environmental sciences proceedings

MDPI

Proceedings Paper

Vulnerability of Small Rivers Coastal Part Due to Floods: The Case Study of Lesvos West—North Coast †

Stamatia Papasarafianou [1,*], Aliki Gkaifyllia [2], Anna-Eirini Iosifidi [3], Stavros Sahtouris [2], Natalie Wulf [4], Alexandra Culibrk [2], Maria-Danai Stamataki [2], Theodoros Chatzivasileiou [2], Ilias Siarkos [2], Celia Rouvenaz [5], Eleni-Ioanna Koutsovili [2], Thomas Hasiotis [2] and Ourania Tzoraki [2]

[1] Department of Science and Technology, University of Napoli Parthenope, 80143 Napoli, Italy
[2] Department of Marine Sciences, University of the Aegean, 80100 Mytilene, Greece; marm21006@marine.aegean.gr (A.G.); s.sahtouris@aegean.gr (S.S.); aculibrk@marine.aegean.gr (A.C.); mard18001@marine.aegean.gr (M.-D.S.); mard20014@marine.aegean.gr (T.C.); isiarkos@aegean.gr, (I.S.); ekoutsovili@aegean.gr (E.-I.K.); hasiotis@marine.aegean.gr (T.H.); rania.tzoraki@aegean.gr (O.T.)
[3] Department of Geography, University of the Aegean, 80100 Mytilene, Greece; geoha21008@geo.aegean.gr
[4] Christian-Albrechts-Universität zu Kiel, 24118 Kiel, Germania; nathalie_wulf@gmx.net
[5] ETH Zürich, 8092, Switzerland; crouvenaz@student.ethz.ch
* Correspondence: stamatia.papasarafianou001@studenti.parthenope.it; Tel.: +30-6981-718-533
† Presented at the 7th International Electronic Conference on Water Sciences, 15–30 March 2023; Available online: https://ecws-7.sciforum.net.

Abstract: This study presents the development of a vulnerability assessment methodology combining both hydraulic and oceanographic values to evaluate the fragility of the island's coast, subject to floods. The study area covers the coastal part Petra—Molyvos in West–North Lesvos Island, Greece. Petra stream drains the catchment area of 7.97 km^2. The flooded sections of the river's coastal part are analyzed by the HEC-RAS model, while the coastal vulnerability index (CVI) was calculated by the InVEST model. The scenario of habitats' role in beach protection showed 53% of coastal protection and the CVI moderate exposure to sandy beaches. A change in the geomorphology of the estuary was observed during the summer period, due to the river sediment dredging and small delta reclamation processes.

Keywords: HEC-RAS; Coastal Vulnerability model; erosion; Lesvos

Citation: Papasarafianou, S.; Gkaifyllia, A.; Iosifidi, A-E.; Sahtouris, S.; Wulf, N.; Culibrk, A.; Stamataki, M-D.; Chatzivasileiou, T.; Siarkos, I.; Rouvenaz, C.; et al. Vulnerability of Small Rivers Coastal Part Due to Floods: The Case Study of Lesvos West—North Coast. *Environ. Sci. Proc.* **2023**, *5*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Published: 15 March 2023

1. Introduction

Beaches are critical components of the coastal zone; coastal services are contributing around 43% of the total benefits provided by human well-being [1,2]. Beaches provide cultural and ecosystem services, such as food, flood protection, natural environmental conservation, and recreation activities [2,3]. With multiple increasing human activities, the bio-geological resources exploit and polluted, and exposed to stressful uses and pressures increasing the coastal vulnerability. As a result, coastal erosion. threaten the tourist zones and services.

On the balance of sentimental transport has been observed the significance of rivers' contribution to replenishment in coastal zones. Coastal erosion constitutes a contemporary environmental problem and the projections of coastal retreat under climate change and vulnerability highlight the threat to sustainable growth in the Aegean archipelagos [8,9]. The threat of coastal retreat increased as the rivers had been dammed sediments are arrested in the reservoirs an indirect impact on water storage due to the transport of sediments by the surface water flow. For example, flash floods can be perceived negatively due to (i) damage to farms, and infrastructures, (ii) bank erosion, (iii) and transport of sediment and coarse material [4,5]. As a large problem that puts the achievement of multiple sustainable development goals of the United Nations at risk, it should be managed through an integrated approach considering sustainable growth [3].

