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Erosive phenomena in the proximity of Kaulon archaeological park: origins and remedies

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Abstract

The paper analyses the beach erosion which affected the coast of Monasterace Marina, Italy, where the Kaulon archaeological site is located. The site extends along the coast for 1 km, itI made of an ancient town, a museum and a Doric Temple which are inside a sand dune along the coast. During the winter season between 2013-2014, two severe storms completely eroded the beach, reaching to the Doric Temple, which was partially destroyed.
All the possible causes of the erosional phenomenonare investigated through the analysis of cartography, wave, weather and climate data, and the use of soil. This analysis is carried out for different historical periods over the last 60 years. Also, a quick and temporary solution is described.

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*Keywords:*Beach erosion;coastal protection;artificial structures; shoreline change; wave climate;storm impacts

1. Introduction

Appropriate coastal management can only be achieved if the weather climate is well defined, and then only if the entire physiographical area is taken into consideration.For this reason the phenomenon should be studied from a holistic point of view to include all the aspects involved (Barbaro, Foti & Sicilia, 2014), in particular wave and

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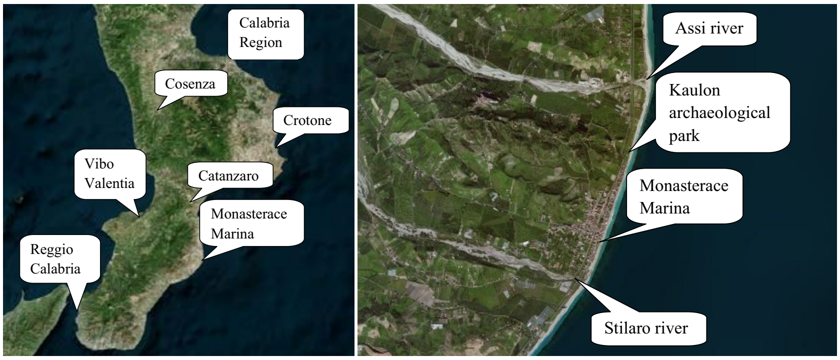
weather climate analysis (Boccotti, 2015; Arena, Laface, Barbaro & Romolo, 2013; Arena, Malara, Barbaro, Romolo & Ghiretti, 2013; Arena, Barbaro & Romolo, 2013; Barbaro, Foti & Malara, 2013; Barbaro, Foti & Sicilia, 2013; Barbaro, 2011; Boccotti, Arena, Fiamma, Romolo & Barbaro, 2011; Barbaro, 2007), and the contribution of longshore and river sediment transport (Tomasicchio, D'Alessandro, Barbaro, Musci & De Giosa, 2015; Barbaro, Foti, Sicilia & Malara, 2014; Tomasicchio, D'Alessandro, Barbaro & Malara, 2013).

The present paper describes the erosion of Monasterace Marina beach, Italy, where the Kaulon archaeological site is located, and investigates all the possible causes. Cartography data consistsin aero photogrammetry by CASMEZ (1958), IGM (1958) and aerial photos (1998 and 2008), provided by the Calabria Basin Authority (ABR), and satellite imagery provided by Google Earth Pro. Wave time series starts on 1986/10/01 and finishes on 2006/31/03 and provided by the Met Office database. The land cover data used are related to year 2000 and year 2006 (Corine Land Cover project), which is freely available on the government agency website "Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)". The weather and climate data are average rainfall registered in the station near the area (Serra San Bruno, Monasterace Punta Stilo, Stilo Ferdinandea, Mongiana e Fabrizia). This analysis is carried out for different historical periods over the last 60 years and has as its objective the evaluation both the individual causes and the interactions that exist between them. Also, a quick and temporary solution is described.

2. Geographic Classification

The site is located between the town of Monasterace Marina (Calabria Region, Italy, Fig. 1a) and the mouth of the river Assi and Stilaro (Fig. 1b).

a



b

Fig. 1. Location of Monasterace Marina (a); location of Kaulon archaeological site (b).

