Recent evolution and the present-day conditions of the Campanian Coastal plains (South Italy): the case history of the Sele River Coastal plain

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Abstract

The low coasts of the Campania are generally located in the main alluvial coastal plains of the region. These coasts have been affected, during late Quaternary, by strong progradation and more recently by erosion and episodic flooding particularly during storm events. The causes are essentially to be sought in the decrease in sedimentary discharge due to forest hydraulic engineering works but especially to the construction of many artificial dams along the main rivers, coupled whit subsidence and or increases in sea levels. Such events generally occur in coastal plains where the sectors close to the present-day dune ridge are morphologically lower (in general no more than 1–3 m a.s.l.). The main goal of this study was to provide a synopsis of the coastal vulnerability and present a new semi-quantitative method to assess coastal erosion. Eight factors describing the current system state of the beaches and the effects of the wave climate and human activity were combined to assess the potential erosion of the Sele River coastal plain. The method shows the high erosion potential at the mouths of the Sele, Picentino and Tusciano Rivers, while the areas south of the Sele river mouth and the zone stretching from Lido Lago to the Asa channel showed low hazard levels.

Keywords: coastal vulnerability, coastal erosion potential, Campanian coastal plains, South Italy.

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1 Introduction

In the last six millennia the plains in the southern Italian region of Campania have experienced coastal progradation amply documented by several dune systems. Since the 20th century this trend has been interrupted and many stretches of the coastline are now affected by erosion, at times severe. This has serious implications both for public safety and of a socio-economic nature. The causes are essentially to be sought in the decrease in sedimentary discharge due to forest hydraulic engineering works but especially to the construction of many artificial lakes along the main water courses. Clear evidence of this is the transformation of the mouths of the main water courses from fluvial-dominated to wave-dominated. A further factor is intense urbanisation, which took place especially after World War II in the wake of tourist development. These trends may be further amplified by the rise in sea level due to climate change [1]. This could increase the possibility of storms producing coastal erosion, temporary or episodic inundation. For much of the coastline in northern Campania, the state of the coastline and the relative coastal hazard have been extensively described by De Pippo *et al.* [2]. To assess the erosion vulnerability of the coastline in southern Campania, especially the plain of the River Sele (fig. 1), we used a new semi-quantitative method.

2 Geomorphological setting

The Tyrrhenian flanks of the Campanian Apennines are characterized by a very articulated topography due to alternating mountainous transverse ridges, valleys and alluvial plains. From NW to SE the Campanian coastal area presents the structural high of Monte Massico, the graben of the Campana Plain, the structural high of the Sorrento and Amalfi peninsula, the graben of the Sele plain and the structural high of the Cilento (fig. 1). The presence of two topographic highs, the Phlegraean Fields and Vesuvius volcanoes, causes the zoning of the Campana plain, from NW to SE, into the Volturno coastal plain, the alternating high and low coasts of the Phlegrean fields, the Sebeto coastal plain, the alternating high and low coasts of the Vesuvian area, and the Sarno River coastal plain. The plains along the coastal strip of Campania result from the aggradation of structural depressions of differing width and geometry whose bed is as much as several thousand metres lower than the Apennine massifs and other hills in between [3–6]. These coastal plains are the terminal point of the major water courses in the region, with their catchment areas comprising almost the whole of Campania, especially that of the River Volturno and the River Sele. At the mouth, both rivers, especially the Volturno, have a marked delta cusp that interrupts the straight coastline. It is precisely such sectors that have been – and still are – subject to sudden phases of coastline advance and retreat.

