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Accelerated sea level rise and coastal vulnerability in the Hersonissos coastal region (Crete, Greece)

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Abstract

The IPCC predictions for climate changes in the 21st century assess sea level rise from 5 to 10mm/year due to the Greenhouse effect. We have already entered a period of accelerated temperature and sea level rise and one of the most important impacts of these changes is the severe erosion of the coastal areas. According to Bruun rule, a sea level rise of 1cm induces a coastal retreat of (approximately) 1m in low-lying coastal areas. Taking into consideration the inundation concept, the historical retreat and the Bruun erosion model, the assessment of the coastal setback comes nearer to the response of nature due to climate changes.

In the coastal region of the Hersonissos in Crete, Greece and for 21km of its shoreline, the impacts of the above models are considered in order to assess the vulnerability due to the Greenhouse effect. The results are impressive and estimate a coastal retreat of more than 280m up to the end of the century, posing a threat to the coastal infrastructure. In view of the results, decisions and measures should be considered without delay.

Keywords: Climate change; Inundation; Erosion; Historical retreat; Hersonissos; Crete.

Introduction

Global warming is not a future, distant threat. In fact, there is compelling evidence that a shift in our planet's weather patterns and changes in climate are already underway. Climatic phenomena from all over the world clearly signal that a change is occurring. From droughts to melting glaciers, from dramatic flips in ocean currents to regional increases in extreme and violent storms, the indications are that climate change is happening now; affecting habitat, wildlife, human health, economy and, finally, the world can no longer wait to deal with the causes and reduce the effects of global warming. The evidence of global warming and its consequences are accumulating rapidly and require the world's immediate attention. The Intergovernmental Panel on Climate Change (IPCC) concluded in 1995 that global warming is real, serious and accelerating and its most likely cause is primarily from humans' burning oil, gasoline, coal and the increasing amount of CO_2 and other greenhouse gases trapped in the earth's atmosphere. The evidence and course are clear: global warming is already acting on our planet and it is time to recognize its effects and respond without delay.

One widely publicized consequence of global warming is a rise in global sea level. This rise is expected partly due to an increase in the volume of ocean water resulting from thermal expansion and partly from the addition of water presently stored on land in the form of ice. According to the IPCC, global mean sea level is projected to rise by 0.09 to 0.88m between 1990 and 2100 (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2001). The rate and magnitude of this sea level rise (SLR) will not be uniform over the globe. It will vary from ocean basin to ocean basin, reflecting variations in ocean heating and the way in which ocean currents redistribute the heat and mass. Practical interest centers on the change in sea level with respect to the shore or relative sea level. Local geological and geophysical processes may cause vertical movements of the shoreline, which cancel or worsen the projected effects of global warming. For example, it is well known that the Thermaikos gulf is subsiding at a rate of 4mm/century (BROCHIER, F. & RAMIERI, E., 2001). There is also concern that changes in weather patterns may give rise to more frequent occurrences of unusually high or low sea levels, resulting in flooding of areas that are normally low lying or exposing of normally submerged areas.

Human population is attracted to coastal zones to a greater extent than to other regions. Urbanization, rapid growth of coastal cities and heavy tourist development have, therefore, been a dominant population trend over the last decades. At least 200 million people were estimated to live in the coastal floodplain in 1990 (in the area inundated by a 1 in 1000 year flood) and it is likely that their number will increase to 600 million by the year 2100 (BROCHIER, F. & RAMIERI, E., 2001). Thus, this is placing growing demands on coastal resources as well as increasing people's exposure to coastal hazards.

