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Coastal Vulnerability and Risk Parameters

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Abstract: The natural environment is unequivocally the life support for all human systems. Far for being a luxury available only to those who can afford it, successful environmental management will increasingly become the basis for the success or failure of the economics and social systems of entire countries. In the last two decades, concern has been expressed about possible effects of climate change in coastal areas. By the year 2100 the rate of global sea level rise may increase to over 10mm/year (pessimistic scenario), which would represent a sevenfold increase over present rates. The Coastal Vulnerability Index (CVI) is used to map the relative vulnerability of the western Pelleponese in Greece for a coastal length of about 50 Km. Along this coastline, ecological sensitive areas, Ramsar forests, drained coastal lakes, very important lagoons, riparian forests, magnificent beaches etc., form a coastal area which has to be carefully monitored and protected due to the accelerating sea level rise. Geomorphology, regional coastal slope, rate of relative sea level rise, shoreline erosion and accretion rates, mean tidal range and mean significant wave height are the physical contributors to the CVI calculation which highlights the regions where the effects of sea level rise might be the greatest. Each CVI is computed along a thousand of cross sections on 1/5000 digitized maps along the studied shoreline and all available and proposed formulas to calculate the CVI are used for comparison reasons. Using percentiles specially designed for Greece, the coastline is grouped to low, moderate, high and very high vulnerability from the effects of the rising sea level. In particular coastal areas where the CVI reaches very high numbers, digitized maps of 1/500 scale are used to cross-examine, validate and justify the high vulnerability of the coastal area. In an age of rising sea level, the CVI has become a necessary and important tool for locating the vulnerable areas with high degree of confidence.

Key words: climate change, risk parameters, coastal vulnerability.

1. INTRODUCTION

The last several years have witnessed a significant evolution in what society wants to know about global environmental risks such as climate change, ozone depletion and biodiversity loss. Most scientific analyses and assessment of such risks focused on the anatomy of conceivable environmental changes themselves, while devoting relatively little attention to the ecosystems and societies the changes might endanger. Recently, however, questions about the vulnerability of social and natural systems are emerging as a central focus of policy-driven assessments of global environmental risks in arenas as different as the Intergovernmental Panel on Climate Change (IPCC), the World Economic Forum and the World Food Programme.

It has been estimated that around 60% of the world's population live near the coast and not surprisingly it is here that many problems are being experienced due to unrestricted development and unsustainable use of coastal resources. In addition to these problems, concern has recently been expressed about possible effects of climate change in coastal areas. Potential impacts such as sea level rise, changes in the frequency, intensity and patterns of storm events and associated storm surges and flooding could make the already degraded coastal areas more vulnerable to erosion.

It is important for a country like Greece to understand the biophysical and socio-economic effects of climate change and assess the costs and benefits of alternative responses in order to improve coastal zone planning and management.

The aim of carrying out a vulnerability assessment study is to help achieve the sustainable use of coastal resources by identifying coastal vulnerability and incorporating coastal values and hazards into planning and decision making for integrated coastal zone management. One of the most important applied problems in coastal geology today is to determine the physical response of the coastline to sea level rise. Predicting shoreline retreat, beach loss, cliff retreat and land loss rates are critical for planning coastal zone management strategies and assessing biological impacts due to habitat change or destruction. The prediction of coastal evolution is not straightforward because there is not a standard methodology and the kinds of data required to make such a prediction are not rigid and clear. A number of predictive approaches have been used including historical erosion rates, static inundation, sea level rise induced erosion, application of sediment dynamics, etc. One of the most common worldwide methods of assessing coastal vulnerability is the Coastal Vulnerability Index (CVI) (Gornitz et al., 1997). This approach combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions and yields a relative measure of the system's natural vulnerability to the effect of sea level rise (Jeftic et al., 1996). The vulnerability classification is based upon the relative contributions and interactions of six risk variables:

- Coastal Slope (CS): it is linked to the susceptibility of a coast to inundation by flooding and to the rapidity of shoreline retreat.
- Subsidence (S): it is deduced from a network of tide gauge stations. The relative sea level change at each locality is a composite of the eustatic component and other vertical land motions. Subsiding coastal areas in excess of the eustatic rate of sea level rise (SLR) face greater inundation hazards.
- Displacement (D): it is a measure of the past tendency of a shoreline to retreat or advance due to the SLR. Shores with accretion have low risk and those with erosion have correspondingly higher risk.
- Geomorphology (G): it is associated with the erosivity risk of a coastal area. Beaches having silt size geology have much more erosivity risk than beaches made of boulders.
- Wave Height (WH): waves and longshore currents actively transform the shoreline via shoreline transport. This variable is an indicator of the amount of beach materials that may be moved offshore and thus be permanently removed from the coastal sediment system. The risk variable assigned for wave height is based on the maximum significant wave height for each coastal area.
- Tidal Range (TR): it is linked to both permanent and episodic inundation hazards. A large tidal range determines the spatial extent of the coast that is acted upon by waves. Areas with large tidal waves have wide, near zero relief intertidal zones and are susceptible to permanent inundation following sea level rise. Besides, they are susceptible to episodic flooding associated with storm surges, particularly if these coincide with high tide.

