Report Phase B

Partner 2, ICRAM, Istituto centrale per la Ricerca Scientifica ed Applicata al Mare;

Partner 3, University of Ferrara, DST – Department of scienze della terra

Submersion risk assessment on coastal zones

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Introduction

In the literature, numerous methodological approaches are used for the management of areas exposed to environmental risk; in such sense, multidisciplinary methods are often used allowing the integration of data deriving from the historical and actual analysis of the state of the territory, with the identification and the quantification of the frequency, the intensity, the spatial and temporal distribution of the natural events potentially destructive. At the same time, the interferences and the synergies between these parameters and the human activities are considered. The association between the vulnerability and the level of anthropisation of the territory allows the risk assessment of the coastal zone.

In order to evaluate the vulnerability of a shoreline, a detailed analysis of the morphology and of the sedimentary characteristics of the beach can be used as indicators of the complex energetic processes, on which depends directly the coastal morphodynamic.

In the framework of this study, the methodology developed by Gornitz *et al.* (1994) for the risk assessment related to sea storm, already applied and implemented in Emilia Romagna by Simeoni *et al.* (2003) and in the Province of Venice by Fontolan *et al.* (2001), will be used. This methodology leads to the definition of vulnerability (**V**) and risk (**R**) through the creation of a territorial database and some simple procedures of calculation.

Such methodological protocol may also be an useful tool to support the optimization of intervention strategies, because: a) this method uses objective and univocal criteria for the classification of the shorelines features in function of the relative value of vulnerability; b) it provides foreseen patterns useful to calibrate the intervention actions in terms of integrated management.

A specific "informative level" will supply an indication about the potential incidence of the coastal submersion patterns, which are function of the value of set-up to coast connected to the recurrence of the extreme events, and of the forecasted sea level rise for the 2100 (Sea Level Rise, SLR).

The chosen areas for the application of the methodology are situated in the coastal zone of the Emilia-Romagna Region and in the portion central-southern part of the Lazio Region. These represent morphologically depressed sectors in which the submersion phenomenon is critic in the short term as well as in the long term.

1. ANALYSES OF THE SUBMERSION RISK

The proposed methodology in the framework of the MEDPLAN sub-project, is based on the parameterisation of the degree of shoreline trend to the submersion and on the evaluation of its distribution along the coast, through the identification of sectors with similar behaviour.

Obviously this kind of analysis, taking advantage of the variability of the geo-morphological and anthropic parameters, strictly depends on the territorial scale of reference. The choice of the parameters that characterise the coastal dynamic depends of the ability to identify and to represent their spatial variability. Therefore, the analysis of the Hazard will provide an evaluation of the direct impacts (submerged territory) in function of the entity of the set-up at coast for a given return period of the extreme events and for determined coastal typologies. These last ones are deduced from the interaction between geo-morphological characteristics and typologies of protective structures.

For the evaluation of the shoreline vulnerability, the detailed analysis of the morphology and the study of the sedimentary and anthropic characteristics of a beach can be use as indicators of the relations characterising the coastal state and, in particular, the submersion coastal tendency.

The degree of submersion tendency or vulnerability is synthesised by the use of indices, in particular a real vulnerability (Vr) can been defined from the interaction of:

- Potential vulnerability index (Vp), that expresses the degree of submersion trend in terms of geo-morphological, sedimentary and anthropic characteristics, if the littoral is considered without protection;
- efficiency index of the defences (IED) that synthesises the passive efficiency to the submersion phenomenon produced by coastal protections (natural and anthropic).

