Electronic Supplementary Material

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A multi-risk methodology for the assessment of climate change impacts in coastal zones.

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Public institution	Responsibilities in coastal management/ administration	Name	Number
Coastal Region	Coastal protection and regional territorial planning	Friuli Venezia Giulia (FVG) region: Environment protection area; Town and territorial planning area. Veneto Region: Environment protection area; Town and territorial planning area.	4
Coastal Province	Provincial town and territorial planning	FVG provinces: Trieste, Gorizia, Udine. Veneto provinces: Venice, Rovigo.	5
Coastal Municipality	Local town and urban planning	FVG municipalities: Muggia, Trieste, Duino-Aurisina, Monfalcone, Staranzano, Grado, Marano Lagunare, Lignano Sabbiadoro. Veneto municipalities: San Michele al Tagliamento, Caorle, Eraclea, Jesolo, Cavallino Treporti, Venice, Chioggia, Rosolina, Porto Viro, Porto Tolle.	18
Port Authority	Planning and coordination of ports activities	Trieste, Monfalcone, Venice, Chioggia.	4
Civil Engineering Office	Safeguard of water resources, restoration and maintenance of coastal defences	Trieste and Venice.	2

Regional Environment Protection Agency (ARPA)	Monitoring and safeguard of the state of environment and sea; integrated management of marine and coastal habitats	Arpa FVG: Upper Adriatic observatory. Arpa Veneto: Upper Adriatic observatory.	2
River Basin Authority	Planning of the integrated management of water resources (quantity and quality)	Upper Adriatic River Basin Authority.	1
Public Works and Water Management Authority	Venice lagoon reclamation, hydraulic works, ports and lighthouses.	Venice Water Authority.	1
Total			37

Table S1. Public institutions involved as local stakeholders and experts during the implementation of the multi-risk assessment methodology in the North Adriatic coast [source: adapted from (Santoro et al., 2013)].

$\boldsymbol{h_1}$	$w_{1,2}$	$w_{1,3}$
$w_{2,1}$	$\boldsymbol{h_2}$	$w_{2,3}$
$w_{3,1}$	$w_{3,2}$	$\boldsymbol{h_3}$

Table S2. Example of hazard influence matrix. Hazard scores are placed in the grey cells. Weights used to measure hazard interactions (e.g. influence of sea level rise (h_1) on coastal erosion (h_2)) are placed in the white cells.

Linguistic Evaluation	Scores
Most important class/weight	1
Weakly less important class/weight	0.8
Rather less important class/weight	0.6
Strongly less important class/weight	0.4
Demonstratively less important class/weight	0.2
Absolutely not important class/weight (i.e. no vulnerability)	0

Table S3. Linguistic evaluation supporting the experts in the assignation of relative scores and weights (adapted from [1]).