The aforementioned risk variables are ranked on a linear scale from 1 to 5 in order of increasing vulnerability due to sea level rise (Klein and Nicholls, 1999). A value of 1 represents the lowest risk and a value of 5 represents the highest risk. These six risk variables are used to formulate the CVI which can be used to spot coastal areas that are at risk to erosion and permanent inundation. In our analysis the square root of the product mean of the six variables is used to calculate the CVI of the coastal region studied (Gornitz et al., 1997):

$$CVI = \sqrt{} [CS\ 3S\ 3D\ 3G\ 3WH\ 3TR]/\ 6 \quad (1)$$

Using quartiles (0-25%, 25-50%, 50-75% and 75-100%), and characterizations from low vulnerability – moderate - high - to very high vulnerability, each computed value falls into the relevant quartile and the coastal region is then characterized accordingly.

THE COASTAL VULNERABILITY OF THE WESTERN PELOPONNESE

The case study presented herein was undertaken along the western Peloponnese in south Greece. The coastal regions considered are depicted in Fig.1.

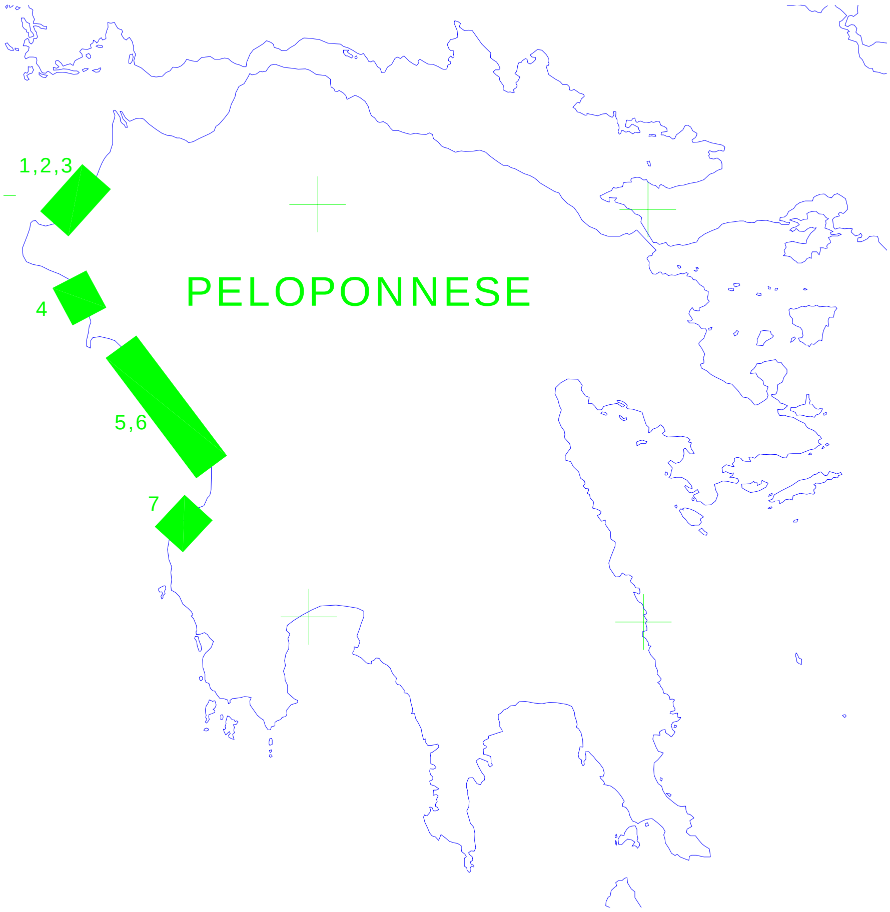

Fig.1. The coastal areas studied in the western Peloponnese

The specific region was chosen due to its unique morphological, ecological and environmental characteristics, and namely:

Sub-regions 1, 2 and 3:

- Kalogria beach: sandy substrate and beach hosting Caretta-caretta, dune system, Kotychi lagoon, beds of Posidonia oceanica.
- Kalogria lagoon and Strofilia forest: 22 Km of coastal zone with two lagoons, marshes and forest. Most of the area lies on sand-dune formations covering an area of 1200 Ha. The soil of the seashore consists of unconnected single-grained, fine sized sand. The site presents a large variety of lagoons, forests, sandy beaches, dunes, salt and freshwater wetlands. The forest ecosystem of Strofilia is of great ecological interest because it is the most extensive Pinus pinea forest in Greece and one of the largest in Europe. The area is a natural ecological laboratory.
- Kotychi lagoon: a brackish coastal lagoon covering 800 Ha and with a depth of 30-40 cm. At the center of its western side there is an opening almost 30 m in width which links the lagoon with the sea. It is the most significant lagoon in Pelloponnese and a Ramsar Convention site.