At the same time, the hydrological regimes of Intermittent Rivers and Ephemeral Streams are characterized by flow cessation and dry events at certain periods of the year [6], and ephemeral streams exhibit certain conditions in the hydro-geomorphological processes of runoff generation. Ephemeral streams are more frequent globally, and more than 50% of the river network is intermittent [6]. The Mediterranean strip is the most affected, with 20% in France, 90% in Sardinia and Sicily, and more than 70% of fluvial systems are ephemeral streams in the southeast of Spain [7]. The flowing phase enhances sediment transport the non-flowing and dry phases facilitate river access and sand and gravel extraction [5].

The objective of the current study is to evaluate the vulnerability of beaches that consist of the outflow of small rivers due to flash flood events. Vulnerability calculation was done using InVEST Coastal Vulnerability index, combining oceanographic and ecological parameters, while HEC-RAS was used to calculate the critical cross-sections in the Petra River.

2. Materials and Methods

2.1. Study Area

The study area covers the coastal part from Petra to Molyvos in West–North Lesvos Island, Greece (Figure 1). The area is characterized by a typical Mediterranean climate with warm and dry summers and cold and wet winters. The mean annual precipitation is 545 mm, and the mean temperature is 17.39 °C. During the winter the precipitation records showed January, February, and December as the wet months. The main wind directions are North–Northeastern with a maximum intensity of 4 to 5 bft, and 5 to 6 bft. Petra stream 1.75 km in length drains a catchment area of 7.97 km^2, a mean width of 6.15 m, a mean slope is 1.03%, a mean depth is 1.63 m, and flows into the Aegean Sea.

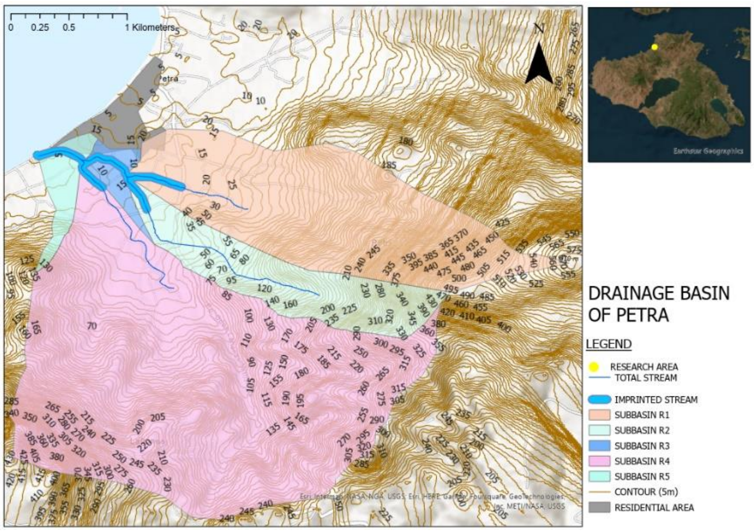


Figure 1. Petra catchment: the basin was divided into 5 subbasins for analyzing the mainstream of Petra River.

2.2. Coastal Vulnerability Models

The InVEST Coastal Vulnerability model is widely still used to assess coastal erosion, which can provide a framework for regional coastal zone protection and future development planning. To estimate erosion from coastal hazards to people throughout Petra—Molyvos coastline, we mapped and valued the changes in ecosystems, which can lead to converting in the flow of many different benefits [8]. The model builds on previous similar indices that account for bio-geophysical components to compare their exposure to erosion and flooding in severe weather [9]. The InVEST CV model produces a qualitative index of coastal exposure to erosion, as well as summaries of human population density in proximity to the coastline. The exposure of erosion in the study area is defined by calculating the coastal vulnerability index (CVI), which ranks sites from lowest exposure (rank = 1) to highest risk of erosion (rank = 5) and inundation by using some variables: habitat types, the local bathymetry and topography, and the relative wind and wave forcing associated with storms, and the population density (Equation (1)).

$$CVI = (R_{Habitats} R_{Shorline\ Type} R_{Relief} R_{Waves} R_{Surge})^{1/5} \quad (1)$$

2.3. HEC-RAS Model

The software Engineers River Analysis System (HEC-RAS) developed by the Hydrologic Engineering Center, allows users to model rivers flowing through open natural channels and is used for computing water surface profiles [10]. HEC-RAS system capabilities and abilities to simulate one-dimensional steady flow water surface profile computations and uses geometric and hydraulic computation routines. The river geometries such as centerlines, bank lines, flow paths, and cross-sectional lines are the major parameters processed in HEC-RAS to generate flood-prone areas [10].

