Sea level rise impact on the beach zone of Katerini region, NW Aegean Sea

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Abstract: The present contribution provides an initial assessment of the impacts of the longterm (climatic, i.e. sea level rise) and episodic (meteorological) on the sandy beach zone along the coast of Katerini region (NW Aegean Sea). Thus, the future retreat of the coastline, due to sea level rise (SLR) induced by climate change, has been estimated on the basis of an ensemble of 5 coastal morphodynamic models. Model's outputs showed that shoreline retreat range between 7.9-27.3 m and 23.5-70.0m for SLR of 0.38m and 1.0m, respectively. An initial assessment of coastal flooding has been examined after consideration of the astronomical tidal range, storm surge estimates and calculations of wave runup for intensive wave conditions (Ho>4 m). The results showed that the locations adjacent to Paralia and Olympiaki Akti residences are the most vulnerable to coastal flooding, whilst in the case of future sea level the study area could be subjected to coastal flooding.

Keywords: coastline retreat, runup, storm surge, sea level rise, coastal hazards

1. Introduction

Beaches (i.e. the low-lying coasts consisting of unconsolidated sediment) form extremely important economic resources, particularly for Greece (Velegrakis *et al*., 2005), the significance of which in the present financial climate has a distinctive role for the Greek economy. Beaches are also very dynamic coastal environments and are currently under increasing erosion (EUROSION, 2004), which can be differentiated into: (i) long-term erosion, i.e. irreversible retreat of the shoreline position, due to mean sea level rise and/or negative coastal sedimentary budgets (Dan *et al*., 2009) that force beach landward migration and/or drowning; and (ii) short-term erosion, caused by storm waves/surges, which may or may not result in permanent shoreline retreats (List *et al*., 2006), but can nevertheless be devastating (Smith and Katz, 2012). Climate change, either as mean sea level rise (a moderate estimate of 0,4m for 2100 after IPCC, 2013) and/ episodic storm events will both initiate and/or enhance the already beach erosion, with severe impacts on coastal activities, infrastructure and assets (Jiménez *et al*., 2012), and the beach carrying capacity for recreation/tourism (Valdemoro and Jiménez, 2006).

In the case of the Greece 1/3 of its coastline has been subjected to erosion with the West Macedonia prefecture having its 45.1% under erosion to be second in order after Crete where erosion covers the 65.8% of its coastline (EUROSION, 2004). Obviously, erosion affects primarily beaches, which accounts for the 36% of the Greek coastline, and from which more than 30% have been under erosion (Alexandrakis *et al*., 2013).

The present contribution provides an initial assessment of the impacts of the longterm (sea level rise - SLR) and episodic (meteorogical) in the case of the sandy beach zone along the coast of Katerini region.

2. Study area

The study area is located at the NW part of Thermaikos Gulf (NW Aegean Sea) (Fig. 1). It accommodates a low lying coastal relief (slopes <1%) of uncosolidated alluvial sediments at the easternmost part of the extensive alluvial plain of Katerini. The coastline of the area under investigation is oriented in a NNE-SSW direction and has a total length of up to 21 km. It receives the sediments of 6 intermittent flow torrents which drain an area of >625 km^2, which in combination with the prevailing marine processes (e.g. longshore sediment transport), control the overall morphology of the coastal zone. The latter incorporates the Alykes lagoon at its northern part, a significant salt production unit in Greece with a major ecological footprint. Furthermore, Paralia Katerinis settlement, located at the central part of the study area, is an important touristic unit with considerable contribution to the local economy.

Waves related to SE winds are considered to be the most important in terms of magnitude (Ho>4 m). The study area is a microtidal marine environment exposed to a mean tidal range of about <20 cm (Hellenic Navy Hydrographic Service, 2005).