In historic times, but even more profound in recent years, coastal populations around the world have suffered from serious disasters caused by storm floods and related wave and wind attacks and precipitation. Remember the extreme climatic events and phenomena in Greece in January and February this year. Global climate change and the threat of accelerated SLR exacerbate the already existing high risks of storm surges, severe waves and tsunamis. Climate change may not only enhance the most threatening extreme events but also aggravate long term biogeophysical effects, such as sea level rise, shoreline erosion, sediment deficits, loss of coastal wetlands and saltwater intrusion to coastal aquifers. According to the most pessimistic scenario, the wetland loss due to SLR for the EU Mediterranean countries could be nearly 100% by 2080 (BROCHIER, F. & RAMIERI, E., 2001). In Greece, 33% of the irrigated land is currently threatened by salinization due to soil degradation and inadequate use of water (GEORGAS *et al.*, 1996). Many regions in Crete could lose at least half their current extent of beach with only 50cm of SLR (BROCHIER, F. & RAMIERI, E., 2001). It is therefore not surprising that as early as 1990, UNEP warned, *'it is likely that the impact of climate change will first be felt in the Mediterranean water resource system'* (UNEP, 1990).

In light of these existing hazards and increasing risks in coastal regions, there is a great need to gain as much insight as possible into the exact nature and extent of possible risk increases related to future climate trends. Thus, it is essential to carry out analyses of the coastal systems' responses to climate change impacts as well as to assess the threats posed to human society (BARIC & GASPAROVIC, 1992). Unfortunately, vulnerability to impacts is a multi-dimensional concept and can be defined as 'the degree of incapability to cope with the consequences of climate change and accelerated sea level rise' (UNEP, 1990). Consequently, vulnerability assessment includes the assessment of both anticipated impacts and available adaptation options.

Materials and Methods

Coastal vulnerability studies can focus on scenarios of climate-induced changes in the environmental conditions of a study area, especially sea level rise. However, the fact that climate change will trigger socio-economic developments that in turn affect the manifestation of coastal impacts is not considered in the present assessment. Irrespective of the necessity to consider multiple scenarios, relative sea level change remains the most important variable for coastal vulnerability assessment. Due to the fact that relative SLR is the sum of global SLR, regional oceanic effects and vertical land movements, it follows that scenarios for relative SLR can have the form:

$$SLR_R = SLR_G + SLR_L + V * t \quad (1)$$

where SLR_R : the relative SLR in year t
SLR_G: the global SLR in year t
SLR_L: the local SLR induced by global oceanic changes in year t
V: the vertical land movement and
t: the number of years in the future (e.g. 50 for 2050 with base year 2000)

Taking into account the uncertainties of SLR_G, it is vital that the scenarios are selected such that they encompass the likely change e.g. a maximum scenario in which SLR_G equals 1m in 2100 is quite appropriate for screening approach (BIJLSMA, L. *et al.*, 1996). Information on the SLR_L factor is not available in Greece yet and values for V can be assessed from a number of different sources, e.g. geological analysis, precise geodetic surveys and analysis of long-term tide-gauge records. However, in areas subject to human-induced subsidence (e.g. coastal aquifer over pumping), future vertical land movements may be quite uncertain, as they will depend on human action, necessitating scenarios for subsidence. It is, therefore, plausible, that for the impact assessment studies of the Hersonissos/Crete only the global sea level rise will be considered.

Sea level rise can activate two important mechanisms that result in the loss of land, namely, erosion and inundation. Erosion represents the physical removal of sediment by wave and current action, while inundation is the permanent submergence of low-lying land. Sea level rise contributes to the erosion of erodible cliffs, sandy and muddy coasts by promoting the offshore transport of sedimentary material. The best-known and most widely applied model to estimate erosion has been developed by BRUUN in 1962 for applications on straight sandy shores (BRUUN, P. 1962). Land loss resulting from inundation is simply a function of slope: the lower the slope, the greater the land loss.

Trying to compare the displacement of points along a sandy beach, one can use the following simple expression (CAMPERS, G., 1998):

$$S = (HR + I + E) * F \quad (2)$$

where S : the one-dimensional displacement of a point on the shoreline (in perpendicular direction)
HR: the historical retreat
I: the inundation effect
E: the erosion of the beach and
F: a factor that includes ecological, social and planning conciderations.

