

ASSESSMENT OF SUSCEPTIBILITY TO SEA-LEVEL RISE IN THE COASTAL AREA OF PIERIA PREFECTURE

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Abstract

Tourism development in Greece has led to increasing pressure on coastal areas, which makes the study of sensitive coastal areas essential, in order to find appropriate solutions for their shielding. The aim of this study is an estimation of the effects of an anticipated sea level rise for the touristically developed part of Pieria Prefecture, which includes the settlements Paralía, Skála of Katerini, Olympic Beach, Korinos Beach and extends north to the area of the Kitrous saltworks and south to the mouth of Mavroneri river. Therefore the Coastal Vulnerability Index (CVI) is applied, in an attempt to determine the susceptible parts to the potential sea level rise. CVI depends on the following parameters: (a) coastal geomorphology, (b) coastal slope, (c) shoreline erosion/accretion rate, (d) relative sea-level rise fluctuations, (e) mean tidal range and (f) mean significant wave height. The classification of the coast, which is of particular socio-economic significance since it hosts urbanized areas, into five CVI classes (from very low vulnerability to very high vulnerability), showed that 43.6% of the entire coastline is of very high vulnerability.

Keywords: erosion, climate change, sea level rise, Coastal Vulnerability Index.

Περίληψη

*Η ελληνική ανάπτυξη έχει οδηγήσει σε αυξανόμενες οικιστικές πιέσεις στον παράκτιο χώρο, γεγονός που καθιστά αναγκαία τη μελέτη των ευαίσθητων παράκτιων περιοχών, προκειμένου να βρεθούν οι κατάλληλες λύσεις για τη θωράκισή τους. Στόχος της συγκεκριμένης εργασίας είναι η προσπάθεια εκτίμησης των επιπτώσεων από μια ενδεχόμενη άνοδο της θαλάσσιας στάθμης για το τουριστικά αξιοποιημένο τμήμα του Νομού Πιερίας, που περιλαμβάνει τους οικισμούς Παραλία Κατερίνης, Σκάλα Κατερίνης, Ολυμπιακή Ακτή και Παραλία Κορινού και εκτείνεται βόρεια ως την περιοχή των αλυκών του Κίτρονς και νότια ως τις εκβολές του χειμάρρου Μαυρονερίου. Εφαρμόστηκε, επομένως ο Δείκτης Παράκτιας Επικινδυνότητας – Coastal Vulnerability Index (CVI), με σκοπό τον εντοπισμό των επιρρεπών στην αναμενόμενη άνοδο της θαλάσσιας στάθμης περιοχών. Ο ΔΠΕ αποτελεί μαθηματικό τύπο που συνεκτιμά τις παραμέτρους που σχετίζονται με: (α) τα παράκτια γεωμορφολογικά χαρακτηριστικά, (β) την παράκτια κλίση, (γ) την οπισθοχώρηση/προέλαση ακτογραμμής, (δ) τη σχετική άνοδο της θαλάσσιας στάθμης, (ε) το μέσο παλιρροιακό εύρος, (φ) το μέσο σημαντικό ύψος κύματος. Για κάθε μια παράμετρο η ακτή βαθμονομήθηκε σε πέντε κατηγορίες επικινδυνότητας από πολύ χαμηλή (κατηγορία 1) έως πολύ υψηλή (κατηγορία 5). Η συνεκτίμηση των παραμέτρων οδήγησε στη διαπίστωση ότι 43.6% του συνόλου της ακτογραμμής, η οποία φιλοξενεί κυρίως αστικές χρήσεις (ακτές οικισμών) και βοσκότοπους, χαρακτηρίζεται ως πολύ υψηλής τρατότητας. **Λέξεις κλειδιά:** διάβρωση, κλιματική αλλαγή, άνοδος της θαλάσσιας στάθμης, Δείκτης Παράκτιας Επικινδυνότητας.*

1. Introduction

Coastal areas have always been attractive settling grounds for human population. They constitute the transitional zone from terrestrial to marine area, a particular area with unique natural and socio-economic characteristics which encourages the concentration of people and activities and the development of significant civilizations. At present, coastal zones continue to be areas of many possibilities, of paramount importance on local, regional, national and international scale. However, the socio-economic activity characterizing coastal areas in recent years has been growing rapidly and in an uncontrolled manner, putting severe pressure on natural resources. At the same time, the changing climatic and socioeconomic conditions, increasingly threatens the productive and ecological balance of coastal zones.

