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Risk assessment and management strategies to sea level rise along the Sele River mouth (southern Italy)

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***Abstract* – Rising sea level due to global warming increases the need to analyse coastal risk to conceive management and adaptation strategies aimed at coping with potential marine impacts. In this context, this study presents future scenario of inundation risk along a strategic coastal area located in the Campania Region (southern Italy): the Sele River mouth. This zone is characterized by low topography and relevant subsidence rates that make it prone to be impacted by sea level rise. Expected local sea level for the year 2065 has been evaluated coupling the global IPCC projection with local subsidence trends. Once the risk has been evaluated as a combination of hazard and exposure, a set of management strategies, which include both operative Best Management Practises (BMPs) and monitoring actions, have been suggested and applied on the tested area.**

I. INTRODUCTION

Campanian coastal plains are the result of the complex interaction among sedimentary inputs, tectonics and eustatism [1-3]. Among them, the Sele coastal plain (Fig. 1) is characterized by an extended beach-dune ridge system formed by the Gromola-S.Cecilia and the Arenosola-Aversana paleoridges that dated back to the Last Interglacial period (MIS 5). Based on chrono-altimetric data of the MIS 5 palaeo-sea level, the plain experienced a slight uplift in the last 100–120 ky [4-5]. The back-barrier domains were filled up with lagoon and fluvio-palustrine sediments when the sea level rise stopped and aeolian sands finally formed several coastal ridges. Remnants of the back-barrier terrace related to these high-stand phases are preserved in the modern landscape at 11–14 m a.s.l., while the coeval shoreface sediments occur up to 13 m a.s.l. and the dunes up to 23 m a.s.l. [5].
The present coastline (Fig. 1) testifies the evolution of the Holocene barrier-lagoon system [6]. Specifically, a composite sandy ridge forms a dune system with a mean height of about 3 m a.s.l. that is currently interrupted by rivers and artificial drainage channels. A large back-ridge depression (reaching around 0.50 - 1.5 m below sea level) hosted palustrine and marshy environments [7] that have been artificially drained and today result prone to be affected by marine inundation [8].

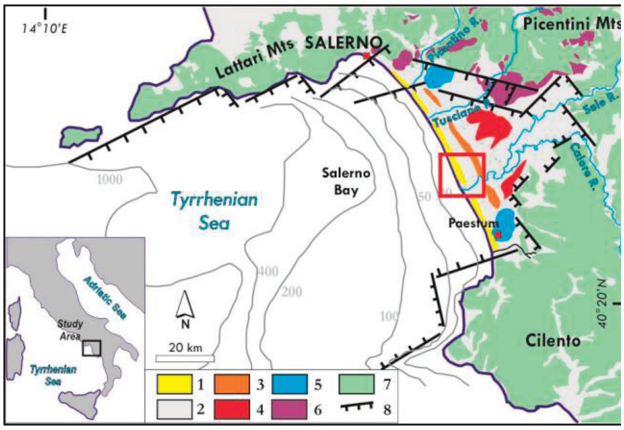

Fig. 1. Schematic geological map of the Sele Plain area (after [5]); the red square indicates the location of the study area, reported in Figs. 2 and 3.
Legend: 1) Laura-Sterpina sandy barriers (Holocene); 2) fluvial-marshy and volcano-clastic deposits (Late Pleistocene - Holocene); 3) Gromola-S. Cecilia-Arenosola-Aversana sandy barriers (Late Pleistocene); 4) marine, continental and transitional deposits (Middle-Late Pleistocene);5) travertine deposits (Middle Pleistocene - Holocene); 6) Eboli Conglomerates (Early-Middle Pleistocene); 7) Pre-Quaternary bedrock; 8) Main faults.

The infill of the plain is characterised by several marine to continental lithofacies among which dunal and coastal sands, back-ridge (lagoon and palustrine) silty clays, paleosols and thick peaty layers are the more diffused. Their abundance may promote local subsidence, mainly in sectors where the silty clays and peaty layers are thicker, such as in the back-barrier sectors of the plain [5] (Fig. 1). In this context, the risk assessment procedure applied for the area of the Sele River mouth allows obtaining a zonation that accounts for the dynamic component associated with the local Vertical Ground Displacements (VGDs) and future eustatic projections. Therefore, the high-resolution results obtained in this study enable to adapt risk management strategies to the local topographic characteristics and to identify the most effective adaptation measures suitable to cope with expected future sea level positions.

II. METHODS

In order to assess the future scenario of permanent coastal inundation risk and to identify possible management strategies, a four steps methodology is proposed:

Step 1 - Proneness analysis (H): the low topographic areas are classified in four hazard classes of inundation due to local sea level rise, as proposed in [8-10]. To this aim, the expected relative sea level for the year 2065 is evaluated as a combination of global sea level projection proposed in [11] under the RCP8.5 scenario (corresponding to 0.30 m) and local vertical displacement rates estimated by MT-InSAR data analysed following the methodological approach proposed in [12].