Function	Description
1) $h_i' = h_i \cdot [1 + \frac{\sum_{j=1, j\neq i}^{n} w_{j,i} \cdot \overline{\emptyset}(h_j)}{\sum_{j=1, j\neq i}^{n} \overline{\emptyset}(h_j)}]$ h_i' = hazard score associated to the i^{th} hazard weighted according to the influence of other hazards in the investigated cell. The score ranges in [0,2]; h_i = hazard score associated to the i^{th} hazard for the investigated cell; h_j = hazard score associated to the j^{th} hazard for the investigated cell; $w_{j,i}$ = weight assigned to the influence of h_j to h_i using the hazard influence matrix (Table 1); $\overline{\emptyset}(h_j)$ = "not empty function" which assumes the value equal to 1 when the hazard j is present in the investigated cell and 0 otherwise; n = number of hazards in the system.	Function 1 is aimed at calculating the weighted score of each hazard affecting the investigated cell considering all the interactions with other hazards. If in the investigated cell a hazard (e.g. H_1) is not influenced by another, it will maintain its score (i.e. the score that it has on the analysed cell, h_1). Otherwise the score of h_i is multiplied by $1 + \frac{\sum_{j=1, j\neq i}^{n} w_{j,i} \cdot \overline{\emptyset}(h_j)}{\sum_{j=1, j\neq i}^{n} \overline{\emptyset}(h_j)}$ representing synergic influence of all the hazards affecting the investigated cell. The synergic influence is increased by 1 in order to better visualise the increasing score of the considered i^{th} hazard due to the hazard interactions. If there are no hazard relationships, synergic influence will turn to the indeterminate form of 0/0 which, for simplification, is assumed as 0.
2) $h = \frac{\sum_{i=1}^{n} h_i'}{2n}$ h = multi-hazard score associated to the investigated cell weighed and normalized in [0,1]; $h_1', \ldots, h_n'$ = single hazard scores associated the investigated cell weighted according to the hazard influences (calculated by Function 1); n = number of the investigated hazards in the case study.	The final result of Function 2 allows the normalization of the multi-hazard score in [0,1], considering that if in a cell a single hazard is located with a score of 1 (i.e. the maximum hazard score) with no other influencing hazards, than the multi-hazard score of that cell will be lower than the initial single hazard score h_i calculated with Function 1.
3) $p = P_n^V(H) = P_{n-1}^{\vee}(H) + p(h_n) - P_{n-1}^{\vee}(H) \cdot p(h_n)$ p = probability of the n hazards affecting the investigated cell in the same timeframe ranging in [0,1]; P^V = disjunctive probability function; H = vector of hazard scenarios for the investigated cell; n = number of the investigated hazards in the case study.	If the investigated cell is interested by a single hazard (e.g. H_1) only the probability of the hazard should be considered (e.g. $p(h_1)$). If the investigated cell is interested by 2 or more hazards (e.g. H_1, H_2), the disjoint probability of the hazards affecting the cell should be considered. Function 3 allows providing a probability to each cell considering that the hazards affecting the cell could happen individually (i.e. probability of the single hazard: for instance, it happens h_1 or h_2) or simultaneously (e.g. $h_1$happens together with h_2).

Table S4. Multi-hazard functions and their description applied in the multi-hazard assessment.

Sea level rise	0,8	0,5
0	**Storm surge**	0,8
0	0	**Coastal erosion**

Table S5. Hazard influence matrix applied to the North Adriatic case study. In the white cells the influence weights are listed.

Vulnerability factor	Vulnerability class	Storm surge score	Coastal erosion score	Description of the vulnerability classes
Slope angle (degrees)	Plains: 0°-6°	1	1	Low-lying areas are more vulnerable to flooding movements inland and should retreat faster than steeper regions [2, 3, 4, 5].
	Gentle to moderate slope terrain: 6°-20°	0,6	0,6	
	Steep slope terrain: >20°	0,2	0,2	
Coastal typology	Muddy coast	1	1	Muddy and sandy beaches are the most vulnerable geomorphic themes that could be affected by storm surges and coastal erosion [2, 5].
	Sandy coast	0,6	0,6	
	Rocky coast	0,2	0,2	
Shoreline evolution	Coast in erosion	NA	1	Retreating coasts are more vulnerable to coastal erosion, compared to stable or advancing ones [4, 5, 6].
	Stable coast	NA	0,6	
	Advancing coast	NA	0.2	
Mouth typology	Estuary	NA	1	Estuaries are considered more vulnerable than deltas to erosion as they are less prone to sedimentation processes [2, 4, 5].
	Delta	NA	0,2	
Dunes	Absence	NA	1	The absence of natural dunes can aggravate the vulnerability to coastal erosion as they cannot protect the surrounding area from the impact [7, 4, 5)
	Presence	NA	0,2	
Wetland typology	Inland wetlands (marshes, peatbogs)	1	NA	Inland freshwater wetlands can be affected more severely by the investigated impacts and they are considered more vulnerable (i.e. more sensible to salt water), respect to coastal wetlands [8].
	Coastal wetlands (salt marshes, salines, intertidal flats)	0,6	NA	
Wetland extent (Km²)	0 – 8.56	1	1	Small wetlands are considered to have higher vulnerability as they could be more sensitive to coastal erosion and storm surge pressures than wider [4, 5]).
	8.57 – 17.12	0,8	0,8	
	17.13 – 25.68	0,6	0,6	
	25.69 – 34.24	0,4	0,4	
	34.25 – 42.80	0,2	0,2	
Vegetation cover	Natural grassland and meadow	1	1	Natural grassland and meadow do not provide enough cover to the territory increasing its vulnerability to coastal erosion and storm surge [4, 5].
	Vegetation with shrubbery	0,6	0,6	
	Forest	0,2	0,2	
Agricultural use	Arable land	1	NA	Arable lands (i.e. lands under a rotation system or fallow lands) are more vulnerable as they are less defensive for the affected territory to storm surge than other identified classes [9, 4, 5].
	Stable meadow-Pastures	0,6	NA	
	Permanent crops	0.2	NA	
% of urbanization	> 10% of the land occupied by urban and industrial areas (per municipality)	NA	1	Areas in which more than 10% of the land is urbanised are considered more vulnerable to coastal erosion, as they cannot cope with erosion processes such as urban areas less urbanised [10, 4, 5].
	5% and 10% of the land occupied by urban and industrial areas (per municipality)	NA	0,6	
	< 5% of the land occupied by urban and industrial areas (per municipality)	NA	0.2	