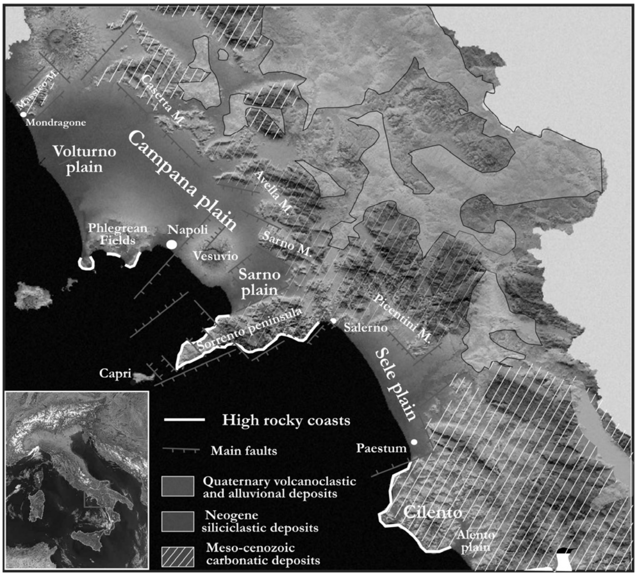

Figure 1: Geological and structural setting of the Campanian coasts.

3 Long- and middle-term evolution of the Campania coastal plain: current state of knowledge

3.1 The Campana plain

The Campana Plain comes from volcano-sedimentary aggradation of the peri-Tyrrhenian graben of the same name, whose fault margins are roughly at the foot slopes of the carbonatic reliefs (fig. 1). This graben is identifiable from the Lower Pleistocene [7, 8]. Thus extensive parts of the area currently occupied by the Campana Plain were invaded by transitional and shallow marine environments: the sedimentation rates, with a significant contribution from the Phlegraean and Vesuvian eruptions, on average managed to offset subsidence. Indeed, the sea-level rise during the Tyrrhenian interglacial (MIS 5) brought the coastline almost right up to the limestone massifs at the margin of the plain (fig. 2A). To confirm this, the coastal deposits of MIS 5 have been found by probes tens of metres below sea level at several points in the plain subsoil [7, 9] and raised along the margins of the Avella Mts [7].

Since the Upper Pleistocene the Campana plain has been divided into two large physiographic units due to the emergence of volcanoes around Naples: the Volturno plain to the NW and the Sarno plain to the SE. Contributing significantly to the forming of the two plains is the thick ignimbrite layer of *Tufo Grigio Campano* (39 ka BP, De Vivo *et al.* [10]) which produces rapid volcanoclastic aggradation and shoreline progradation for several kilometres.

For the Volturno plain, during the final phases of Versilian sea-level rise the shoreline formed a type of gulf reaching some km inland from the present-day terminal sector of the river (fig. 2A).

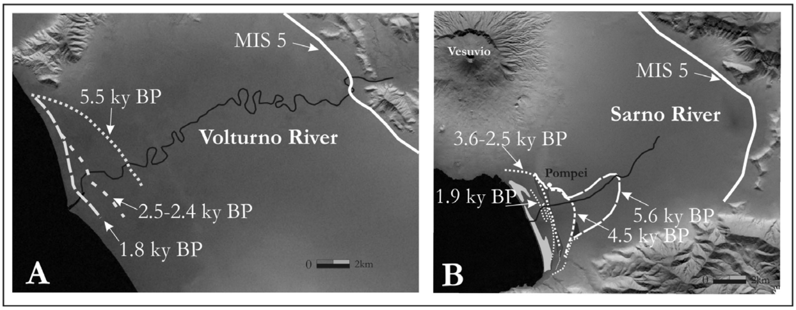

Figure 2: Late Pleistocene and Holocene shorelines of the Campana plain. A. the Volturno river alluvial-coastal plain; B: Sarno river alluvial-coastal plain. The dune ridge positions are shown in dark and light grey.

The last progradation phase of about 2 km occurred during the last 6,000 years when the rates of sea-level rise slowed considerably, leading to the formation of coastal lagoon-dune barrier systems. For the historical and protohistoric period the most morpho-dynamically active sector was that of the river mouth, which presented alternately landward (palaeogulfs) and seaward shorelines (delta cusps). Based on Cocco *et al.* [11], drawing on archaeological data and an analysis of historical maps, it is possible to reconstruct the trend in the shoreline near the delta cusp of the Volturno mouth (fig. 3).