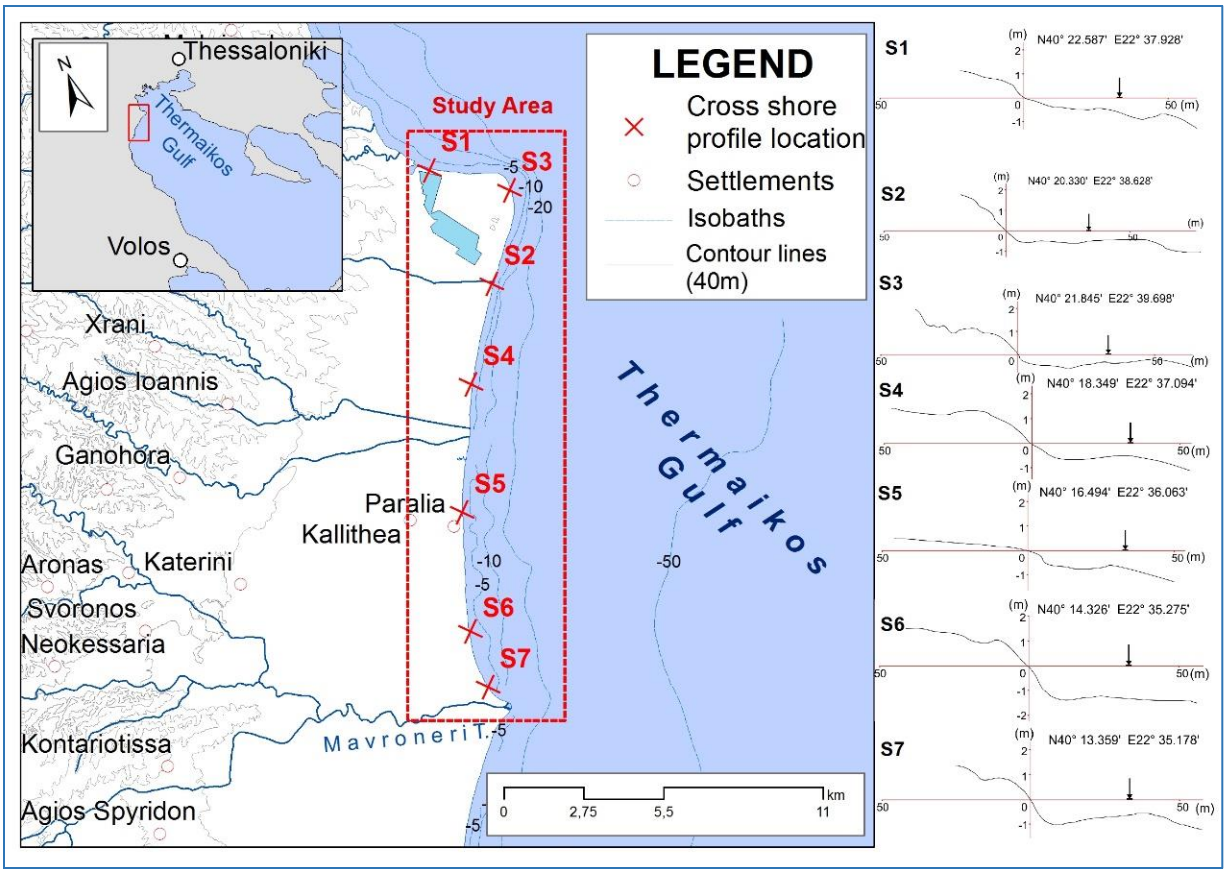

Figure 1. Study area location map depicting also S_1-S_7 cross-shore profiles.

3. Data and methods

The coastal retreat due to sea level rise has been assessed through the application of an ensemble of three analytical (Edelman, 1972; Bruun, 1988; Dean, 1991) and two numerical models (Larson and Kraus (S beach), 1989; Leont'yev, 1996).

The Bruun model (e.g. Bruun, 1988) is based upon the concept of the equilibrium profile (Zhang *et al*., 2004), with the coastal retreat controlled by the height of the beachface and the distance between the coastline and the closure depth (Komar, 1998). Edelman's (1972) model can deal with more realistic beach profiles and temporally-variable sea level changes. The Dean (1991) model, developed initially for the diagnosis/prediction of storm-driven coastal retreat, is also based on the equilibrium profile concept, with the coastal retreat controlled by the water depth at wave breaking, the height of breaking waves, the surf zone width and the beach sediment texture. The S-Beach model (Larson και Kraus, 1989) is a 'bottom-up' morphodynamic model, consisting of combined hydrodynamic and sediment transport modules and containing detailed descriptions of the wave transformation and sediment transport in the coastal zone. The sediment continuity equation is addressed by finite differences and a 'stair – step' beach profile discretisation, whereas sediment transport is controlled by the wave energy flux and the beach slope. Finally, the model based on the Leont'yev (1996) algorithm uses the energetics approach (Battjes and Janssen, 1978), with the wave energy balance in the cross-shore direction controlled by the wave propagation angle, the wave energy and its dissipation; sediment transport rates are predicted separately for the surf and swash zones.