Table S6. Vulnerability factors, classes and scores for the receptors analysed in the North Adriatic case study. NA means Not Applied and concerns the vulnerability classes that are not relevant for the considered hazards.

VULNERABILITY FACTOR	WEIGHT
Slope angle (degrees)	0,8
Coastal typology	0,8
Shoreline evolution	0,8
Mouth typology	0,5
Dunes	0,6
Wetland typology	0,6
Wetland extent (km^2)	0,5
Vegetation cover	0,5
Agricultural typology	0,5
% of urbanization	0,4

Table S7. Weights assigned to the vulnerability factors in the North Adriatic case study.

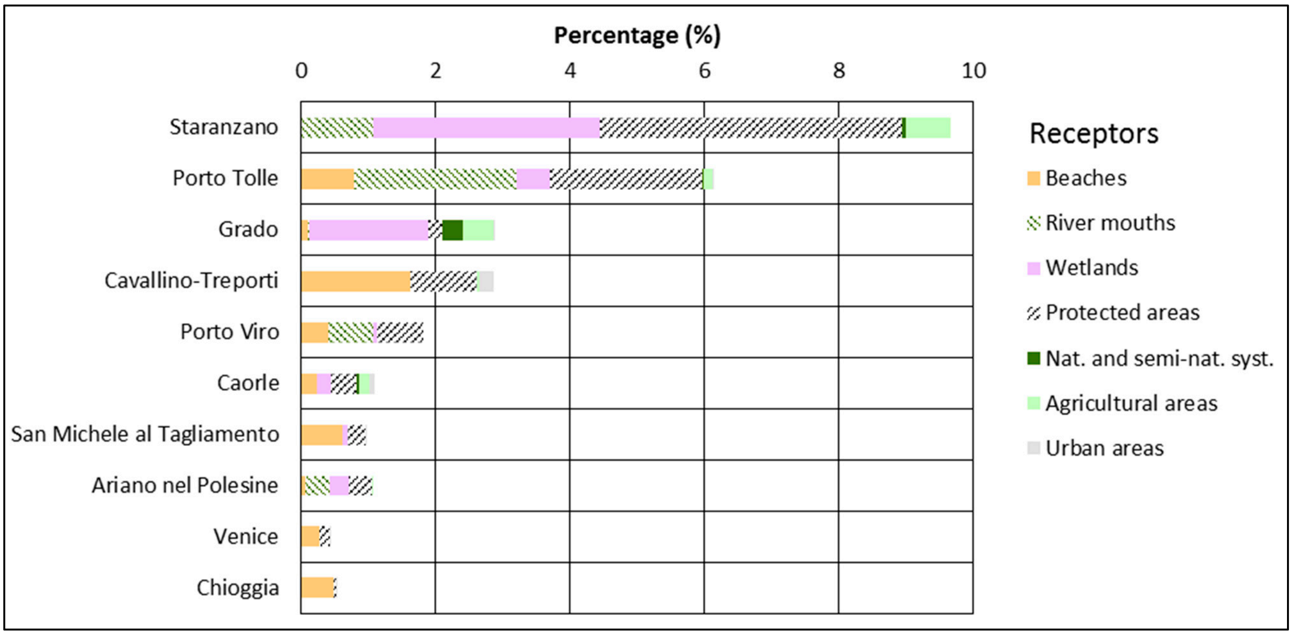

Figure S1. Percentage of surface associated with the very high and high multi-risk classes for the investigated receptors in the ten coastal municipalities most affected by multi-risk in the North Adriatic coast.

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