Step 2 - Exposure analysis (Ex): the anthropic and natural elements located in the areas prone to be impacted by sea level rise as well as the social-vulnerability level are evaluated, and four classes of exposure level are proposed [10].

Step 3 - Risk assessment (R): once the hazard and the exposure classes are identified (Step 1 and Step 2), the risk to sea level rise is calculated by spatially combining these layers. The resulting risk is classified in four classes (ranging from R1- low risk to R4 – very high risk), using the matrix in Table 1, as proposed in [9-10].

Table 1. Coastal risk matrix. The risk is evaluated by combining the coastal Hazard level (H) with the Exposure level (Ex).

Risk		Exposure			
		E_x4	E_x3	E_x2	E_x1
Hazard	H4	R4	R4	R3	R2
	H3	R4	R3	R2	R1
	H2	R3	R2	R2	R1
	H1	R2	R1	R1	R1

Step 4 – Application of coastal risk management measures: a set of suitable planning actions and management strategies are proposed for the management of the coastal areas potentially at risk. According to the "Plan, Do, Check, and Act" (PDCA) Cycle [13-14], which also reflects the general coastal management cycle [15], different conservation, defence, and recovery actions are proposed:

- PLAN: assessing hazard and risk scenarios;
- DO: defining Best Management Practices (BMPs);
- CHECK: scheduling monitoring actions for the validation of the coastal impact scenarios;
- ACT: planning effective adaptation strategies.

First, BMPs to be undertaken for each specific risk class (R1, R2, R3, and R4) are suggested. Then, several checking actions are proposed for monitoring the present trends and validating the future projections provided by models. Finally, once the risk is validated by observational data, several actions are proposed for ensuring the conservation of the natural ecosystems, their related services and the maintenance of human activities by introducing, in addition to BMPs, structural and non-structural adaptation strategies.

III. RESULTS

The results of the quantitative assessment of the subsidence process referred to the studied coastal plain is showed in a 50-m spaced grid maps (Fig. 2A), displaying the average rates of VGDs (expressed in mm/year) referred to the period 1992-2010. This map shows that the analysed coastal sector on the Sele River plain is characterized by complex subsidence patterns. In detail, the Sele River mouth area is characterized by moderate values of subsidence (-2.5 to -7.5 mm/y) with a hot spot developing 3 km inland. In the northern part of the study area, a continuous coastal strip is characterized by subsidence values ranging between -2.5 to -10 mm/y.

To identify the areas located below the projected future sea level positions (evaluated as sum of eustatic sea level and local vertical ground movements), the GIS topographic model has been processed following the "bathtub approach" [16-17]. The extent of each hazard class has been evaluated for the investigated coastal area considering the RCP8.5 scenario for the years 2065 (Table 2). Considering the 2065 projection (Fig. 2B), the extent of H4 class is more than 10%, with an extension of 3.5 km^2, while H3 and H2 classes extend respectively 11% and 15%. Accounting for H1 class, its surface occupies 63% on the investigated area.

Regarding the exposure evaluation (Fig. 2C), it has accounted for the current spatial distribution of the vulnerable assets and social vulnerability. Results are shown in Table 1 both in km^2 and as a percentage of the investigated area. Results show that the more diffused exposure class is the EXP3, with a value of 54% (17 km^2). In order to assess the spatial distribution of the different risk levels along the investigated coastal area, the hazard

(Fig. 2B) and the exposure (Fig. 2C) classes have been combined (cf. Step 3 - Table 1). Risk has been classified in four classes and the results are shown as coastal risk map (Fig. 2D). Furthermore, the extent of each class risk is indicated in Table 2. It results that R4 class occupies a considerable area (2.5 km^2), while R3 class occupies more than 12% of the area analysed.

Table 2. Coastal inundation scenario (H1 to H4), exposure assessment (EXP1 to EXP 4) and risk scenario (R1 to R4) for the Sele River mouth.

H1	**H2**	**H3**	**H4**
(km^2 / %)	**(km^2 / %)**	**(km^2 / %)**	**(km^2 / %)**
19.5 / 62.8	4.6 / 14.7	3.6 / 11.3	3.5 / 11.2
EXP1	**EXP2**	**EXP3**	**EXP4**
(km^2 / %)	**(km^2 / %)**	**(km^2 / %)**	**(km^2 / %)**
0.4 / 1.4	8.9 / 28.5	16.9 / 54.1	5.0 / 16.0
R1	**R2**	**R3**	**R4**
(km^2 / %)	**(km^2 / %)**	**(km^2 / %)**	**(km^2 / %)**
15.8 / 50.3	9.1 / 29.3	3.8 / 12.2	2.5 / 8.2