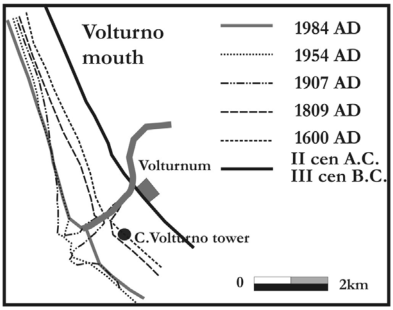

Figure 3: Shoreline variation at Volturno river mouth, from Cocco *et al.* [11].

According to some authors, the coastline has been affected by constant progradation starting from the Roman period (3rd century BC): the delta cusp today extends into the sea over 2.5 km further than the ancient Roman city of Volturnum, founded close to the ancient mouth. The period of peak progradation of the delta cusp occurred during the 19th century. The severe progradation could be related to the well-known cold and wet climatic phase of the Little Ice

Age in the 18th-19th centuries [6, 13]. For the period from 1954 to 1984 the coastline continued to advance between 1.5 m and 2.5 m per year, except for the delta cusp, which was subject to a rapid straightening process, retreating by hundreds of metres, especially in the area on the left. This change could be related to the reduction in river sediment discharge resulting from the end of the Little Ice Age, especially to human intervention in the hydrographic basin (construction of weirs, gravel and sand extraction, “cementification” of extensive sections of the water course). By contrast, in the Sarno plain, south of the Somma-Vesuvius edifice (fig. 2B), subsidence appears to have continued until the historical period [4, 5]: Tyrrhenian coastal deposits are tens of metres lower [13], while the beach linked to the Holocene transgression maximum (more than 6 km beyond the present-day coastline) is about ten metres lower (fig. 2B). This is proof that the rate of Late Quaternary subsidence increased during the Holocene, reaching mean rates of about 2 mm/a. Similar values may also be found for historical times, as shown by the lowering to -4/-5 m of the Roman shoreline near Pompeii [8]. The tendency of the coastline to prograde is only reached when the uplift rate over the base level (given by summing the sea-level variation and subsidence of the plain) is below that of the (sedimentary+pyroclastic) aggradation rate of the plain [14]. Also in this plain progradation has taken place only in the past 5000 years through the juxtaposition of increasingly advanced coastal lagoon-dune barrier systems up to the present-day position (fig. 2B).

3.2 Sele plain

The Sele Plain derives from the aggradation of a Plio-Quaternary depression along the western margin of the southern Apennine chain and known as the Salerno Gulf-Sele Plain graben. Extending about 400 km^2, its triangular shape is delimited seaward by a straight sandy coast, stretching between the towns of Salerno and Agropoli, encircled landwards by a range of calcareous mountains (Lattari, Picentini, Alburni, Soprano-Sottano) as well as by the arenaceous mountains in the Cilento (fig. 1). The southernmost portion of the plain, formed during the Last Interglacial (Tyrrhenian stage, MIS 5 [15–17]), is characterized by beach-dune ridges (Gromola-S. Cecilia-Arenosola-Aversana ridges) (fig. 4).

The present elevation of about 11–15 m a.s.l. of the Tyrrhenian coastal deposits proves that the plain has been moderately uplifted since the last interglacial [3]. A younger coastal sector occurs between the Tyrrhenian sandy-coastal ridge and the present shoreline. This belt represents the evolution of a barrier-lagoon system, shifted alternatively landwards and seawards during the Holocene. It includes a composite sand ridge system, elevated 1-5 metres a.s.l., which is partly exposed along the present coast and disappears inland under a muddy depression, rising about 1 m a.s.l. At the beginning of the Holocene, the progradational trend was interrupted by at least three phases of formation of sandy coastal ridges, knows as the Laura ridge (dating to the interval that spans from 5.3 to 3.6 ky BP) and Sterpina ridges (I and II, dating, respectively, to before 2.6 ky BP and about 2.0 ky BP) [15, 16, 18–21].

