings provide valuable insights that can be extended to other similar coastal regions in Cyprus.

Keywords: Sentinel 1 SAR, Coastal erosion, Sentinel Application Platform (SNAP), Southeast Cyprus coastlines

1. INTRODUCTION

Remote sensing is an increasingly important technology for the Maritime ecosystem [1]. Coastal regions are a crucial concern impacted by the dynamic growth and erosion processes shaping these Maritime areas. Coastal zone monitoring is essential for sustainable development and environmental protection [2]. The coastline is considered one of the most dynamic linear features in the coast [3], and it is defined as the physical interface between land and water [4]. It is one of the most essential linear features on the earth's surface, which is dynamic [5]. Coastal erosion can pose a safety risk to people living or working in these areas and the tourism industry. Tourism, an important economic activity, has been increasingly associated with vacationing wholly or partially at coastal locations and beach recreational activities, according to the Sun–Sea–Sand (3S) model [6]. Therefore, beach aesthetics and adequate carrying capacity and infrastructure are crucial for the tourism sector and the economy [7,8]. Coastal erosion often leads to an irreparable loss of information used to identify maritime structures and activities [9]. It has been a major problem for many areas around the world. The coasts are economically important for many countries as a large part of the gross domestic product is derived from coastal activities, and they are being eroded too fast [10].

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About 40% of the world's population lives near coasts. Coastal erosion whether it is caused by natural or human activities, it has important effects on the populations who can no longer live close to the coastline, and the infrastructure [10]. There is an increasing trend of erosion along the world's coastlines, with twice as much land lost, than what was replaced over the last 30 years. It is estimated that this covers a surface area of about 28 000 km^2 [10]. Monitoring coastal environments and tracking their evolution provide fundamental information to policy and decision-makers on local, regional, and national levels [10]. Officially, the serious erosion problem that the famous beach presents, like several others in Protaras (Southeast Cyprus) [11], is attributed to the morphology of the soil and to the anomalies and damages that the beach has suffered from the weather conditions and the sea turbulence during the winter, resulting in the sea to absorb all the sand from the beach and only the rocks are left outside [11]. One of the solutions to the problem is the transfer of sand to the area that has been stripped. Moreover, the observed minimal erosion can be attributed to a breakwater, a coastal infrastructure typically composed of rock and rubble mound structures that run parallel or close to the coastline. Its main functions include mitigating incoming wave energy, providing a sheltered beach area, and safeguarding vessels against the impacts of waves and currents.

This paper uses Sentinel-1 satellite data to monitor Coastal Erosion patterns along the Southeast Cyprus coastlines, Famagusta District. The findings of this study could help manage coastal resources and improve maritime safety and security in Cyprus. This study thereby contributes to the broader body of knowledge concerning coastal erosion monitoring using satellite-based remote sensing data, explicitly emphasising the application of Sentinel-1 SAR imagery. The study's methodologies and findings provide valuable insights that can be extended to other similar coastal regions in Cyprus. The preliminary results show that the Sentinel-1 SAR data would give effective results and spatial information about erosion along the coastline to decision-makers.

2. METHODOLOGY

2.1 Study Area

The study's area of interest (AoI) is the Southeast Cyprus coastlines, Famagusta District. Figure 1 shows the study area. The data includes SAR Sentinel-1A level 1 ground range detected high-resolution (GRDH) data acquired on 03 April 2023 with interferometric wide swath (IW) mode. Level 1 GRD data denotes that the data have been projected using an ellipsoid earth-modelling approach [1]. Table 1 gives a detailed overview of the SAR Sentinel-1 imagery used in this study.

Figure 1: The area of interest (AoI) (red rectangle) used in this study (Satellite View on 03 April 2023).

Table 1: The detailed overview of the SAR Sentinel-1 imagery on 03 April 2023

No	Characteristic	Data 1
1	Mission	Sentinel-1A
2	Acquisition Date	03 Apr. 2023 15:56:50
3	Acquisition Mode	IW
4	Pass Direction	Ascending
5	Polarization	VH, VV
6	Product Type	GRD
7	Instrument Name	Synthetic Aperture Radar (C-band)

2.2 Methods

The main idea of this study is to present an analysis of erosion patterns in the Southeast Cyprus coastlines, Famagusta District. Data from Sentinel-1 from the Copernicus Open Access Hub was used through the online interface. The methodology was formulated for the Sentinel application platform (SNAP), a typical architecture satellite toolbox [1]. SNAP enables accurate assessment of erosion rates, identification of erosion-prone areas, and understanding of the underlying factors influencing erosional processes in the specific Area of Interest. The overall methodology adopted in this study consists of fifteen (15) processing steps briefly described below (see Figure 2):

Step 1: Select Areas of Interest from Copernicus Open Access Hub using Polygon.