It has to be stated here that the factor F assumes the value of 1 in the present study but can generally take values up to 2.5 depending on the existence of coral reefs, indicators of long-term erosion, sand extraction, existence of marine parks etc (AMPERS, G., 1998). None is present in the study area.

The area under the vulnerability assessment study is located in northern Crete eastwards of the town of Heraklion. It comprises over 20km of sandy beach, lowlands, small villages and hundreds of coastal hotels very near the seafront. The area is the major part of the gulf of Malia and one of the heavily exploited coastal areas in Crete (Fig. 1).

Fig. 1: The study area of Hersonissos (Crete, Greece). The scale is arbitrary.

In order to assess the impacts of the inundation of the coastal zone due to sea level rise, the following geoinformation was used:

1. 18 topographic maps with scale 1/500
2. Aerial photographs taken in 1960 and 1989 (scales 1/15000 and 1/5000 respectively)

The software used was:

1. The ERDAS IMAGINE 8.6 2.The AutocadMap2000 and 3. The Wide Image

In the first stage, the maps were scanned using Wide Image software in .jpg format and 150dpi resolution and the aerial photographs with 300dpi. Next, the software ERDAS IMAGINE 8.6 transformed the digital .jpg format to .img format and the geometric correction was applied to a local reference system using corner points of the image. Next, the permitted RMS of the geometric correction was computed as:

$$RMS \leq 1.25m \bullet \sqrt{2} = 1.768m$$

and our error of the geometric correction was 1.68m, which was eventually accepted.

The geometrically corrected .img file was changed to .geotiff format using the 'export' command and the produced map-file was introduced to the AutocadMap2000 software. According to the described procedure, the final file preserved its georeference with respect to the local reference system. All raster elements from the aerial photographs and the topographic maps (1/500) were then introduced into the .dwg file of the software AutocadMap2000. With the 'move', 'rotate' and 'scale' commands, all digitized elements of the aerial photographs and maps were overlaid on to GEOTIFF file. 58 transects every 160m were drawn perpendicular to the shoreline, extending from the 10m isobath up to the 4m contour line. By this procedure, the coastal slope and the beach retreat could then been determined. Figure 2 depicts the studied area and the transects for computing coastal slope and beach erosion.

In Table 1 the results of the accumulative impacts due to inundation, erosion and historical retreat are computed projected to the end of this century.

In Table 1, columns 3, 4, 5 and 6 have been calculated as:

a. Column 3, is the multiplication of the erosion rate (estimated from column 2) with the time period of 111 years (2100-1989).
b. Column 4, is the distance from the shoreline to the isobath of 10m extracted from the hydrographic maps.
c. Columns 5 and 6, are the retreat due to erosion computed via the Bruun's model

Table 1
Computation of inundation, erosion and historical retreat of the 58 transects along the study area and the sandy beaches (distances in m).