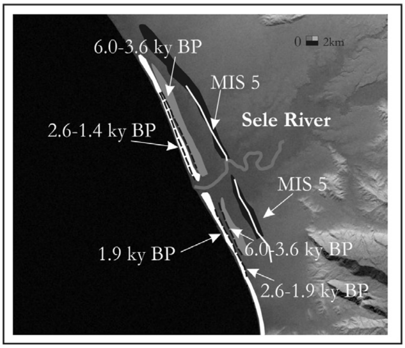

Figure 4: Late quaternary shorelines of the Sele river alluvial-coastal plain. In dark and light grey are the Tyrrhenian and Holocene dune ridges.

The coastal area of the Sele plain could be vulnerable to a relative sea-level rise, storms and flooding due to the presence of large areas with a topographic height lower than 2m. The shoreline from 1200 to 1809 was in a progradation phase, with a mean value of about 0.3-0.4 m/year. Indeed, the coastguard towers built in this period at a short distance from the shoreline are at present located about 200 m from the sea [22, 23]. During this progradation phase, a coastal dune system (Sterpina dunes) was formed. From 1809 to 1908 a strong progradation of the littoral zone occurred over the whole coastal area, reaching its maximum extension at the right of the Sele mouth, while only the Tusciano mouth was affected by erosion [23]. From 1908-1954 the progradational phase is predominant in the areas closest to the Sele mouth, with the exception of its right lobe that has retreated by about 25 m. Since 1954, the coastal area of the Sele plain has experienced an erosional phase [23–25]. Very recent studies using the method of shoreline comparison available in the Digital Shoreline Analysis System (DSAS [26]) have highlighted the shoreline variation from 1870-2009 [27]. Comparison of shoreline variations occurring in all eight investigated time intervals (fig. 5) shows the decrease in the shoreline variation rate from 1870 to 2009 and that the highest rates of coastal retreat are around the river mouth (Sele mouth: maximum erosion −4.8 m/y, Picentino-Tusciano mouths: maximum erosion –1.8 m/y) [28]. This analysis suggests that the shoreline changes along the beaches of the Sele river basin might be mainly associated to a reduction in coarse-grained sediment outflow from the Sele River. Direct measurements of river sediment transport are absent. However, a recent study by Ferrante *et al.* [29] and Vallifuoco *et al.* [30] combining numerical models and core stratigraphy seems to support this hypothesis. The retreat of the shoreline, mainly occurring at the Sele mouth, was also due to the interaction between two longshore currents with opposite directions that generate a cross shore current directed seawards with a direction 220 N. This current coupled with oscillatory motion generates a nested current in the bottom boundary layer that removes sand from the littoral cell and releases it on the inner shelf during major sea storms [29].

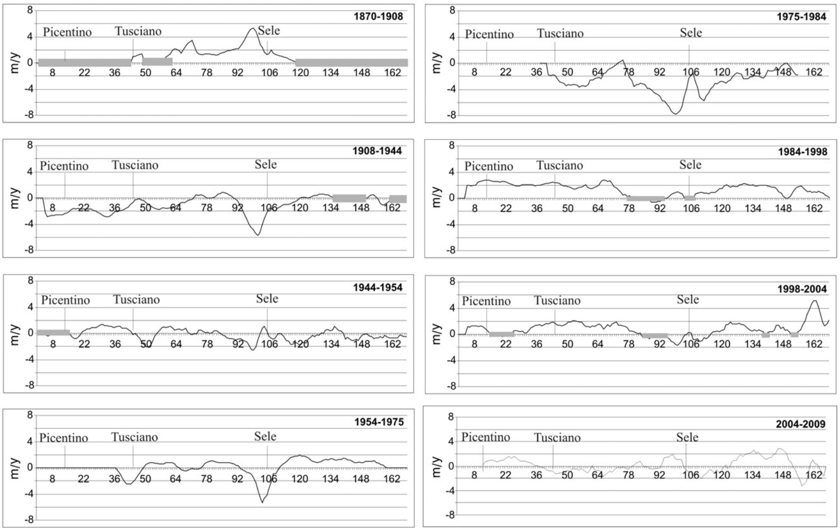

Figure 5: Shoreline variation in different time windows. In the grey areas such variations cannot be defined [28].