The coastline has an inclination of 15° from the North.The site is affected by the prevalent winds that blow from South and South-Eastdirection to the North and North-East direction andit is affected by storms surges mainly from South and South-East direction, where the fetch is up to 700 km (Fig 2a).The archaeological site extends along the coast for 1 km and consists of an ancient town, a museum and a Doric Temple (Fig. 2b) which are inside a sand dune along the coast (Tomasicchio, D'Alessandro& Barbaro, 2011).

a

b

Fig. 2. Fetches characterizing Kaulon archaeological site (a); view of Kaulon archaeological site (b).

Duringthe 2013-2014 winter, two severe storms completely eroded the beach, reaching up to the Doric Temple, which was partially destroyed (Fig. 3).

a b

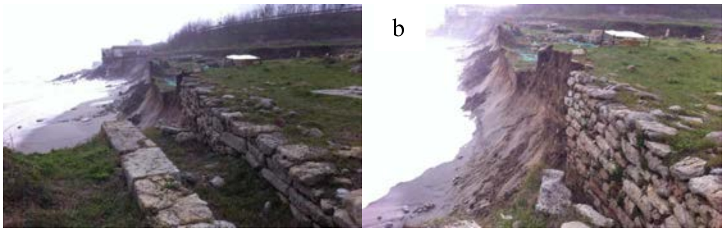


Fig. 3. Doric Temple after December 2013 storm (a); Doric Temple after February 2014 storm(b).

3. Causes investigation

3.1. Historical evolution of the coastline

Cartography data was processed using QGS 2.8.3 (Fig. 4 and Tab 1).

a

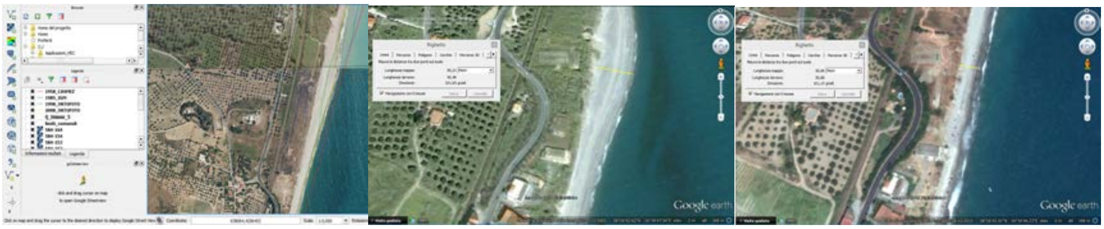


Fig. 4. Beach width at 1958and 2008 (from ABR) (a); beach widthat 2001/03/13 (from Google Earth Pro) (b); beach widthat 2011/08/13 (from Google Earth Pro) (c);

Table 1. Coastline compared to different period between 1958 and 2011 (red: erosion, green: accretion, white: equilibrium).

Data	Beach Width [m]	Changes from the previous period[m]	Changes from the previous period [%]
1958	57	-	-
1985	39	-18	-32
1998	47	+8	+21
13/3/2001	50	+3	+6
2008	29	-21	-42
13/5/2010	30	+1	+3
11/3/2011	30	-	0
12/8/2011	30	-	0

The erosion in front of the archaeological site is evident, as it has developed over the last 50 years in two phases. Due to the lack of continuous monitoring of the coastline the followingevents happened in the timegaps. The first event happened between 1958 and 1985, during which phase more than the 30% of the original beach was eroded. The second time gap phase was between 2001 and 2008, during whichphase the erosion is more evident. and in fact was over 40%.

Between these two phases another one is evident, characterized by beach accretion,being between 1985 and 1998. Between 2008 and 2011 the coastline appears to have been in an equilibrium state.

3.2. Deep water wave climate

Wave time series have been extracted throughABRC-MaCRO (provided by the ABR) from the Met Office database. The series starts on 1986/10/01 and finisheson 2006/31/03. The whole sea states have been divided into different significant wave heights. The entire data has been subdivided in two different sets of time periods, one set was regular, being every 5 years, and the other set was irregular in accordance with the cartographic data (1986-2001 and2001-2006) (Tab. 2). All the statistical parameters required have been calculated.