The logical structure, as shown in figure 1, is given by:

Potential vulnerability (Vp) ⇨ Protection Efficiency (IED) ⇨ Real Vulnerability (Vr)

For each homogeneous stretches, the degree of risk (R) will depend from the value of the Vr, and from the evaluation of the socio-economic value of the same area:

Real Vulnerability (Vr) ⇨ Socio-Econmical Value (E) ⇨ Risk (R)

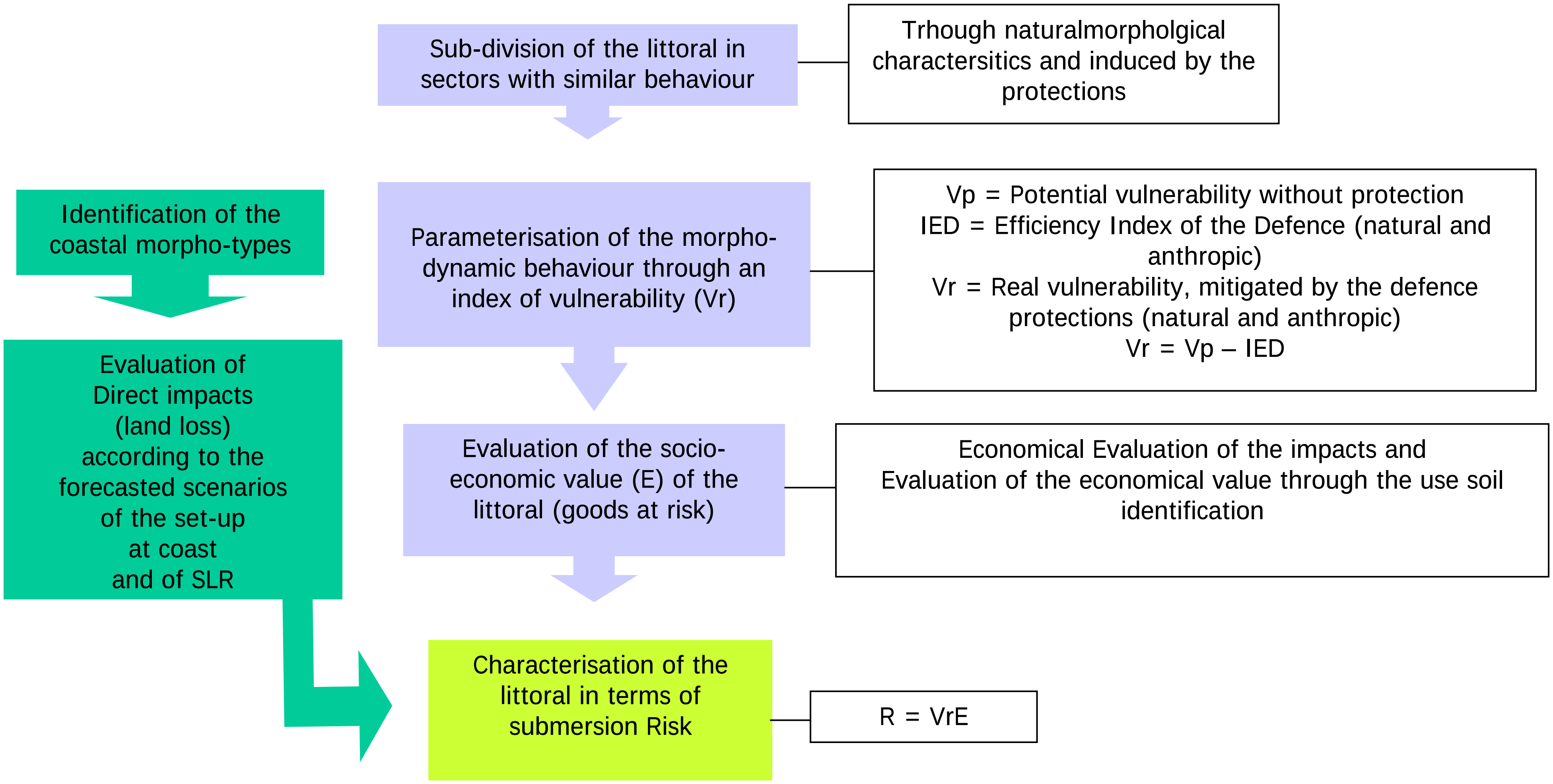

Figure 1. – Methodology pattern for the evaluation of the submersion Risk.