4 Erosion potential assessment in the Sele coastal plain

Starting from the method proposed by Gornitz *et al.* [31] to define the coastal vulnerability index as the sum of permanent inundation, episodic inundation and erosion potential, we proposed the following eight factors to define the erosion potential of coastal areas at regional and local scale.

The *condition of the dunal system (DS)* was defined qualitatively, as a relation of three sub-factors:

$$DS = \frac{(DE + DC + DA)_x}{(DE + DC + DA)_{MAX}} \cdot 100 \tag{1}$$

where DE is the erosional state of the dune, mainly based on the evaluation of topographic profile and vegetation type; DC indicates the spatial continuity of dune system and DA the presence or absence of artefacts. The DS assumes a normalized percentage with the maximum value in the study area.

The *backshore width (BW)* corresponds to the beach width measured between the dune crest and shoreline position at high tide:

$$BW = \frac{SW_x}{SW_{MAX}} \cdot 100 \tag{2}$$

where SW_x is the maximum backshore width in the study area, while SW_{MAX} is the backshore width along the coastal sub-zones.

The g*rain size of the intertidal beach* (*GS*) assesses the influence of the wave climate [32–35] on coastal erosion. It is calculated as follows:

$$GS = \frac{ID50_x}{ID50_{MAX}} \cdot 100 \tag{3}$$

where *ID50* is the maximum grain size at the 50th percentile in the whole study area, $ID50_x$ is the grain size diameter at the 50th percentile calculated for the coastal sub-zones (zoning of the Sele Plain in a 2 km-long sector).

The *rate of shoreline change* (*SC*) was defined, considering both long (100-year) and short term (30-year) variations, as follows:

$$SC = 0{,}75 \cdot SC_1 + 0{,}25 \cdot SC_2 \tag{4}$$

where SC_1 is the short term and SC_2 the long term.

The *effects of the wave climate on the beach* were defined using two variables, the *maximum run-up of storm event* (*XR*) and *tide range* (*XM*), calculated as follows:

$$XR = \frac{R_{2\%}}{SW \cdot sen\beta} \cdot 100 \tag{5}$$

$$XM = \frac{M}{SW \cdot sen\beta} \cdot 100 \tag{6}$$

where$R_{2\%}$ is the run-up due to extreme events as defined by Stockdon *et al.* [36], *M* is the maximum tide range for the study area*,* *SW* is beach width at each transect and β is the slope of the intertidal beach.

Fluvial system (*FS*) features were defined for each sector as follows:

$$FS = \frac{(MT + LT + AB + RB - DI)_x}{(MT + LT + AB + RB - DI)_{MAX}} \cdot 100 \tag{7}$$

where *MT* is the mouth type, LT indicates the lithology, *AB* the basin area, *RB* is the ratio between the basin area calculated from the dam to the mouth and whole basin area.

The last parameter considered is the *Coastal Erosion Defences (ED)*. This parameter qualitatively describes the conservation state of man-made coastal defences.

The eight factors described above were ranked linearly into five classes (very low, low, moderate, high, and very high) as proposed by [37] Gornitz *et al.* and subsequently adopted by several authors [38–41].

These ranked variables (tab. 1) are combined as the square root of their product and divided by the total number of variables to calculate *coastal erosion potential* (*EP*).

$$EP = \sqrt{\frac{DS \cdot WB \cdot SE \cdot SC \cdot XR \cdot XT \cdot FS \cdot ED}{8}} \tag{8}$$

EP was calculated for 16 zones (labelled from A to P) 2 km long and shown in the erosion potential map (fig. 6). The study area was ranked into five classes, from very high to very low, by using the natural break method which defines the

Table 1: Ranking of factors used to define coastal erosion potential.