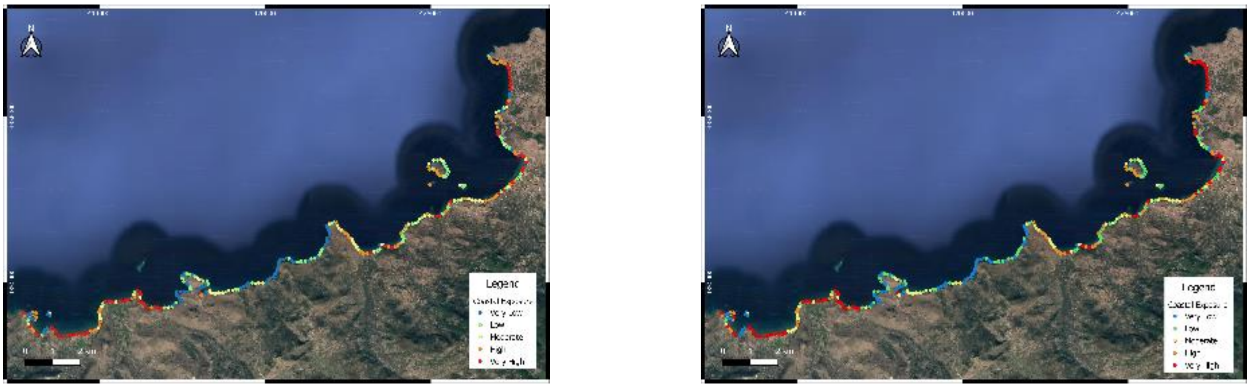
3. Results

The Aegean Archipelago climate, water masses movement, and geomorphology have been able to develop strong ecological and human resilience to degradation. However, both environmental and anthropogenic important changes are threatening the precarious balance between water resources and flood risk [7].

3.1. Coastal Vulnerability

Natural activities play a significant role in coastal vulnerability. The Aegean circulation ends with a northern flow in the eastern basin. The passage between Asia Minor, Chios, and Lesvos has more kinetic energy than the rest of the eastern basin (low kinetic energy) due to the 200 m isobath, which turns to the east. Also, the currents near Petra have low kinetic energy [11]. The complex physiography of the Aegean archipelago influences the wind and in addition to the wave climate. In general, the winds and waves are because of the short fetches and durations relatively mild [2]. It seems that mostly northern winds and waves form the Northern Aegean coastlines and thus the coastline of Petra—Molyvos. Despite the fact that waves are in general more energetic in the winter season, even in the summer waves are in the Aegean Sea and in Petra energetic, which are mainly forced by the strong, dry N-NE 'etesian' winds [12,13].

The results of InVEST Coastal Vulnerability model showed that the exposed areas of erosion are mainly sandy beaches. The two vulnerability scenarios—with habitats (Figure 2a) and without habitats (Figure 2b)—showed the importance of habitats' role in beach protection. 13% of the coastal zone showed a high risk of erosion (rank = 4 to 5) and 21% of the coastal zone had moderate risk (rank = 3), for the scenario without habitats. The vulnerability scenario with habitats gave a 53% of coastal protection, and the CV index gave moderate risk (rank = 2 to 3). Additionally, the results from the CV index showed low exposure (rank = 1 to 2) to rock beaches and high exposure (rank = 4 to 5) to sandy beaches (Figure 2).



(**a**) (**b**)

Figure 2. Map of Petra—Molyvos exposure to erosion (**a**) with Habitats variable, and (**b**) without Habitats variable.