1.1. SUBDIVISION OF THE COAST IN HOMOGONEOUS STRETCHES

The first and delicate step for the vulnerability definition, based on the adopted methodology, consists in the subdivision of the coastal zone in sufficiently homogenous stretches, in which the submersion tendency can be considered constant.

Various approaches may be used for such operation, between which the simplest one is based on the subdivision of the coast in equal parts. This method can only be applied when the length of the segments is so limited that consents an implicit morphodynamic and anthropic homogeneity (in their inside) because it does not consider the peculiar characteristics of the coast.

In the present study it has been adopted a semi quantitative approach. First, through the analysis of macroscopic evidences, the limits in coincidence of the harbour jetties and of the main fluvial mouths have been traced, because they clearly separate the downdrift side from the updrift one. Moreover, limits have been traced at the beginning and at the end of massive and extended defence works because they deeply affect the natural evolution of the coast and they are responsible of the dissimilarity between the protected and unprotected stretches.

Ulterior limits have been defined according to the morphological characteristics of the beach and shoreface in order to characterise sufficiently homogenous areas. For such purpose it may be used a *clustering* procedure of multidimensional type, resulting from a Main Components Analysis and a successive *Cluster Analysis*.

The combined use of the two techniques (*Cluster Analysis* and Main Components Analysis) may be more effective respecting to a direct application of the *clustering* techniques since, much greater is the number of variable on which carrying out the procedure of classification, much more complex and less precise is the *clustering* operation. However, the application of such procedure of coastal zonation requires that the significance of the information statistics must be calibrated with the geo-morphologic significance through an iterative analysis of the factorial structures and *clusterisation.*

1.2. IDENTIFICATION OF THE ENVIRONMENTAL PARAMETERS

The criterion used to define the areas presenting a greater vulnerability to the marine ingression must be based on the objective evaluation of the fundamental characteristics of the divers coastal stretches. These characteristics are represented by a set of variables related to 5 distinguished compartments:

1. marine-weather conditions
2. geological-morphological conditions and use pressure of the beach:
    - shoreface width
    - emerged beach width
    - emerged beach height
    - mean diameter of the sediments
    - pressure of use of the beach;
3. Evolutive trend of the beach:
    - Shoreline evolution (recent)
    - Shoreline evolution (historical)
    - Shoreface evolution;
4. Subsidence of the coastal territory;
5. Typology of the defence structures along the coast and in the inland:

- Soft protections
- Hard protections
    - Marine structures
    - Adherent structures
    - Structures in the hinterland.

All these parameters constitute the base for a subdivision of the littoral, expressed in terms of vulnerability.

The marine weather conditions have a significant importance for characterising the Hazard to the extreme event. The behaviour of the geological-morphological parameters and the pressure of beach use characterise physically the beach system in terms of accommodation and mitigation capacity against the submersion. The evolutive trend provides an evaluation of the beach system behaviour for a short and long term period. The subsidence affects the phenomenon of the coastal submersion. Finally the different typologies of structures identify the passive mitigation response of the beach to the submersion.

1.2.1. Marine - weather conditions

The wave condition represents the basic condition to evaluate the vulnerability from marine ingression. The Hazard of the extreme events is associated to the value of the significant wave height (Hs) at the coast, and to its occurrence probability. For such reason, the offshore waves values are used for the calculation of the onshore wave propagation. It is well known that the deep water waves, propagating towards the coast, will be transformed and will dissipate their own energy due to the refraction, the shoaling and the effect of bottom friction. Similarly, the mean potential waves can increase or decrease in function of the waves interaction with the marine defensive structures like breakwaters. In particular, if there are a lot of protections the geometric disposition of these structures can induce resonance phenomena.