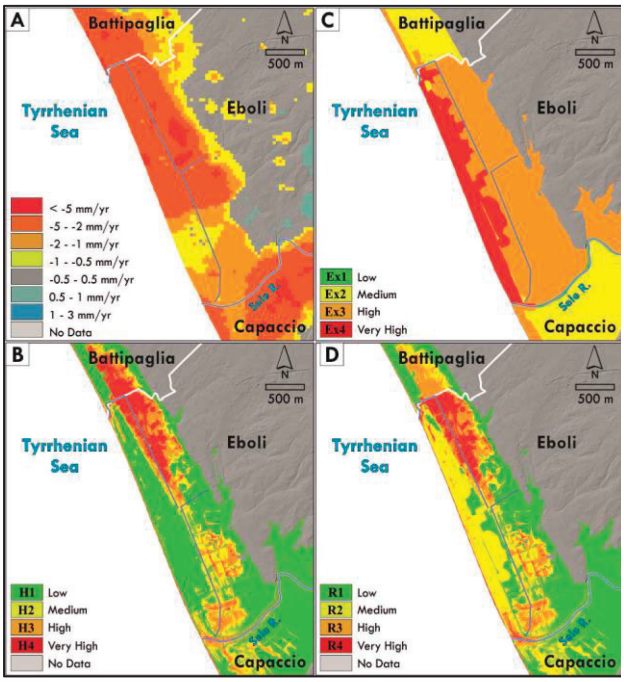

Fig. 2. (A) Subsidence map, (B) hazard map, (C) exposure map, (D) risk map evaluated for the year 2065 along the Sele River mouth area.

To provide a practical example on how to use the proposed approach for the risk management, a sector of the Sele coastal plain has been considered as a testing site for the identification of the areas suitable for each of the selected actions (Fig. 3). The area is characterized by the presence of a wide range of land use categories, including touristic beaches and wide agricultural zones. Furthermore, the results of the risk analysis have shown that the selected area is characterized by a different distribution of the risk classes (Fig. 2D).

Specifically, BMPs and monitoring actions have been classified accounting for the different land use categories, and then localized in the tested area in order to zone the territory according to the practices proposed. The proposed classification is shown in Fig. 3 (A, B).

Best Management Practices:

- MP1: Introducing land use restrictions;
- MP2: Limiting urban expansion;
- MP2a: Introducing strategies of land use and urban expansion;
- MP3: Avoiding coastal erosion due to human perturbations;
- MP3a: Limiting coastal erosion due to human actions;
- MP4: Avoiding groundwater over-pumping;
- MP4a: Limiting groundwater over-pumping;
- MP5: Promoting specific strategies of civil protection;
- MP6: Enhancing the population's awareness;
- MP7: The management of the territory is regulated by the present-day local management plans of local Basin Authorities.

Monitoring Actions:

- CM1: Tide gauge and buoy monitoring system;
- CM2: Weather monitoring system;
- CM3: Beach monitoring system;
- CM4: Hydrological monitoring system;
- CM5: Groundwater and saline wedge monitoring system;
- CM6: Topographic DGPS and UAV surveys;
- CM7: Remote sensing monitoring system.

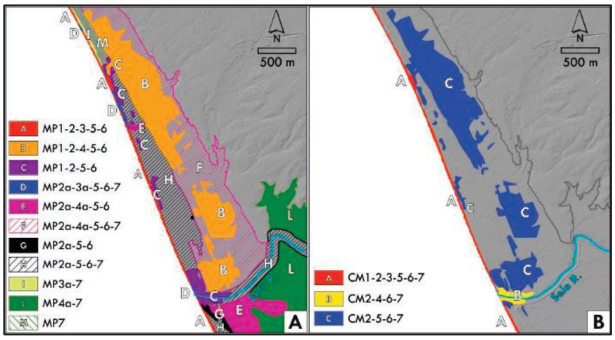

Fig. 3. Application of the actions proposed for the coastal risk management on a tested area of the Sele plain. (A) Management practices; (B) Monitoring actions.

IV. CONCLUSIONS

The performed analyses allowed evaluating and mapping the potential coastal inundation risk along the Sele coastal plain for the year 2065. The results suggest, in accordance with other studies [8, 18-20], that in the next few decades natural areas, beaches, human infrastructures, and wide portions of agricultural areas could be potentially affected by marine impacts (shoreline regression and inundation processes), with several zones with high hazard level.

In line with the most recent international indications, the here proposed hazard and risk maps represent a valuable tool for increasing effective territorial management aimed at the reduction of future climate-induced risks.

As strongly suggested by the international community [21-22], the approach here proposed for a strategic planning of the coastal area relies upon a detailed understanding of the coastal processes leading to local future sea level positions and related impacts.

Accounting for the proposed management practices, civil protection actions, mainly aimed at improving the local response and at enhancing the population's awareness, should be implemented in all the zones potentially prone to be impacted by sea level rise Furthermore, specific operative actions, such as limiting the groundwater pumping and avoiding anthropic beach erosion, should be tailored according to the specific land use context.

In conclusion, the results of this study can effectively address the national and international request of improving the knowledge and raising the awareness of policymakers and local administrators about the potential impacts of climate change to promote and facilitate the definition of effective coastal management regulations and the implementation of suitable adaptation strategies.

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