Step 2: Search for appropriate data pertinent to severe coastal erosion, mainly focusing on the Southeastern coastlines of Cyprus.

Step 3: Download data from Sentinel-1 via the Copernicus Open Access Hub using the online interface.

Step 4: Using SNAP (Sentinel Application Platform) software. Opening Intensity_VH band to visualise the band.

Step 5: Import the download data to SNAP

Step 6: Image Subset: Since our Area of Interest (AoI) is relatively small and there is no need to process the whole image, we start with sub-setting the scene to a more manageable size. This will reduce the processing time in further steps and is recommended when the analysis is focused only on a specific area and not the complete scene [1].

Step 7: Apply-Orbit-File: The orbit file provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated [10].

Step 8: Thermal Noise Removal: Thermal noise in SAR imagery is the background energy generated by the receiver. It skews the radar reflectivity to higher values and hampers the precision of radar reflectivity estimates [10].

Step 9: Calibration: The procedure converts digital pixel values to radiometrically calibrated SAR backscatter [12].

Step 10: Speckle Filtering: Speckles are caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatters within each resolution cell. Speckle noise reduction can be applied either by spatial filtering or multilook processing [10].

Step 11: Terrain correction: Terrain corrections are intended to compensate for the distortions arising from the sensor's side-looking geometry so that the geometric representation of the image will be as close as possible to the real world [13]. Digital Elevation Model (DEM) is crucial for geocoding, terrain correction, and generating interferograms. In this study for erosion purposes the Shuttle Radar Topography Mission (SRTM) was used.

Step 12: Land-Sea Mask: The first stage is masking the land areas to avoid false target detections on land [12].

Step 13: Storing the imagery of the Sigma0_VH band.

Step 14: Masking – Band Maths: To process the images further and distinguish the boundaries between land and sea to determine the shoreline. In our situation, the value we will utilise to distinguish land from the sea will be a 0.02 threshold value. Using Band Maths, we write this expression if Sigma0_VH > 0.02, then NaN else Sigma0_VH. In simpler terms, this expression checks the value of Sigma0_VH. If it exceeds 0.02, it replaces that value with 'NaN' (Not a Number). If it doesn't exceed 0.02, the value remains unchanged.

Step 15: Results, Comparison – Export Products for QGIS and Google Earth.