Sub-region 4:

- Delta Pineiou: it is a Holocene, birdfoot delta with tow zones of dunes. The first dune zone is lowland and the second has a higher altitude (3m). For land protection reasons, an artificial wood was planned with great aesthetic value.

Sub-region 5, 6:

- Kiparissias Bay: wide beaches of fine sand are backed by dunes along the coastline. Beds of Posidonia are very well developed forming an important marine ecosystem. The adjacent sandy beaches of the bay are very important nesting areas for Caretta-caretta.
- Zacharos coastal forest and Kaifa Lake: two distinct dune zones, a unique in shape and size forest of Strofilia and the Kaifa Lake, a significant wetland with an area of 200 Ha. The lake is

located behind the forest and is connected to the sea by a canal. This combination of forest, dunes, lake, wetland, etc. consists an important and complex ecosystem with reach flora and fauna.

Sub-region 7:

- Kiparissias dunes: the coast of this site is exposed to open sea and consequently to the prevailing SW winds that cause sand-dune formations. This unique sand dune ecosystem has a great ecological value in view of the disappearing dunes in Greece.

Table 1. Results of the Coastal Vulnerability Index determination using risk parameters

Map code number	Coastal length (Km)	Natural features	CVI	Characterization
SUB-REGION 1, 2, 3				
6240(8) 6250(2)	7.5	COASTAL LAGOON	35	High vulnerability
SUB-REGION 4				
6270(1)	1.5	RIVER DELTA	21.6	Moderate vulnerability
6270(2)	2.8		17.7	Moderate vulnerability
6270(4)	3.2		19.3	Moderate vulnerability
6270(6,8)	3.5		19.3	Moderate vulnerability
SUB-REGION 5, 6				
6281(3)	5	DRAINED COASTAL LAKE	20.3	Moderate vulnerability
6281(4)	3.1		25	Moderate vulnerability
6281(6)	1.6		16	Moderate vulnerability
6282(5)	2.5		28	High vulnerability
6282(7)	5	RIVER DELTA	38.6	Very high vulnerability
6292(2)	3		38.6	Very high vulnerability
6282(8)	1		14.1	Moderate vulnerability
6293(1)	0.7	DRAINED COASTAL LAKE	14.1	Moderate vulnerability
6293(3)	4		30.5	High vulnerability
SUB-REGION 7				
7203(1,2,3)	6.2	SAND DUNES	17.6	Moderate vulnerability
7204(5)	3.1		22.8	Moderate vulnerability

It is more than evident that the whole region described above deserves an assessment vulnerability study to spot regions of high or very high vulnerability in order to promote relevant intergraded management planning. For this reason, maps of 1/5000 scale were collected and digitized for all the above regions, as well as, a time series of air photographs from 1960 to 2000 in order to study the historical retreat. On the final digitized map of every sub-region, the following topographic information was depicted:

1. The different shoreline positions
2. The isobath of 10m and all height contours up to 4m
3. All natural or man-made structures, e.g. roads, rivers, houses, etc.

4. Transects every 50m along the shoreline in order to study the historical shoreline change and inclination of the coastal zone.

Then, the Coastal Vulnerability Index (CVI) was calculated for every transect and, then, its average of the CVI's for the region. The results are given in Table 1.

CONCLUDING REMARKS

Climate change is likely to affect coastal systems through the variation of mean sea level, precipitation patterns, sea hydrodynamics, frequency and magnitude of extreme events. The Coastal Vulnerability index yields a relative ranking of the possibility that physical changes will occur along the shoreline as sea level rises. Along the western coasts of Peloponnese studied, the most vulnerable areas are spotted at the river delta and coastal lagoons. The character of "high vulnerability" drives the attention of the coastal engineer and planner to engage protection techniques in due time before it is late for protection. The CVI determination presented here provides an insight into the relative potential of coastal change due to future sea level rise and can be viewed in two ways:

1. As a base for developing a more complete inventory of the risk variables influencing the coastal vulnerability to future sea level rise (e.g. storm surges frequency and intensity) and
2. As an example of assessing coastal vulnerability to future sea level rise using objective criteria.

A coastal nation like Greece with CVI determination along its coastline can effectively plan its "defense" against the accelerating greenhouse effect and its implications.

REFERENCES

Gornitz, V., Beaty, T., and Daniels,R., (1997). 'A coastal hazards data base for the US West Coast', Goddard Institute for Space Studies, NASA, Publ. No 4590.

Jeftic, L., Keckes S., and Pernetta J.C., (1996). Climate change and the Mediterranean, volume 2, Edward Arnold, London, UK.

Klein, R and R. Nicholls, (1999). Assessment of Coastal Vulnerability to Climate Change. Ambio, 28(2): 182-187.