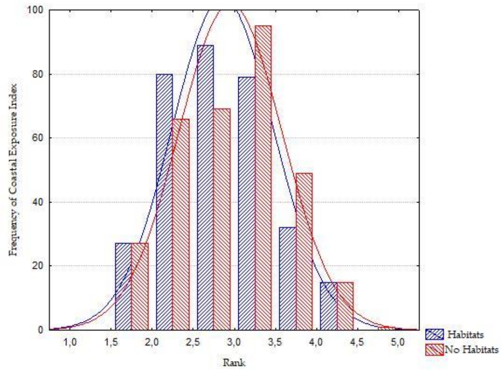


Figure 3. Histogram with a frequency of occurrence of observed values of the coastal vulnerability index.

3.2. Hydraulic Study

The Froude value at the location R5 (Table 1) of the cross-section S2 is 0.15 and is characterized as subcritical. This cross-section is located 17 m upstream (Figure 4a,b) from the mouth of the stream towards the sea. It presents the lowest velocity and energy line slope values in the branch (v = 0.57 m/s, slope = 0.0005 m/m), and the mean velocity of 1.33 m/s. The Froude value at the cross-section S18 location is 0.14 (Figure 4a,c) and is characterized as subcritical. The S18 has the smallest geometry in the branch. The values of velocity and slope of the energy line are also small (v = 0.48 m/s, slope = 0.0005 m/m)., and the branch average velocity is 1.10 m/s. The Froude value at the cross-section S26 location is 0.44 (Figure 4a,c) and is characterized as subcritical. The S26 geometry is the second smallest for the branch. The power line velocity and gradient values are low throughout the branch, with the following values on the cross-section (v = 0.87 m/s, slope = 0.0059 m/m), and the branch average velocity is 0.90 m/s. Upstream of the cross-section, there is a hydraulic jump, the flow changes from supercritical to subcritical. The Froude value at the cross-section S32 location is 0.27 (Figure 4a,e), and the velocity and slope of the energy line are significantly lower than all other cross-sections (v = 0.66 m/s, slope = 0.001856 m/m). The wetted surface is the largest present in branch R1, while the branch average velocity is equal to 1.42 m/s. Finally, the Froude value at the cross-section S37 location is 0.43 (Figure 4a,f) and is characterized as subcritical. The velocity and slope of the energy line are the third smallest (v = 0.99 m/s, slope = 0.006421 m/m). Also, the cross-section shows the second smallest geometry., and the branch average velocity is equal to 1.25 m/s. The simulation results show that under flashy rain events, several cross sections of the stream are overflooded.