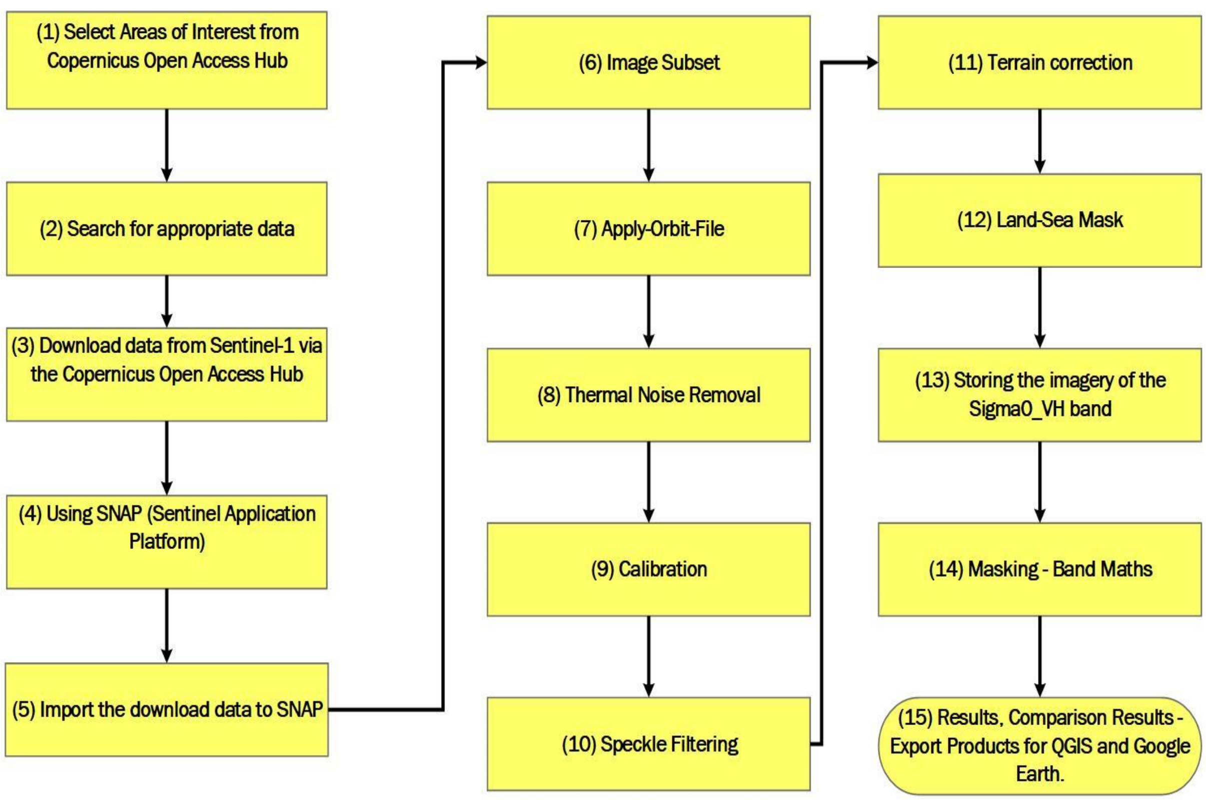

Figure 2: The overall methodology adopted in this study.

3. RESULTS

Figure 3 presents the results for Cyprus Coastline, 03 April 2023 —the mask analysis of the Sentinel-1 SAR data results processed with SNAP. However, the separation of land and sea from Sentinel-1 data was also making some separation of surface waters or humid areas and land, as shown in Figures 4 and 5, because the surface waters or humid areas and sea have almost the same backscattering values. Then when density slicing was performed, surface waters became the same class as the sea [2]. But for this study, this case did not influence coastline extraction because the important one is the boundary between land and sea.

The following are the main findings regarding erosion in Cyprus from the analysis of Sentinel-1 SAR data processed with SNAP:

- Erosion Hotspots: SNAP-processed SAR data facilitated the identification of erosion hotspots across Southeast Cyprus coastlines. These hotspots were predominantly located in steep terrain, vulnerable soil types, and intensive human activities, such as tourist developments.
- Coastal Erosion: The SNAP-processed data allowed for an in-depth assessment of coastal erosion along the coastline. The results highlighted specific coastal regions experiencing rapid erosion, raising concerns about the impacts on coastal ecosystems and infrastructure.

Furthermore, Figure 4 displays the SNAP mask output generated by applying the methodology using Google Earth Image, described above in this paper. This representation comprehensively illustrates the regions susceptible to coastal erosion along the Southeast Cyprus coastlines. Subsequently, Figure 5 presents a Google Earth Image showcasing the imported mask (grey color), enabling a comprehensive analysis of the variations and implications of coastal erosion along the Southeast Cyprus coastlines, explicitly emphasising the renowned Fig Tree Bay in Protaras, Paralimni (Figure 1), one of the most popular beaches on the island as thousands of local and foreign visitors gear up to head to Famagusta district for their summer holidays [14].

Figure 5 points out the coastline changes between that periods (every ten years) using three (3) shorelines. The shorelines of 2003 (yellow), 2013 (purple) and 2023 (red). The shorelines were derived using historical Google Earth Satellite Images. In this area, the relative sea level is rising, or where sediment availability is reduced, a further coastal squeeze results from a steepening beach profile and foreshortening of the seaward zones [15], as illustrated in Figure 5. The results show an increasing trend of erosion along the Fig tree bay coastline, reaching -1.5 m/year according to the historical Google Earth Satellite Images. Correspondingly, Figures 6 and 7 show images (June 2020) of Fig tree bay beach, where the shoreline has visibly receded. This demonstrates coastal erosion, often worsened by rising sea levels.

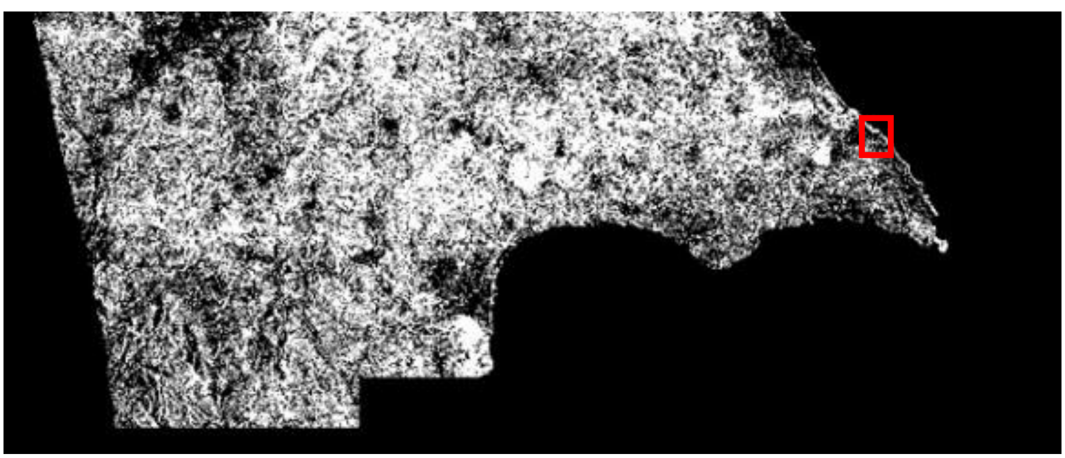

Figure 3: This figure showcases the results of a mask analysis for the Cyprus Coastline dated 03 April 2023, utilizing Sentinel-1 SAR data processed through SNAP. The area of interest (AoI) is highlighted by a red rectangle in the study.