A full description of the aforementioned models (morphodynamic concept and equations) are presented by Monioudi *et al* (2016).

The models were applied at seven -shore-normal profiles for high wave conditions related to SE direction, i.e. wave height (Ho) of 5.5 m and period (T) 9.0 s and two SLR senarios 0.38 m (IPCC, 2013) and 1 m (e.g. Pfeffer *et al*., 2008). Morphometric measurements along seven shore-normal profiles (for locations, see Fig.1) were carried out by means of a Nikon A20 Total Station for the subaerial parts and a Hondex single-beam portable echo sounder for the subaqueous parts.

A gross estimate of potential coastal flooding (storm induced) could be approached by calculating the total water level (TWL) as the sum: Tidal range (T) + storm surge (SS) + Wave runup ($R_{2\%}$) + Sea-level rise (SLR)

In the case of the Thermaikos Gulf (NW Aegean Sea) tidal amplitude is in the order of 0.1 m, the storm surge accounts for 0,4 ±),1 m (after Karambas (2015) and Androulidakis *et al* (2015)) whilst SLR = 0 for present time becoming 0,38 m at 2100 (according to moderate scenario of IPCC (2013).

The wave runup could be approached using the following equations provided by Stockton *et al*. (2006), Komar 1998 and Holman (1986); these are:

$$R_{2\%} = 1.1\left(0.35\beta(H_o L_o) + \frac{\left[H_o L_o (0.563\beta^2 + 0.004)\right]^{0.5}}{2}\right)$$

$$R_{2\%} = 0.36 * g^{0.5} * \beta * H_0^{0.5} * T_0$$

$$R_{2\%} = H_{mo}\ \alpha\ \xi_o^{\ b} + c$$

where, Ho: offshore wave height, To: wave period, β foreshore slope that in the case of the Greek tideless environment coincides to some extend with beach face, $\xi_o=\beta/(H_o/L_o)^{0.5}$ whilst according to Hunt's (1959) data suggested α=1 b=1 and c=0 for deep water regular waves.

4. Results and Discussion

The estimated values of beach retreat, for the seven locations S_1-S_7, their averages and for comparison, the current beach widths are presented on Table 1.

Beach retreat ranges from 7.9m to 27.3m for SLR=0.38m and from 23.5m up to 70m for SLR=1.0m. The smallest retreat values for both scenarios of SLR have been calculated for the S_7 beach profile, which is located at the mouth of Mavroneri torrent at the southernmost part of the study area. On the contrary, the highest values of beach retreat, have been attributed to beach profile S_5 that is located adjacent to Paralia Katerinis residence area with major economic impacts on the tourism sector and the local economy in general.

On the basis of these estimates the current beach widths will be reduced by at least 30% (S_6) and up to 63% (S_2) for the moderate scenario of SLR, with the exception of S_3 location where retreat is almost equal to beach width. If SLR reaches the 1 m, then there will be a total loss of the beach width, only with the exception of S_6 where the beach will be reduced by 80%.

Table 1. Beach retreat in (m) for each cross-shore profile for SLR 0.38m and 1.0m until 2100.

Profile	Beach width	SLR (m)	Beach retreat (m)						Beach loss (%)
			Leont'yev	**SBEACH**	**Edelman**	**Bruun**	**Dean**	**Average**	
S_1	23	0.38	4.0	3.4	13.1	16.3	21.1	11.6	50.4
		1	18.2	18.2	34.4	43.0	42.5	31.3	>100
S_2	19	0.38	3.0	3.2	15.0	14.1	24.2	11.9	62.6
		1	7.8	7.5	39.6	37.2	48.8	28.2	>100
S_3	14	0.38	2.7	2.8	18.1	15.6	29.3	13.7	98.0
		1	14.5	14.3	47.8	41.1	58.9	35.3	>100
S_4	10	0.38	2.9	3.08	17.9	18.1	28.8	14.1	>100
		1	12,0	12.6	47.1	47.7	58.1	35.6	>100
S_5	63	0.38	32.6	34.8	17.2	23.8	27.8	27.3	43.3
		1	92.1	93.9	45.4	62.7	56.0	70.0	>100
S_6	39	0.38	3.1	3.4	14.3	14.2	23.0	11.4	29.7
		1	17.8	16.9	37.6	37.4	46.3	31.5	80.0
S_7	15	0.38	2.6	2.4	9.2	10.1	14.9	7.9	52.6
		1	17.8	18.3	24.4	26.8	30.1	23.5	>100