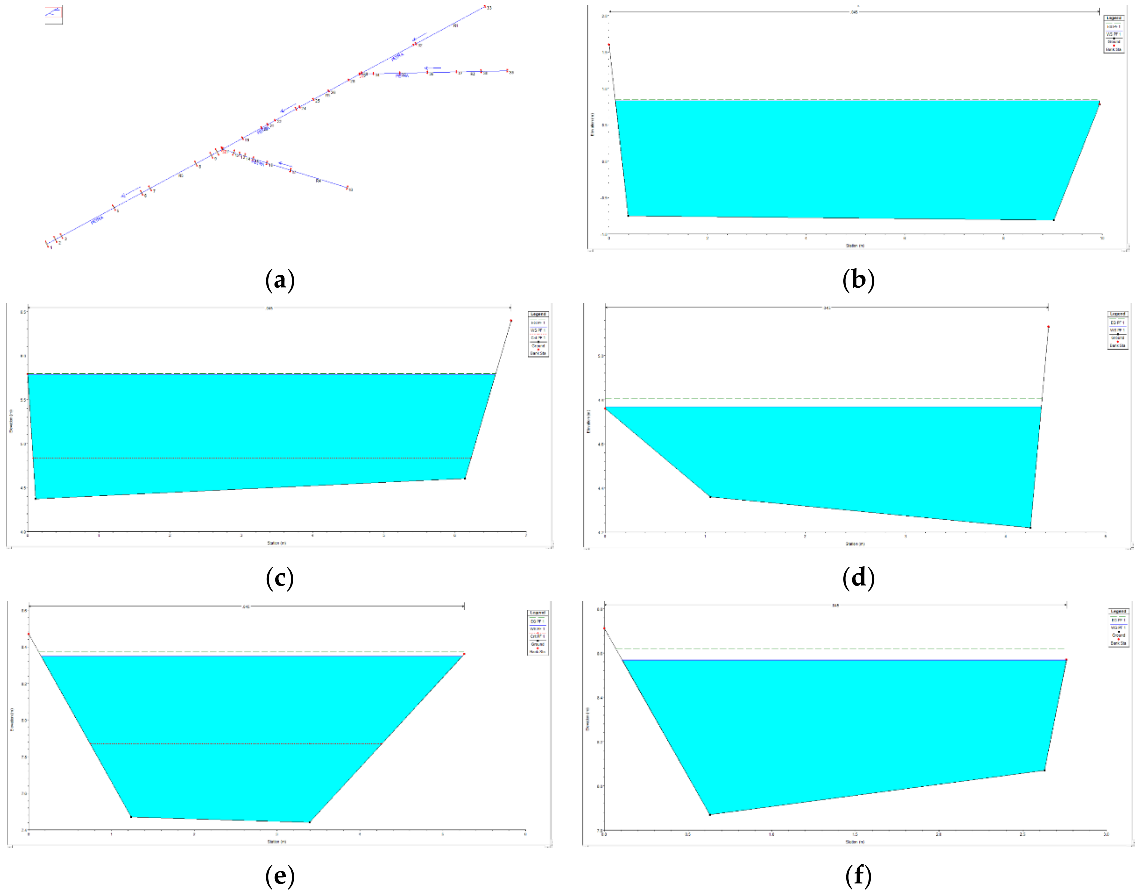


Figure 4. The critical cross section and the stream plot: (**a**) the Petra stream (**b**) S2, (**c**) S18, (**d**) S26, (**e**) S32, and (**f**) S37.

Table 1. Stream of Petra hydraulic characteristics.

Stream of Petra					
Reach	**Subbasin Area (km²)**	**Subbasin Δη (m)**	**Reach Length (m)**	**Q (m³/s)**	**Overflow Section**
R1	2.06	560	375	2.15	S32
R2	0.87	485	317	1.40	S37
R3	0.14	15	399	1.55	S26
R4	4.65	345	258	3.90	S18
R5	0.20	145	367	8.50	S2

4. Conclusions

This paper combines the main results with an analysis of floods after flushy rain episodes and the coastal erosion vulnerability of the sandy and rock beaches. The aim is to discuss how ephemeral streams could behave to water and sediment balance in a touristic beach, under human and natural pressures.

Multiple indicators are used to evaluate the vulnerability of each coastline. According to the results, the habitat is an important part of the coastal zone, and its influence on coastal exposure plays a significant role. All kinds of habitats, whether along the coastline or in the water, have protective effects on the coast [14]. Further, if the coastline is composed of many rocks, low in exposure and high in relief, it can reduce the erosion of waves on the coast. However, the coastline composed of sandy beaches, which are high in exposure and low in relief, has little effect on reducing the impact of wind and waves [14].

Moreover, the hydraulic analysis of the Petra River, during the rainy events showed low velocities in geometrically small cross-sections. More information was provided by the field surveys with anthropogenic activity in the river's hull negatively affecting sediment transport to the coastal zone. People should pay more attention to some impacts, such as storm surges, floods, coastal erosion, and other natural disasters that endanger the economy, life, property safety, and the ecological environment around the coastal zone when people focus on the development of the coastal zone [14].

Acknowledgments: The authors thank Hasiotis T., Tzoraki O., and Sahtouri S. for the operating costs of the present research which were partly funded by Partner, INTERREG Greece-Cyprus, Coastal erosion due to climate change: assessment and ways of effective treatment in tourist areas of the North Aegean and Cyprus. Koutsovili E.I., Stamataki M.D., Culibrk A., and Chatzivasileiou T. for funded by the Operational Program National Strategic Reference Framework (NSRF) North Aegean 2014-2020, AEGIS+. Papasarafianou S. is funded by the Ph.D. program Phenomena and Environmental Risk by the University of Naples, Parthenope, and Wulf N. research is part of the ERASMUS Plus.