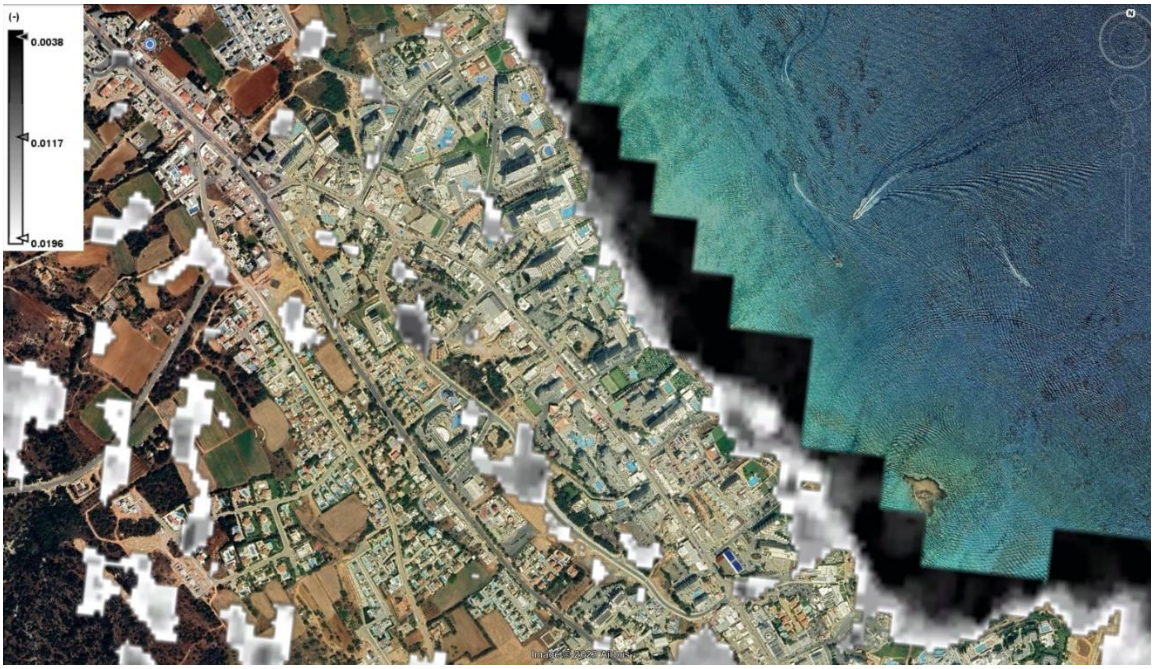

Figure 4. A Google Earth image overlaid with an imported mask (in grey), highlighting the impact and patterns of coastal erosion along the Southeast."

Figure 5: Visualization of decade-wise coastline alterations with mapped shorelines from 2003 (yellow), 2013 (purple), and 2023 (red), highlighting the coastal squeeze and beach profile steepening due to relative sea-level rise and reduced sediment availability. The shorelines were derived using historical Google Earth Satellite Images.

Figure 6: Visual evidence of coastal erosion at a Fig tree bay beach [14], with a marked shoreline recession indicative of the heightened effects of rising sea levels.

Figure 7: Image depicting a distinct shoreline recession indicates the escalating coastal erosion at fig tree bay [14], often exacerbated by the rising sea levels.

4. CONCLUSIONS

Applying SNAP to process Sentinel-1 SAR data enabled a comprehensive erosion analysis in Cyprus. The results contribute significantly to understanding the spatial distribution and temporal trends of erosional processes on the island. The results show an increasing trend of erosion along the coastline of the study area, reaching -1.5 m/year correspondingly.

This information is crucial for land management authorities and policymakers in developing effective erosion mitigation strategies and preserving the environmental integrity of Cyprus. Coastal erosion usually results from a combination of natural and human-induced factors that operate on different scales. The most important natural factors are winds and storms, near-shore currents and relative sea level rise (a combination of vertical land movement and sea level rise [16].

While a single scene can provide valuable insights, its representativeness should be interpreted cautiously. It would be beneficial to analyze multiple scenes across different times and conditions to ensure a comprehensive and accurate representation of the Cyprus coastline or any other studied region.

As a result, future studies could explore the potential for implementing erosion control and coastal protection measures in areas prone to erosion. Coastal engineering solutions, habitat restoration projects, and the establishment of protected areas help mitigate erosion impacts and promote coastal resilience. We are planning more profound future research in monitoring erosion in other regions of Cyprus using Sentinel 1 data.

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