TRANSECT	HISTORICAL RETREAT FROM 1960 to 1989 (m)	RETREAT IN 2100 (m)	DISTANCE FROM -10M (m)	EROSION WITH SLR 50 CM (m)	EROSION WITH SLR 100 CM (m)	TOTAL RETREAT WITH SLR 50 CM (m)	TOTAL RETREAT WITH SLR 100 CM (m)
1	114	435	794	39	79	475	515
2	108	413	718	35	71	448	484
3	59	224	426	21	42	246	267
4	93	354	807	40	80	395	435
5	35	133	895	44	89	178	223
6	24	92	765	38	76	130	168
7	16	62	641	32	64	94	126
8	36	136	526	26	52	162	189
9	94	360	536	26	53	386	413
10	62	236	569	28	56	265	293
11	120	460	641	32	64	492	524
12	171	652	602	30	60	682	712
13	29	109	571	28	57	138	167
14	59	224	640	32	64	256	288
15	74	282	528	26	52	308	335
16	77	294	638	31	63	326	358
17	129	492	714	35	71	528	564
18	88	336	724	36	72	372	408
19	74	282	702	35	70	317	352
20	82	314	687	34	68	348	383
21	69	264	654	32	65	297	330
22	52	198	588	29	58	228	257
23	50	190	624	31	62	221	253
24	75	285	570	28	57	314	342
25	67	255	594	29	59	285	314
26	23	86	525	26	52	113	139
27	71	270	493	24	49	295	320
28	65	248	927	46	92	294	341
29	72	275	841	42	84	318	360
30	60	230	754	37	75	268	305
31	78	297	718	35	71	333	369
32	59	225	626	31	62	256	288
33	41	157	585	29	58	186	215
34	109	417	640	32	64	450	482
35	64	244	621	31	62	275	306
36	45	172	582	29	58	201	230
37	81	309	551	27	55	336	364
38	64	244	541	27	54	271	298
39	24	92	451	22	45	114	137
40	64	243	416	20	41	264	285
41	49	187	585	29	58	217	246
42	59	225	436	21	43	247	269
43	89	339	439	21	43	361	383
44	66	253	502	25	50	278	303
45	48	184	522	26	52	210	236

46	39	150	530	26	53	176	203
47	25	93	511	25	51	119	144
48	41	155	472	23	47	179	203
49	72	275	614	30	61	306	337
50	69	265	585	29	58	294	324
51	75	288	433	21	43	309	331
52	27	103	309	15	30	119	134
53	110	422	274	13	27	436	450
54	57	216	285	14	28	230	244
55	91	349	422	21	42	370	391
56	59	227	484	24	48	251	275
57	68	261	489	24	48	285	310
58	126	482	453	22	45	505	527

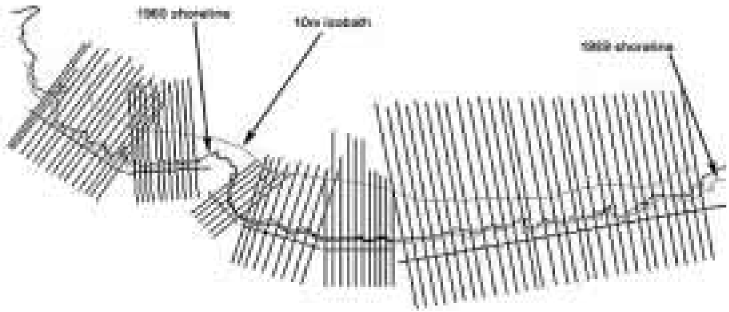

Fig. 2: The study area, the used transects and the shorelines of 1960 and 1989. The scale is arbitrary.

c. Columns 5 and 6, are the retreat due to erosion computed via the Bruun's model with 50 and 10cm sea level rise respectively.

Results and Discussion

The anticipated sea level rise will affect the coastal zone of the Hersonisos through permanent inundation of low-lying areas, acceleration of beach erosion and, therefore, greater frequency of flooding episodes. It is evident from Table 1 that the total retreat of the shoreline would be 290m (on average) by the end of the century and SLR of 50cm and 320m with 100cm SLR. One might think that 100cm for SLR is a too pessimistic figure but going through the Mean Sea Level (MSL) secular trends derived from PSMSL RLR data for Heraklion harbor (20km westwards from the study area) will conclude that for the period 1985-1999 the MSL trend accounted for +6.5mm/year on average (http://www.pol.ac.uk/psmsl/datainfo/rlr.trend). Consequently, even the 100cm SLR could be considered as a 'middle scenario'.

Using Figure 3 for assessing the total impact of inundation, erosion and historical retreat, we can deduce that the coastal area under threat accounts for 470 ha and 520 ha for 50cm and 100cm of SLR respectively. If these projected scenarios emerge during the 21st century, one can imagine the impacts on land, infrastructure, tourist industry, coastal aquifers etc.