One of the major problems concerning the coastal area and its habitation is determining the physical response of the shoreline to a potential sea level rise. The prediction of land loss and retreat of the coastline is vital to future coastal management strategies and to the evaluation of future impact of any variation of the coastline. For this reason, it is of vital importance to identify areas, and mainly coastal settlements, that are vulnerable to a potential sea level rise, by applying various indicators that give such results.

One of the commonly used methodologies of first assessment of flooding or erosion hazards in coastal areas is the calculation of the Coastal Vulnerability Index (CVI). CVI was initially applied to US shores (Gornitz, 1991) and Canada (Shaw *et al.*, 1998), and has recently been applied in coastal areas of Greece (Alexandrakis *et al.*, 2010; Gaki-Papanastassiou, 2010; Chatzieleftheriou *et al.*, 2007; Karymbalis *et al.*, 2012; Karymbalis *et al.*, 2014). CVI provides a first order approximation of the temporal variability that may be expected in landform components of the shoreline system, thus allowing management to provide more realistic objectives for long-term sustainability in response to both natural and artificial forces. In the present study CVI was estimated for the touristically developed part of Pieria Prefecture, an area of particular socio-economic importance, since it hosts numerous coastal settlements with touristic beaches.

2. Materials and Methods

Katerini is a fairly dynamic city located in the geographic centre of Pieria Prefecture. Part of the municipality of Katerini is the settlement of Paralia, the driving force of the economy of the entire Prefecture. The village of Paralia constitutes an attraction for tourists because of its characteristic sandy beach. The settlement was founded in 1923 and today has become the main tourist resort of Pieria Prefecture and one of the top resorts in northern Greece. However Paralia is one of the most characteristic areas in Greece suffering from coastal erosion.

By utilizing aerial photos of the National Cadastre and Mapping Agency S.A. for the years 1978, 1985, 2000 and recent Google Earth images for the year 2015, the coastline was digitalized in GIS environment, in an effort to record the pressures and problems that the region is facing, due to various implemented structures.

Subsequently, the Coastal Vulnerability Index (CVI) proposed by Thieler and Hammar - Klose (1999) was applied on the basis of field data, existing topographic and geo-environmental information, and utilizing GIS technology. This approach constitutes a relatively simple and objective way to quantify vulnerability of Pieria Prefecture's coastline. CVI is calculated as the square root of the product of six variables, ranked from 1 to 5 according to Table 1, and divided by their total number (equation 1):

Equation 1 - Formula for CVI calculation

$$CVI = \sqrt{\frac{a \cdot b \cdot c \cdot d \cdot e \cdot f}{6}}$$

Where: (a): geomorphology, (b): coastal slope, (c): rate of relative sea-level rise, (d): rate of shoreline erosion / accretion, (e): mean tide range, and (f): mean significant wave height

The coast's classification limits in five categories were proposed by Pendleton *et al.* (2004) (Table 1). For the parameters (c), (e) and (f) the limits proposed for Greek coasts by Karymbalis *et al.* (2012) were used (Table 1). The non-numeric variable of geomorphology was classified taking into account qualitative criteria associated with the resistance of each coastal landform to erosion.

Table 1 - Ranges for vulnerability ranking of the six variables used in equation 1 (Pendleton *et al.*, 2004; Karymbalis *et al.*, 2012).

Vulnerability Categories					
Variables	Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (5)
(a)	Coast occupied by limestones and dolomites.	Coast occupied by ultramafic rocks	Coast occupied by cohesive conglomerates	Coast occupied by phyllitic series	Coastal alluvial plains and seashores loose materials
(b) (%)	>12	12-9	9-6	6-3	<3
(c) (m/y)	>(1,5)	(1,5)-(0,5)	(0,5)- (-0,5)	(-0,5)- (-1,5)	<(-1,5)
(d) (mm/y)	<1,8	1,8-2,5	2,5-3,0	3,0-3,4	>3,4
(e) (m)	<0,2	0,2-0,4	0,4-0,6	0,6-0,8	>0,8
(f) (m)	<0,3	0,3-0,6	0,6-0,9	0,9-1,2	>1,2

Data concerning the geomorphology variable were derived from geological maps of the Institute of Geology and Mineral Exploration of Greece (IGME) at the scale of 1:50.000, while coastal landforms were recorded using recent Google Earth images. The geological formations along the shoreline were identified and mapped utilizing GIS environment (ArcGis 10.1 software).