Table 2. Wave run-up and total water level estimates for the seven positions of the study area

	S_1	S_2	S_3	S_4	S_5	S_6	S_7
BE_{max}	**1.20**	**1.80**	**2.00**	**1.40**	**0.70**	**1.50**	**1.40**
β	0.02	0.03	0.02	0.03	0.01	0.01	0.03
$R_{2\%}$ (Stockton *et al*., 2006)	1.15	1.28	1.15	1.28	1.08	1.05	1.28
$R_{2\%}$ (Komar, 1998)	0.48	0.71	0.48	0.71	0.35	0.29	0.54
$R_{2\%}$ (Holman, 1986)	0.53	0.79	0.53	0.79	0.39	0.32	0.79
$R_{2\%}$ (average)	0.70	0.90	0.70	0.90	0.60	0.60	0.90
TWL_A	1.2	1.40	1.20	1.40	1.10	1.10	1.40
$R_{2\%}$ (Stockton *et al*)	0.87	0.97	0.87	0.97	0.82	0.80	0.97
$R_{2\%}$ (Komar, 1998)	0.36	0.54	0.36	0.54	0.26	0.22	0.54
$R_{2\%}$ (Holman, 1986)	0.55	0.83	0.55	0.83	0.40	0.33	0.83
$R_{2\%}$ (average)	0.60	0.80	0.60	0.80	0.50	0.40	0.80
TWL_B	1.10	1.30	1.10	1.30	1.00	0.90	1.30

Short-term erosion, caused by storm waves/surges, which may or may not result in permanent shoreline retreat has been approached through the calculation of potential Total Water Level, which in the case of Greek waters is primarily controlled by wave run-up. In table 2 wave run-up estimates ($R_{2\%}$) and associated total water level (TWL) values are presented for two scenarios of wave regime: scenario 1 refers to usual high waves (Ho=4 and T=8 s) and rarely occurred very high waves (Ho=5.5 m and T=9 s) (after Athanasoulis and Skarsoulis, 2001 and Soukissian *et al*., 2007).

On the basis of TWL estimates, excluding the factor of SLR, it can be seen that S_1, S_4 and S_7 profiles beach maximum elevation could be reached during high wave conditions. It should be noted that the proximity of these locations with the touristic residence of Paralia Katerinis and the Alykes lagoon ecosystem enhances the socioeconomic impacts of the catastrophic events profile S_5 is susceptible to overtopping and subsequent coastal flood, whilst along profiles S_2, S_3 and S_6 overtopping could not be achieved now but it may happen in the future due to SLR.

5. Conclusion

The Pieria beach zone is currently in morphological equilibrium with the total sea level rise, induced by storm surge and astronomical tides, but a future increase of sea level (i.e., due to climate change) will cause coastal floods, either permanent or periodic. Moreover, the anticipated future rise of sea level even for the moderate predictions (i.e. 0.38 m by 2100) would reduce beach width by 30-65%.

Hence, given the potential level of beach erosion due to sea level rise combined with the possibility of coastal flood occurrence induced by extreme meteorological events, there is a relatively high risk to the tourism sector and to coastal ecosystem sustainability.

References

Alexandrakis G., Ghionis G., Poulos S. A. and Kampanis N.A. (2013) GREECE, (In:) *Coastal Erosion and Protection in Europe: A Comprehensive Overview*, E. Pranzini, A. T. Williams (Eds.), EARTHSCAN Ltd, London, UK, 355-377

Androulidakis Y.S., Kombiadou K.K., Makris C.V., Baltikas V.N. and Krestenitis Y.N. (2015), Storm surges in the Mediterranean Sea; Variability and trends under future climatic comditions. *Dynamics of Atmospheres and Oceans*, **71**, 56-82

Athanasoulis G.A. and Skarsoulis E.K. (1992), Wind and Wave Atlas of the Mediterranean Sea, *Hellenic Navy General Staff*. Athens

Battjes J. A. and Janssen J. P. F. M. (1978), Energy loss and set-up due to breaking in random waves, in: *16th International Conference on Coastal Engineering, ASCE, Hamburg*, 569-587.