References

1. Levrel, H.; Cabral, P.; Marcone, O.; Mongruel, R. The services provided by marine ecosystems. In *Value and Economy of Marine Resources*; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2014; pp. 1–51.
2. Monioudi, I.N.; Velegrakis, A.F.; Chatzipavlis, A.E.; Rigos, A.; Karambas, T.; Vousdoukas, M.I.; Hasiotis, T.; Koukourouvli, N.; Peduzzi, P.; Manoutsoglou, E.; et al. Assessment of island beach erosion due to sea level rise: The case of the Aegean archipelago (Eastern Mediterranean). *Nat. Hazards Earth Syst. Sci*. **2017**, *17*, 449–466. https://doi.org/10.5194/nhess-17-449-2017.
3. Caroa, C.; Marquesa, J.C.; Cunhac, P.; Teixeiraa, Z. Ecosystem services as a resilience descriptor in habitat risk assessment using the InVEST model. *Ecol. Indic.* **2020**, *115*, 106426. https://doi.org/10.1016/j.ecolind.2020.106426.
4. Pastor, A.V.; Tzoraki, O.; Bruno, D.; Kaletova, T.; Mendoza-Lera, C.; Alamanosi, A.; Brummer, M.; Datry, T.; De Girolamo, A.M.; Jakubínský, J.; et al. Rethinking ecosystem service indicators for their application to intermittent rivers. *Ecol. Indic.* **2022**, *137*, 108693. https://doi.org/10.1016/j.ecolind.2022.108693.
5. Stubbington, R.; Acreman, M.; Acuna, V.; Boon, P.J.; Boulton, A.J.; England, J.; Gilvear, D.; Sykes, T.; Wood, P.J. Ecosystem services of temporary streams differ between wet and dry phases in regions with contrasting climates and economies. *People Nat*. **2020**, *2*, 660–677.
6. Skoulikidis, N.T.; Sabater, S.; Datry, T.; Morais, M.M.; Buffagni, A.; Dörflinger, G.; Zoogaris, S.; Sánchez Montoya, M.M.; Bonada, N.; Kalogianni, E.; et al. Non-perennial Mediterranean rivers in Europe: Status, pressures, and challenges for research and management. *Sci. Total Environ.* **2017**, *577*, 1–18. https://doi.org/10.1016/j.scitotenv.2016.10.147.
7. Camarasa-Belmonte, A.M. Flash-Flooding of ephemeral streams in the context of climate change. *Geogr. Res. Lett.* **2021**, *47*, 121–142. https://doi.org/10.18172/cig.4838.
8. Sharp, R.; Tallis, H.T.; Ricketts, T.; Guerry, A.D.; Wood, S.A.; Chaplin-Kramer, R.; Authors, C.; Nelson, E.; Ennaanay, D.; Wolny, S. *VEST + VERSION + User's Guide*; Stanford University: Stanford, CA, USA, 2018.
9. Hammar-Klose, E.S.; Thieler, E.R. *Coastal Vulnerability to Sea-Level Rise: A Preliminary Database for the U.S. Atlantic, Pacific, and Gulf of Mexico Coasts*; U.S. Geological Survey: Reston, VA, USA, 2001.
10. Tamiru, H.; Dinka, M.O. Application of ANN and HEC-RAS model for flood inundation mapping in lower Baro Akobo River Basin, Ethiopia. *J. Hydrol. Reg. Stud.* **2021**, *36*, 100855. https://doi.org/10.1016/j.ejrh.2021.100855.
11. Olson, D.B.; Kourafalou, V.H.; Johns, W.E.; Samuels, G.; Veneziani, M. Aegean Surface Circulation from a Satellite-Tracked Drifter Array. *J. Phys. Oceanogr.* **2007**, *37*, 1898–1917.
12. Androulidakis, Y.; Kombiadou, K.; Makris, C.; Baltikas, V.; Krestenitis, Y.N. Storm surges in the Mediterranean Sea: Variability and trends under future climatic conditions. *Dyn. Atmos. Ocean.* **2015**, *71*, 56–82.
13. Soukissian, T.; Hatzinaki, M.; Korres, G.; Papadopoulos, A.; Kallos, G.; Anadranistakis, E. *Wind and Wave Atlas of the Hellenic Seas*; Hellenic Centre for Marine Research Publications: Athens, Greece, 2007.
14. Ai, B.; Tian, Y.; Wang, P.; Gan, Y.; Luo, F.; Shi, Q. Vulnerability Analysis of Coastal Zone Based on InVEST Model in Jiaozhou Bay, China. *Sustainability* **2022**, *14*, 6913. https://doi.org/10.3390/su14116913.