Potential coastal erosion	***1***	***2***	***3***	***4***	***5***
Dunal system condition **DS (%)**	< 20	20 - 40	40 - 60	60 - 80	> 80
Backshore width **BW (%)**	> 80	60 - 80	40 - 60	20 - 40	< 20
Grain size of intertidal beach **GS (%)**	< 20	20 - 40	40-60	60 - 80	> 80
Rate of shoreline change **SC (m)**	> 2 Accretion	2 - 1	1- -1	-1- -2	> -2 Erosion
Effects of wave climate on the beach **XR (%)**	< 20	20 - 40	40 - 60	60 - 80	> 80
Effects of tide range on the beach **XT (%)**	< 20	20 - 40	40 - 60	60 - 80	> 80
Fluvial system **FS (%)**	< 20	20 - 40	40 - 60	60 - 80	> 80
Coastal Erosion Defences **ED**	Excellent	Fair	Good	Very poor	Insufficient or absent

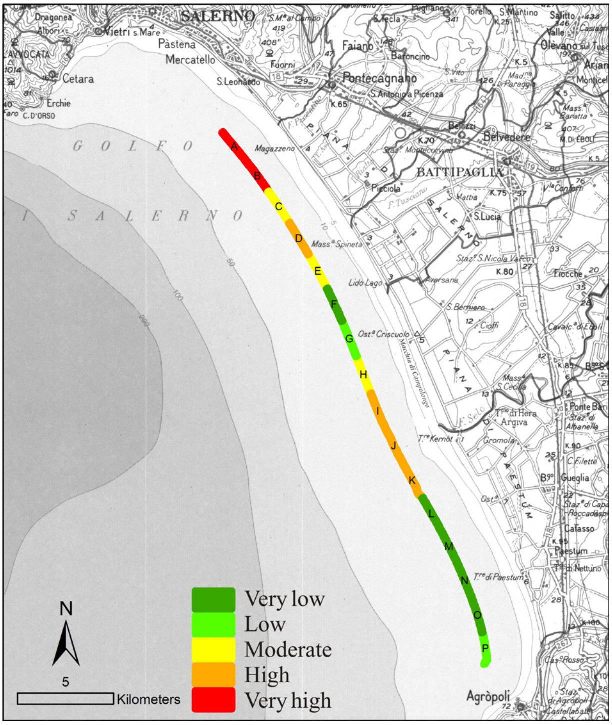

Figure 6: The Sele plain map of coastal erosion potential.

separation points among the frequency values and minimizes the variance in each class. Application of the new method shows that 37% of the coastline of the Sele river plain has a high erosion potential, corresponding to sectors closer to the town of Salerno and the areas on or close to river mouths. By contrast, about 44% of the whole coastline is not subject to erosion, almost all concentrated S of the Sele river mouth. The remaining areas (19%) have an intermediate or moderate erosion potential. High potential erosion is found at the mouths of the main rivers of the Sele plain (Sele, Picentino, Tusciano) and of the Asa stream (transects A, B, D, I, J, K in fig. 6). This is mainly due to the discontinuity or absence of the dune system, the high run-up value and beach width (fig. 6). The opposite features typify the area south of the Sele river and the zone stretching from Lido Lago to the Asa stream (transects F, G, L, M, N, O, P in fig. 6), giving these areas a low and very low erosion potential. Medium hazard potential applies to the zone from the Asa stream and Tusciano river and that close to Lido Lago and Macchia di Capolongo (transects C and H, in fig. 6). This hazard class is mainly due to the condition of the dunal system, the distance from the river mouth and beach width, respectively. The reasons for such differences are to be sought in the set of all elements considered in the calculation model. Human activity, the decrease in sediment transport, and destruction of the dunes over extensive areas are to be considered the prime causes behind such variations.

In conclusion the analysis of the coastal hazard in the Campanian Plains shows that many sectors are exposed to high hazard degrees. De Pippo *et al.* [3] identify for the Volturno Coastal Plain a 55% of coastal area in extreme or high hazard degree, while for the Sarno and Sebeto Plain these hazard classes reach the 80%. On the contrary the Sele Plain is less exposed, in fact only the 37% of coastline is characterized from high to very high hazard degree.

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