Bruun P. (1988), The Bruun Rule of erosion by sea level rise: A discussion on large-scale two- and three-dimensional usages, *J. Coastal Research*, **4(4),** 622-648.

Dan S., Stive M.J.F., Walstra D.J.R. and Panin N. (2009), Wave climate, coastal sediment budget and shoreline changes for the Danube Delta. *Marine Geology*, **262**,(1-4),39-49.

Dean R. G. (1991), Equilibrium beach profiles: characteristics and applications, *Coastal Research* **7**(1), 53– 84.

Edelman T., (1972), Dune erosion during storm conditions, *In: Proceedings of the 13th International Conference on coastal Engineering ASCE*, 1305-1312.

EUROSION, (2004), Living with coastal erosion in Europe. Final report of the project 'Coastal erosion – Evaluation of the need for action', *Directorate General Environment, European Commission*.

Hellenic Navy Hydrographic Service, (2005), Tides and tidal data for Greek harbours, (4^{th} ed.) Athens

Holman R.A. (1986), Extreme value statistics for wave runup on a natural beach. *Coastal Engineering* **9(6)**, 527-544.

Hunt I.A. (1959), Design of seawalls and breakwaters. *J. of Waterways and Harbours Division, ASCE 85 (WW3)*, 123-152.

Jiménez J.A., Bosom E., Valdemoro H.I., Guillén J. (2012), Storm-induced damages along the Catalan coast (NW 20 Mediterranean) during the period 1958–2008. *Geomorphology* **143-144**, 24-33.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], *Cambridge University Press, Cambridge, United Kingdom 15 and New York, NY, USA*

Karambas T.V. (2014), Modelling of climate change impacts on coastal flooding/erosion, ports and coastal defence structures. *Desalin Water Treat* **54**(8):2130–2137

Komar P.J. (1998). Beach Processes and Sedimentation, *2nd Edition Prentice Hall*, 544

Krestenitis Y.N., Androulidakis Y.S., Kontos Y.N. and Georgakopoulos G. (2011) Coastal inundation in the north-eastern mediterranean coastal zone due to storm surge events. *J Coast Conserv*, **15**:353-368,

Larson M. and Kraus N. C. (1989), SBEACH: numerical model for simulating storm-induced beach change; report 1: empirical foundation and model development, Technical Report-*US Army Coastal Engineering Research Center* 89-99.

List J. (2006). Reversing storm hotspots on beaches. *Marine Geology*, **226**, 261-279.

Leont'yev, I.O., 1996. Numerical modelling of beach erosion during storm event, Coastal Engineering 29,**1-2**:187-200.

Monioudi I.N., Karditsa A., Chatzipavlis A., Alexandrakis G., Andreadis O.P., Velegrakis A.F, Poulos S.E., Ghionis G., Petrakis S., Sifnioti D., Hasiotis Th., Lipakis M., Kampanis N., Karambas Th., Marinos E. (2016), Assessment of the vulnerability of the eastern Cretan beaches (Greece) to sea level rise. *Regional Environmental Change* **16**, 1951–1962.

Pfeffer W.Y., Harper J.T. and O'Neel S. (2008). Kinematic constrains on Glacier Contributions to 21^{st} – Century Sea-Level Rise. *Science*, **321 (no 5894)**, 1340-1343.

Stockdon H.F., Holman R.A., Howd P.A., Sallenger J.A.H. (2006), Empirical parameterization of setup, swash, and runup. *Coastal Engineering* **53**, 573–588.

Soukisian T. (2007), Wind and Wave Atlas of the Mediterannean Sea. *Hellenic Center of Marine Research, Athens*

Zhang K., Douglas B. and Leatherman S. P. (2004), Global warming and coastal erosion. *Journal of Climatic Change*, **64**, 41-58.

Smith, A. B., & Katz, R. W. (2013). US billion-dollar weather and climate disasters: data sources, trends, accuracy and biases. *Natural hazards*, *67*(2), 387-410.

Valdemoro H.I. and Jiménez J.A. (2006) The influence of shoreline dynamics on the use and exploitation of Mediterranean 15 tourist beaches. *Coastal Management*, **34**, 405–423.

Velegrakis A.F.; Vousdoukas M.I. and Meligonitis R. (2005), Beach Erosion: Phenomenology and causes of the degradation of the island beaches. Greek Islands in the 21st century. *Sideris Publications*, 243-262. (In Greek with English Abstract).