The regional slope of the coastal zone was calculated using the Digital Elevation Model (DEM) of the area, obtained from the National Cadastre and Mapping Agency S.A.

Shoreline erosion or accretion rates were derived using a topographic diagram of scale 1: 5,000 and an orthophotomap of the region, obtained from the Hellenic Military Geographical Service and from Google Earth, respectively. After digitizing the shorelines of the two different periods, they were superimposed in order to detect shoreline changes during the period 1979-2015.

Although relative sea-level change is the combination of both global eustatic sea-level rise as well as local isostatic and/or tectonic land movements, for this study this variable only includes the eustatism component, since the area is not affected by active Neotectonic faults (Caputo *et al.*, 2010). Bibliographic data regarding the pace of the recent eustatic sea level rise in the Aegean region (Vouvalidis *et al.*, 2005), were taken into account for the assessment of this parameter.

Tidal range was deduced from available data for the region of Northern Aegean (Hellenic Navy Hydrographic Service, 2005).

Finally, mean significant wave height is used as an indicator of the incoming wave energy. The mean annual values of significant wave height have been abstracted from the Wave and Wind Atlas

of the Hellenic Seas (Soukisian *et al.*, 2007), which is based on offshore measurements for the period 1999-2007 (POSEIDON program).

3. Results

After digitizing the coastline, using aerial photographs of the National Cadastre and Mapping Agency S.A. for the years 1978, 1985, 2000 and recent Google Earth images for the year 2015, its shifting was reflected (Figure 1). This change was mainly brought about by various structures implemented in the region without adequate planning.