Table 2. Number of sea states ordered for significant wave height and time periods.

Time periods	1986-2006	1986-2001	2001-2006	1986-1991	1991-1996	1996-2001	2001-2006	1986-2006
Hs [m]	Number of sea states							
0.0-0.5	84114	60326	23788	17703	20633	21990	23788	84114
0.5-1.0	47709	36527	11182	12204	11722	12601	11182	47709
1.0-1.5	17152	13315	3837	4590	4644	4081	3837	17152
1.5-2.0	4269	3316	953	814	1474	1028	953	4269
2.0-2.5	2248	1669	579	384	738	547	579	2248
2.5-3.0	2135	1810	325	636	722	452	325	2135
3.0-3.5	1179	1028	151	255	523	250	151	1179
3.5-4.0	94	76	18	20	40	16	18	94
4.0-4.5	288	258	30	55	136	67	30	288
4.5-5.0	69	69	0	1	59	9	0	69
5.0-5.5	21	21	0	11	5	5	0	21
5.5-6.0	20	20	0	0	20	0	0	20
Total	159298	118435	40863	36673	40716	41046	40863	159298

a b c

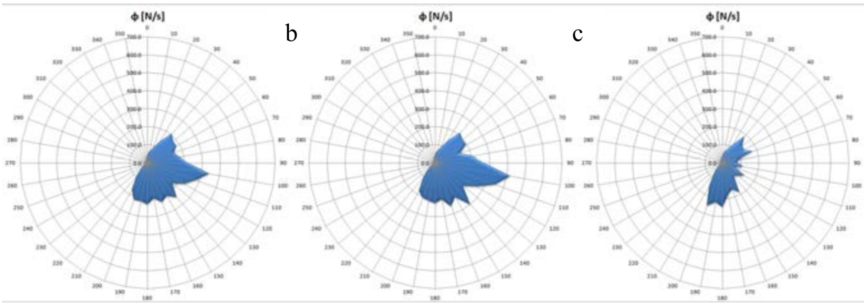


Fig.5. Wave energy flux between1986-2006(a); Wave energy flux between 1986-2001(b); Wave energy flux between 2001-2006(c).

The data across the whole time period shows that greatest part of the wave energy is between 40° and 200° N direction, with a maximum value centred on the 100°N direction (Fig. 5a).

The data referred to in the periods before and after 2001shows that before this time the significant wave height was below the threshold of 5.5-6.0 m, and after 2001 it wasdown to 4.5 m. The wave energy flux in those two periods is quite different, infact before 2001 the flux distribution is similar to the general one (Fig. 5b), but after 2001 there is no energy peak in the 100° N direction (Fig. 5c).

Comparing the time evolution of the coastline with the time evolution of the wave climate it can be observed that the beach accretion occurred when the wave climate was more severe (1985-2001), and,to the contrary, the erosion occurred when the wave climate was less severe (2001-2006).

3.3. River sediment contribution

River sediment contribution has been evaluated by analysing the rainfall time series and the land cover data. The main rivers are the Stilaro and the Assi rivers.

The land cover data used are related to year 2000 and year 2006 (Corine Land Cover project), which is freely available on the government agencywebsite "Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)". Comparing these two periods it can be said that only 2.5% of the entire surface has changed.

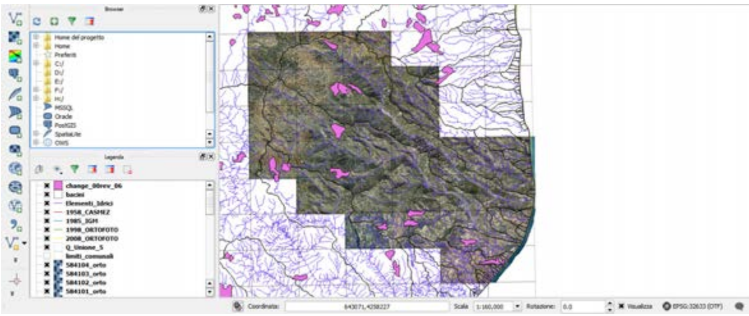


Fig. 6. Changes between Corine Land Cover 2000 e 2006 (violet color) (from ISPRA).