1.2.2. Geological-morphologica conditions

1.2.2.1. Shoreface width

This parameter expresses the dissipative action on the waves of the considered beach stretch. A wider profile, therefore less steep, characterised by bars and channels, is more efficient for the dissipation of the wave energy.

The conventional limits use to measure the shoreface width (or active beach) are the shoreline and the closure depth; such limits are used to determine shoreface width. The seaward extreme limit of the active profile may be obtained by using different methods. Hallermeier (1978, 1981) proposed a mathematical method for the determination of the seaward active profile limit (depth of closure), that uses the height and the period of the incident wave of the considered shoreline. Considering the precedent difficulties, it has been thought more corrected to use this last method. It allows a univocal determination of such limit, applicable also where the bar is not present. According to Hallermeier the depth of closure (d_1) is given by:

$$d_1 = 2.28 H_{s0.137} - 68.5 \left(H_{s0.137}^2 / g T_s^2 \right)$$

- $H_{s0.137}$ is significant wave height at the coast with has a frequency of 0.137% (12 hours) by year
- Ts is the wave period and g is the gravity acceleration.

1.2.2.2. Emerged beach width

This is an other fundamental indicator of the shoreline capacity to absorb a sea storm event. This capacity will be greater when a more or less developed foredune will be present. The presence of anthropic structures in the backshore makes the beach a system more rigid. Consequently the beach is more vulnerable and less able to mitigate the risk of sea storm.

Conventionally, the beach width represents the distance between the shoreline and the first ridge of foredunes. However, when the beach is strongly anthropised, the landward limit can be placed in correspondence to the structures (like dykes, roads...) present in the backshore.

1.2.2.3. Emerged beach height

The vulnerability assessment requires to consider the elevation of the beach at its inner limit, especially where the dunes are absent. In such case, the variations of this height may depend on the relict morphologies that offer, however, a passive resistance to the submersion phenomena during exceptional events.

1.2.2.4. Mean diameter of the sediments

The knowledge of the sediments behaviour is essential in order to predict the effect of the evolution of the coast and of anthropic activities on a coastal ecosystem. The processes control of erosion, transport and deposition of these materials are extremely complex.

The study of the textural and compositional characteristics of the bottom deposits is extremely useful in order to reconstruct sedimentary dynamics. The movement of sediments depends on the hydrodynamic circulation, than characterise the emerged beach - shoreface system.

The grain size analysis furnishes useful information on the energetic level and supplies a record of the transport and deposition processes. In the present study it is possible to read the mean grains dimension of the emerged and submerged beach according to their angle of repose, i.e their steepness, and of the ability to resist to the wave energy.

In the present study the greater grains dimension will be estimated like a mitigation factor of the vulnerability, but with a smaller weight respecting to other variables, because it allows a greater morpho-topographical and bathymetric stability.

1.2.2.5. Beach use pressure

This variable, included in the geo-morphological parameters, synthesizes a part of the anthropic contribution to the coastal dynamics. The main impacts that are representing in this variable are the damage and destruction of the coastal morphologies, therefore its influence on the dissipative ability of the beach system. Moreover, an important tourist frequentation could affect the beach budget, due to the maintenance and cleaning of the bathing establishments, and to the anthropic transport of sand from the beach. For these reasons, the use pressure is closely related to the linear distribution of the tourist presences on the beach. According to the typologies of tourist, and to the statistics on the tourist presences, different classes of use pressure may be defined.

1.2.3. Evolutive trend of the beach

It is represented by the variation of the shoreline and the shoreface, within the closure depth.

1.2.3.1 Shoreline evolution (recent)

The shoreline fluctuations, natural and anthropic, can strongly modify through the time the emerged beach width, either in negative and in positive. Such fluctuations can be observed seasonally, that don't influence the stability of the beach, or in the long term, (decennia), inducing important variations in the emerged beach.