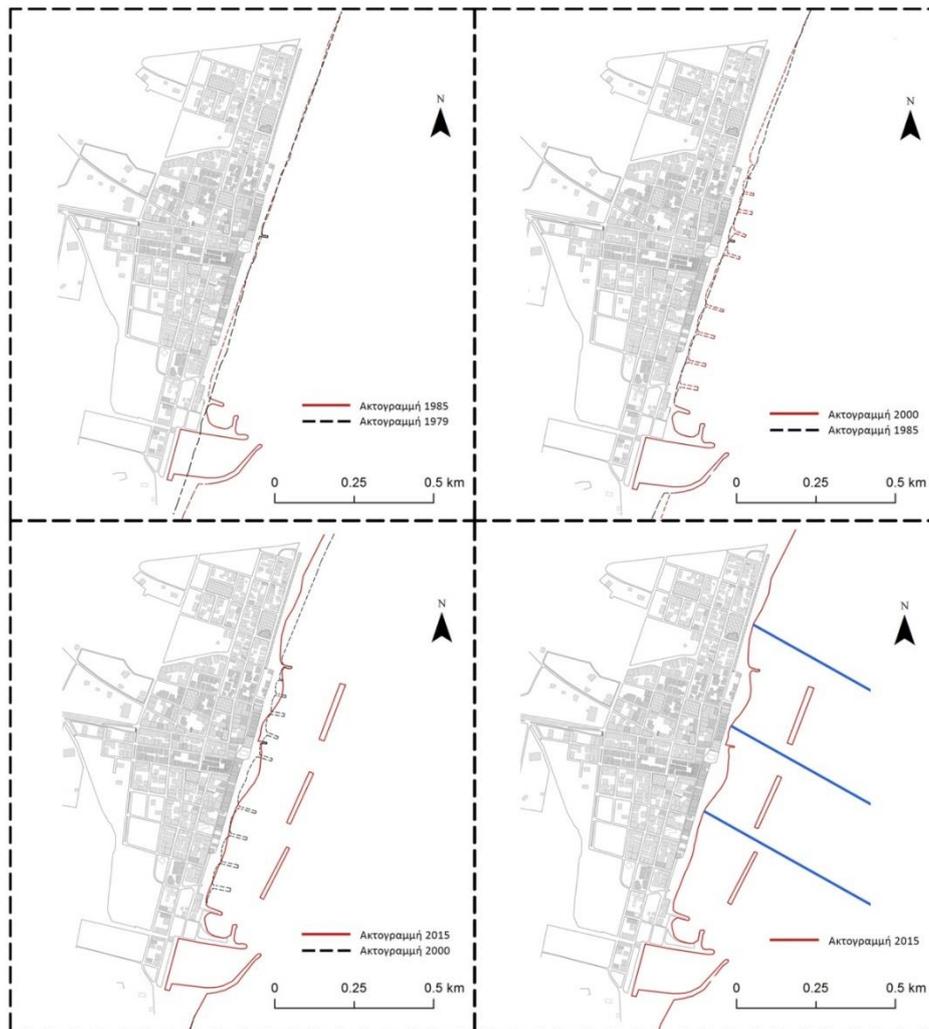


Figure 1 - Maps of comparison of coastline for the years 1979, 1985, 2000, 2015.

3.1 Coastal Vulnerability Index | Variables

The variables for each coastal segment were ranked from 1 (very low vulnerability) to 5 (very high vulnerability), according to the values provided by Pendleton *et al.* (2004) and Karymbalis *et al.* (2012) and are presented in Table 1. Subsequently the CVI value for each coastal segment was calculated using equation 1. In order to have a preliminary assessment of the impacts of the anticipated sea-level rise on the socio-economic activities along the investigated shoreline, land

cover along the coastal zone below the 20 m elevation was defined. This was achieved by utilizing the relevant map of the Ministry of Agriculture and was checked in detail during the field mapping. Land cover was compared with the higher vulnerable areas of higher CVI values.

As a non-numerical variable, geomorphology expresses the relative response of different types of coastal landforms to sea level rise. It is ranked qualitatively according to the relative resistance of the coastal landforms and rocks to marine erosion. The main coastal landforms (25, 02 km) at the study area are sandy beaches along the aprons of alluvial and coastal plains. Therefore regarding this specific parameter the area has very high vulnerability in its majority (Figure 2).

The total region (32 km) has coastal slopes lower than 3 %, and therefore is characterized as of very high vulnerability (Figure 2).

Regarding coastline change rates, 10.39 km of the coastline have an average variation rate (+0, 5) - (-0, 5) m / y, and thereby are classified as of moderate vulnerability (Figure 2). The coastal zone of Paralia in Katerini, is a sandy beach that stretches along the north-south direction approximately. The area has been suffering from coastal erosion issues for more than 30 years. The problems began after the construction of a fishing port and until today, two coastal protection projects were implemented in an effort to control the retreat trends of the coastal front. Due to the rapid tourist development that took place in the study area, a small harbor for fishermen was built during the period 1980-1984. This construction however, destabilized the existing hydrodynamic characteristics of the area, as constructions disturbed the balance of the natural flow and catering of the coast with material from torrent Mavroneri, which lies south of the harbor (Kombiadou *et al.*, 2012). Specifically sand accumulation was observed in the area south of the harbor, while northern strong erosion and gradual retreat of the coastline was caused. In an attempt to reverse the erosive phenomena, a groin field was constructed during the period 1990-1997, consisting of 13 emerged, rubble mount groins. Nonetheless the result of this coastal defense project was to transfer coastal recession northwards and, in some cases even intensify it locally (Kombiadou *et al.*, 2012). The groin field, which was created in the period 1990-1997 in order to solve the phenomenon of erosion, was replaced by a set of three submerged breakwaters, each of approximately 200m length, that were placed at a distance of around 200m from the coast. The gaps between the breakwaters were approximately 110m. However, the erosion problem was not solved, since the response of the breakwater-system to the shore was the progradation of the shoreline on the leeward side of the projects, combined with the retreat of the coastline in the gaps between the breakwaters (Figure 1).

Relative sea-level change is considered to have the same value along the entire coastline. Due to the fact that the area is not affected by active Neotectonic faults (Caputo *et al.*, 2010), bibliographic data regarding the pace of the recent eustatic sea level rise in the Aegean region (Vouvalidis *et al.*, 2005), were taken into account for the assessment of this parameter. According to the eustatic curves of the above, the relative change in sea level in the Aegean region in the last 2000 years shows a steady average increase rate equal to approximately 1mm / yr and so was evaluated as a factor of very low vulnerability for the entire study area (Figure 2).