From Table 1 we can infer that the rates of beach erosion would double or triple relative to the 20th century rates. To compensate for land losses we would need sand to nourish the

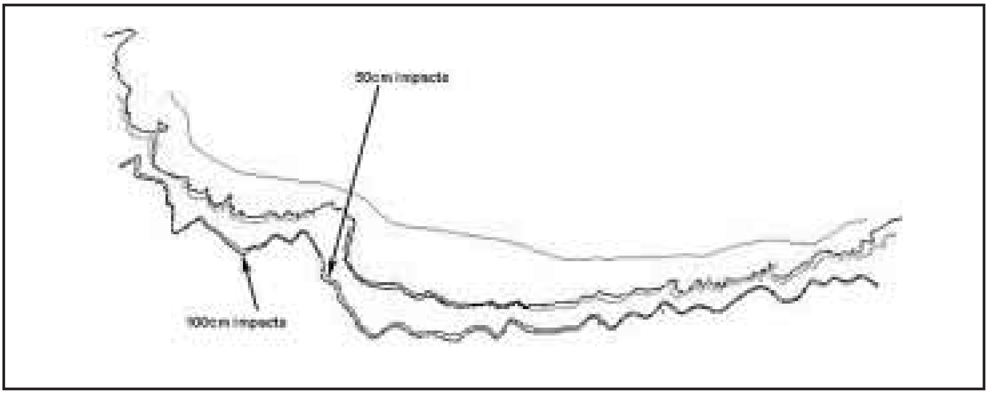

Fig. 3: Vulnerability impact assessment in the Hersonissos (Crete, Greece). The scale is arbitrary.

very sensitive areas but everyone knows the scarcity or absence of sand in Greece. In response to SLR, armoring of the shoreline will be necessary to protect vital infrastructure (e.g. hotels) and also areas of high population density and property value. However, soft or hard protection measures will not be a practical option for the entire coastal area under study. Thus, zoning or setback policies would need to be established to enable an orderly and equitable pullback from the most vulnerable areas matched with long and hard efforts of keeping climate change within tolerable bounds (AMPERS, G., 1998).

References

AMPERS, G., 1998. Planning of coastal change: coastal development setback guidelines in Nevis, COSALC, University of Puerto Rico.

BARIC & GASPAROVIC, 1992. Implications of climate change on the social-economic activities in the Mediterranean coastal zones. p. 428-494. In: *Climate change and the Mediterranean*, edited by L. Jeftic, J.D. Milliman & G. Sestini, Edward Arnold, London, UK.

BIJLSMA, L., EHLER, C.N. et all, 1996. Coastal zones and small islands. p. 289-324. In: *Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis*, edited by R.T. Watson, M.C. Zinyowera & R.H. Moss. In: Contribution of Working Group III to the second Assessment Report of the International Panel on Climate Change, Cambridge University Press.

BROCHIER, F. & RAMIERI, E., 2001. Climate change impacts on the Mediterranean coastal zones, *Fondazione Eni Enrico Mattei (EEE)*, Milano, Italy.

BRUUN, P. 1962. Sea Level Rise as a Cause of Shore Erosion, *Journal of Waterways and Harbors Division* (ASCE) 88: 116-130.

CAMPERS, G., 1998. Planning of coastal change: Coastal development setback guidelines in Nevis, COSALC, University of Puerto Rico.

GEORGAS, D., PERISSORATIS, C. & ARMBARIOTIS, P., 1996. Climate impacts report for Crete, Greenpeace, Athens, Greece.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2001. Working Group 1 Third Assessment Report, January 2001 Summary for Policy Makers, Geneva, Switzerland.

NICHOLLS, R.J. & MIMURA, N., 1998. Regional issues raised by sea-level rise and their policy implications, *Climate Research*, 11: 5-18.

UNEP, 1990. High and Dry: Mediterranean climate in the twenty-first century, UNEP.

Http://www.pol.ac.uk/psmsl/datainfo/rlr.trends.