The importance of the evolution variable is closely related to its capacity to discriminate a transitory effect from a real evolutionary situation, capacity that is related to the typology of temporal series of observations and to the modality of acquisition of them.

1.2.3.2. Shoreline evolution (historical trend)

The analysis of the historical evolution of the shoreline, related to a period at least of 50 years, is complementary to the recent because it allows to discriminate between contingent and chronic situations. Variations in the long term, determined from a general situation of rise/decrease of the medium level sea, subsidence, location from the sedimentary sources and longshore transport, may be inverted according to situations and events.

1.2.3.3. Shoreface evolution

This parameter supplies a stability index through the time of the dissipative efficiency of the submerged beach. The dissipative capacity is closely related to the position of the surf zone respecting the coastline. A situation, in which the evolution trend is characterised by an increase of the slopes, indicates a reduction of the useful space for the dissipation of the wave energy, determining therefore a relative increase of the wave energetic contribution that reaches the emerged beach.

1.2.4. Subsidence of the coastal territory

The subsidence phenomenon (generally expressed in rates of relative topographical lowering; mm/year) represents a factor of amplification of the potentiality of submersion in the coastal zones.

The subsidence in the low coastal zones can be correlated to natural causes (i.e. sediments compaction), or human activities (land reclamation, fluid extraction).

Moreover the superimposition of the effects related to natural processes and anthropic activities, complicates the identification of the role carried out by the different factors and by their interactions. Such aspect makes difficult the elaboration of future scenarios related to the natural causes because it is difficult to consider the times of activation (that is only possible using complicate mathematical models that need long time observations series).

The strategy for the location of the areas greater affected by subsidence can be facilitated by the finding of a great historical, geological and topographical documentation, and by the systematic collection of ground stratigraphy information (relative to surveys and water sinks). Moreover it may be based on the examination of the variations of the superficial water-drainage and the ground water circulation and on the correlation between different surveys. Furthermore, the monitoring through topographical surveys with a network of benchmarks, the monitoring of the groundwater levels, the monitoring of the lesions on the buildings can contribute to estimate the subsidence rates.

In addition, information on the subsidence of a coastal zone may also be obtained from procedures based on studies of neotectonic and/or through paleo-environmental and radiometric analysis of geological surveys. Clearly, with this procedure, it will be almost impossible to distinguish the causes related to human activities but it will give useful information on natural dynamics of subsidence/uplift of the area connected to its regional geology.

1.2.5. **Typology of the defence structures**

Considering the wide range of protections generally used, the structures may be divided in soft or rigid type. In the present methodology, these two types, corresponding to two macro-categories, are described below.

1.2.5.1. Soft protections

In addition to the natural sand dunes, the artificial dykes (levees), that have a similar defensive action of the natural dunes, and the artificial nourishment are considered as soft protections.

1.2.5.2. Hard Protection structures

As hard protection structures it must be considered all structures, composed in reinforced concrete, stones, poles, bags etc, built in order to protect the coast. They can be subdivided in two categories: cross-shore and parallel to the shoreline.

1.2.5.2.1 Marine protections

These protections, situated in the sea, are generally constructed in masses or, alternatively, realised with synthetic materials and filled with sand (Longard tubes, bags). These structures can be emerged or submerged. Their function is, in both cases, to reduce wave energy before it reaches the beach. The emerged structures seem to be more efficient than the submerged ones for the dissipation of wave energy.

1.2.5.2.2. Adherent structures

They correspond to structures located along the shoreline. They can be in reinforced concrete or masses. They are generally built where it is necessary to protect the urban centres, houses or seafront, that are directly exposed to the wave action. Such structures can be important in order to not be exceeded by extreme waves.

1.2.5.2.3. hinterland structures

They correspond to walls, sea walks or bike tracks, situated at the limit beach – urban centre and are elevated compared to the beach. Beyond to the tourist function, they play the function to prevent the “silting up” of the coastal residential zones.