From measurements of the average fluctuation of sea level from the Hydrographic Service of the Navy (Hellenic Navy Hydrographic Service, 2005), it appears that in the northern Aegean relative variation is 0,9m (Alexandrakis *et al.*, 2010). Therefore, the variable is evaluated as of very high vulnerability factor across the entire coastline (Figure 2).

Wave heights are proportional to the square root of wave energy, which is a measure of the capacity for erosion. The wave climate is dominated by offshore significant wave heights of 0.2 m (Soukisian *et al.*, 2007), according to the output of the wave model (POSEIDON program), which has been calibrated with the use of offshore field measurements from the Aegean Sea for a nine years period (1999-2007). Thus the entire coastline was ranked as of very low vulnerability (Figure 2).

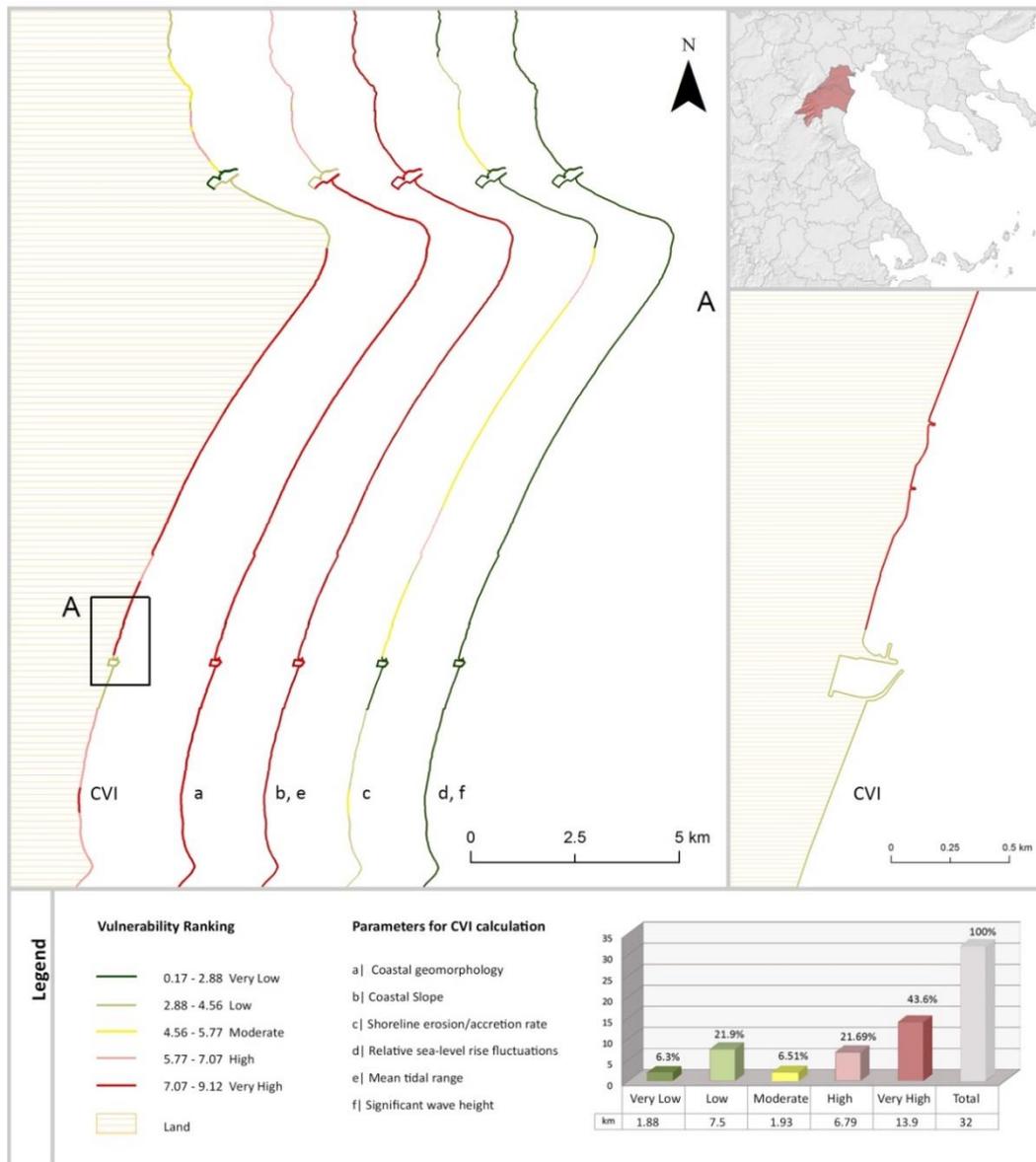


Figure 2 - Coastal Vulnerability Index (CVI) map of Pieria Prefecture's coastline. The coastline is divided into five ranges of vulnerability (from very low to very high).

The calculated CVI values along the coastline of Pieria Prefecture range between 0.17 and 9.12. These values were then categorized into five risk classes from 1- Very Low to 5-Very High. The classification method was natural breaks with five classes. A large central part of the coastline of the study area, with a length of 13.9 km (43.6%), is classified as having very high vulnerability due to: low regional slope, sensitivity of the coastal landforms, and the highly erodible lithology. Respectively 21.69%, a total length of 6.79 km, is classified as having high vulnerability. This area is mainly located in the southern part of the study area. A rate of 6.51%, corresponding to a length of 1.93 km is designated as moderate vulnerability. These coastline segments are located north of the study area. Sections of the coastline in the northern part of the study area (Alyki Kitros) and south of the fishing port in the settlement of Paralia were classified as of low vulnerability. The percentage of low vulnerability coastline amounts

to 21.9% (7.5km). Finally 6.3% corresponding to 1.88 km was characterized as of very low vulnerability and is located at the northern part of the study area (Figure 2).

In terms of the socio-economical implications related to the anticipated sea-level rise, most of the coastal urban areas (cities and settlements as well as tourism activities and facilities) of the coastline are concentrated in the above mentioned highly and very highly vulnerable coastal segments. Thus, a length of 8.1 km along the coastline (25.39 % of the highly and very highly vulnerable coast) is characterized by the presence of human activities (Figure 3). The settlement of Paralia belongs to the high vulnerability zone, which has already been expressed by the continuous erosive phenomena encountered in the region. Additionally, a significant length of the high and very high vulnerable coastal zone is associated with grazing land of economic significance. Therefore 7.58 km, corresponding to 23.68 % of the total very high vulnerable coastline, hosts grazing land (Figure 3).