The average rainfall registered in the station near the area (Serra San Bruno, Monasterace Punta Stilo, Stilo Ferdinandea, Mongiana e Fabrizia) was analysed. The time periods are the same as the ones described previously, and they are reported in Tab. 3. The variation in the different periods is quite regular, and only in the Monasterace Punta Stilo station was a 10% difference registered.

Table 3. Average annual rainfall.

Station	h_{med} (1986-2006) [mm]	h_{med} (1986-2000) [mm]	h_{med} (2001-2006) [mm]
Serra San Bruno	1807.2	1617.9	1608.8
Monasterace Punta Stilo	701.7	467.8	739.1
Stilo Ferdinandea	1578.3	1710.8	1652.7
Mongiana	1844.4	1810.6	1697.2
Fabrizia	1727.6	1652.6	1706.9

4. Quick and temporary solution

After the storms in 2013, a rubble-mound barrier was erected (Fig. 7a) (Barbaro & Foti, 2013). The barrier has a trapezoidal shape, is 3m height, 6m in width and 30m long. It was intended to be only a temporary solution in order to protect the Doric Temple until a wider and more definitive solution could be devised.

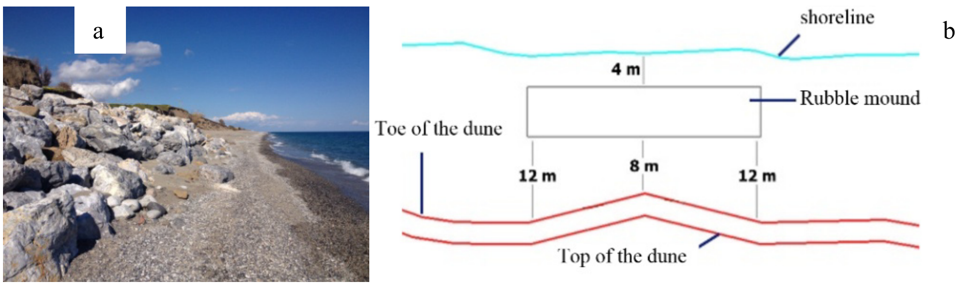


Fig. 7. Rubble-mound barrier(a); sketch after the sea storms(b).

5. Conclusion

The paper deals with the coastal erosion in Monasterace Marina, Italy, near the Kaulon Archaeological site. All the possible erosive causes have been investigated through the analysis of cartography, wave and weather climate data, and the use of soil. In particular, c Cartography data consists in aero photogrammetry by CASMEZ (1958), IGM (1958) and aerial photos (1998 and 2008), provided by the Calabria Basin Authority (ABR), and satellite imagery provided by Google Earth Pro. Wave time series starts on 1986/10/01 and finishes on 2006/31/03 and provided by the Met Office database. The land cover data used was related to year 2000 and year 2006 (Corine Land Cover project), which is freely available on the government agency website "Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)". The weather and climate data was average rainfall registered in the station near the area (Serra San Bruno, Monasterace Punta Stilo, Stilo Ferdinandea, Mongiana e Fabrizia). This analysis was carried out for different historical periods over the last 60 years and has as its objective the evaluation both the individual causes and the interactions that exist between them.

The coastline time evolution has been compared to the wave climate, and the comparison has shown that during the 1985-2001, when the wave climate was more severe, there was beach accretion; and during 2000-2006, when the wave climate was less severe, there was been erosion.

The rainfall and land cover time evolution was studied, and these two phenomena appear to be in an equilibrium phase.

The case history discussed here, gives information regarding the shoreline evolution, in particular it could be said that no straight correlation has been found between the wave climate and the long term shoreline evolution. It is reasonably right to think that the absence of correlation is due to time window of observation, which is too much wide, and it is also due to the lack of information regarding the presence of river structure near the site. Further study should be done in order to better investigate the phenomena.

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