4. Discussion - Conclusion

Without effective treatment and the adoption of specific planning policies, fragmentary reference to the phenomenon of climate change on various spatial plans can not lead to a viable and sustainable future. The integration of climate change as a key parameter in designing is therefore necessary, and must be reported at all levels of planning. Sea level rise is considered to be one of the most serious effects of climate change, which many coastal areas have to face.

The aim of this study is an estimation of the effects of an anticipated sea level rise for the touristically developed part of Pieria Prefecture, which includes the settlements Paralia, Skala of Katerini, Olympic Beach, Korinos Beach and extends north to the area of the Kitrous saltworks and south to the mouth of Mavroneri river. Therefore the Coastal Vulnerability Index (CVI) is applied, in an attempt to determine the susceptible parts to the potential sea level rise. The calculated CVI values along the coastline of Pieria Prefecture range between 0.17 and 9.12. The classification of the coast showed that 43.6% of the entire coastline is of very high vulnerability. The study area, especially the settlement of Paralia in Katerini is the driving force for the economy of Pieria Prefecture. As a result of mass tourism, the unorthodox and rapid development of the settlement during the past years has led to major environmental problems, such as the intense erosion of the coast, leading the settlement to decline.

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In similar studies held in Greece using the same ranges to categorized the parameters of the index, as in the case of the southern coast of the Gulf of Corinth, CVI values were estimated between 0.6 and 9.1 (Karymbalis *et al.*, 2012). Similarly in another study for the island of Salamina CVI ranges were estimated between 0.6 and 5.0 (Karymbalis *et al.*, 2014). In addition to Elafonisos CVI values were estimated between 1.2 to 7.1 (Karymbalis *et al.*, 2014). This indicates that part of Pieria Prefecture's shoreline (study area) is of high vulnerability to an expected sea level rise. Such identification will be useful for coastal management and could find immediate application in many strategies regarding coastal development in both short and long term time scales.

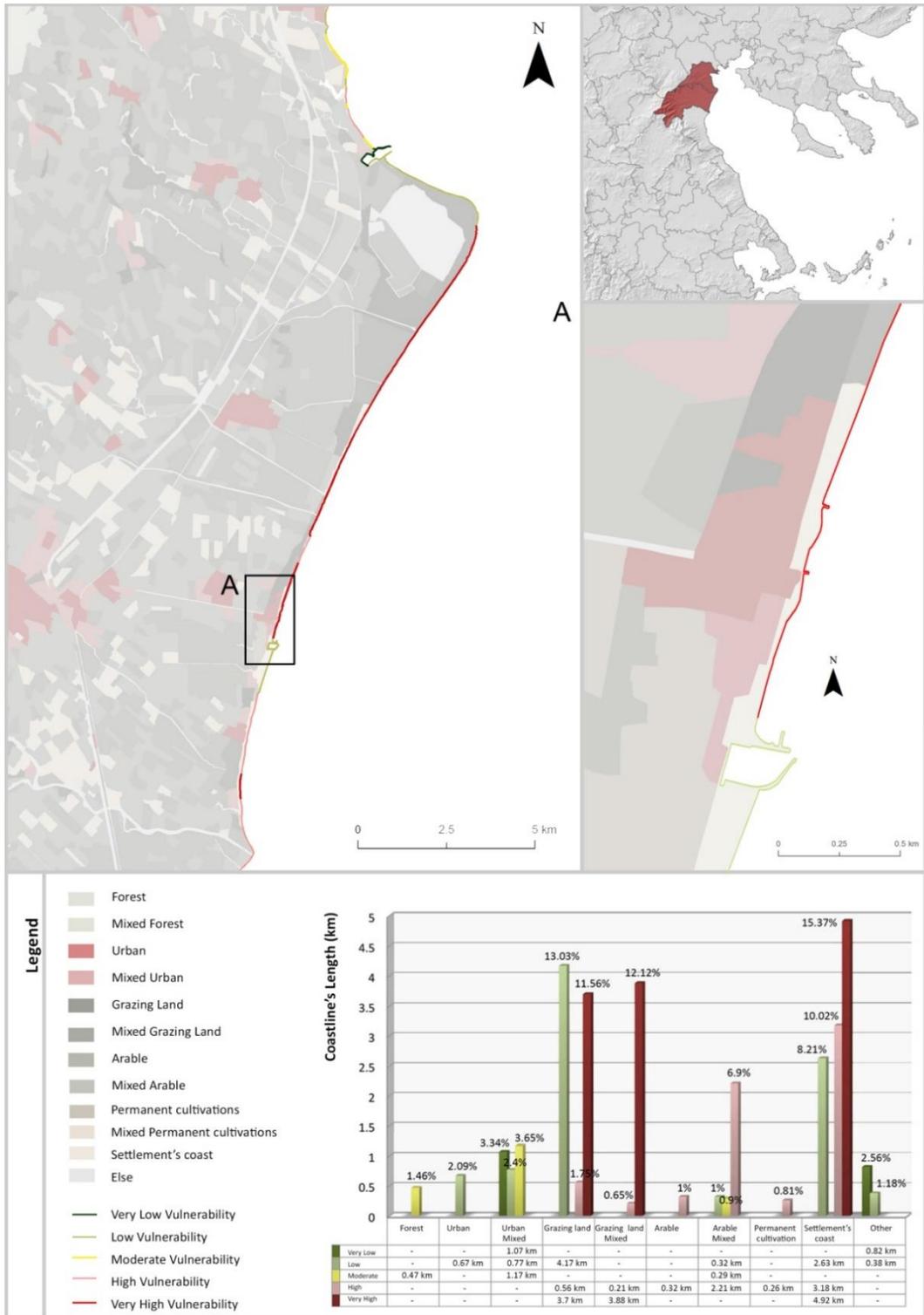


Figure 3 - Coastal Vulnerability Index (CVI) map of Pieria Prefecture's coastline and land cover of the area.

5. Acknowledgments

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