1.3. CALCULATION OF THE “POTENTIAL” VULNERABILITY

Once defined the variables and quantified the mean values of each parameters present in each coastal stretches, the potential vulnerability may be calculated. The potential vulnerability (Vp) represents the vulnerability of the littoral considering that there are no defence structures (natural and/or anthropic) against marine ingression.

The variables used for the calculation of **Vp** are indicated in table 1.

Vp is calculated through a multiple regression (Civita, 1994; Civita e De Maio, 1997) like:

$$V=v_1k_1+v_2k_2+v_3k_3+....+v_nk_n$$

where V = index of vulnerability, v = codified value of the variable and k = ponderal weight assigned to the variable according to the importance of the variable itself to contribute to the system vulnerability.

	Variable description	Sigle	Measure unit
1	Width of the emerged beach	ASE	m
2	Height of the emerged beach	HSE	m s.l.m. sea
3	Width of the submerged beach	ASS	m
4	Recent evolution of the shorelin	ESR	m/yr
5	Historical evolution of the shoreline	ESS	m/yr
6	Shoreface evolution	EF	mc/m/yr
7	Subsidence	S	mm/yr
8	Mean diameter of the beach	Mz	Phi

	sediments		
9	Pressure of use	PU	no. of presence/m

Tabella 1. - Variabili utilizzate per il computo della Vulnerabilità Potenziale (Vp).

Evaluating opportune classes of values, established in function of the peculiarity of the studied littoral, the codified values of the variables are obtained. For instance, the codification of the variable ASE through the definition of 5 classes is reported in table 2. The maximum condition of vulnerability is attributed to the maximal class.

		Classe				
Variable	**Measure Unit**	1	2	3	4	5
ASE	m	> 100	80<>100	100<>50	50<>30	<30

Table 2. – Codification of the variables value, example of the beach width.

Therefore a weight related to the importance for the mitigation of the risk is attributed to each variable. The weight is also defined according to the characteristics and the particularity of the littoral.

1.4. CALCULATION OF THE "REAL" VULNERABILITY

The real vulnerability **Vr** represents the vulnerability of the littoral, mitigated by the natural and artificial defences.

Contemporarily, the mitigation action of the defences are evaluated through the determination of an *Efficiency Index* (D_i) related to the anthropic defences and the natural dunes.

For the anthropic ones, the descriptive variables have been considered and the linear incidence has been expressed in percent on the total length of each stretch. The soft solution are only described according to their percentual presence. The efficiency of each defence structure is represented by::

$$D_i = d * \frac{Vp_{\max}}{e_{\max}}$$

where d = the original value of the class of the structure, Vp_{max} *= theorical maximal potential vulnerability,* e_{max} *= maximal class of efficiency relative to the structure. The rate* Vp_{max}/e_{max} *represents the coefficient of normalisation of the values related to the structures.*

A special index, the *Efficiency and Stability Index* (*IES*), is determined for the natural dunes according to the height of the crest, the rate between the dune height and the width of its seaward side, the linear continuity, the conservation state and the vegetal cover.

The calculation of *IES* is given by:

$$IES = \frac{\sum V_i}{n}$$

where V_i represents all the variables related to the dunes; n is given by the sum of the maximum values attributed to the variables and is used to normalise the index in the range 0-1.

The total efficiency of the structures is:

$$IED = IES + D_i$$

Vr may be therefore calculated:

$$Vr = Vp - IED$$

1.5. CALCULATION OF THE SUBMERSION RISK

The proposed *Risk Assessment* methodology follows the general principles of the European projects Eurosion and CoPraNet (table 3).

CoPraNet	Process of characterization of the threatening event (Hazards) for a given area and a given time period; characterisation based on the analysis of the interaction between the potential consequences (impacts) of the hazards events and their probability of occurrence. In such way it is possible to define the levels of risk (Risk Rating). Hazard is defined as a threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area.
EUROSION	Process structured on: • Territorial database construction • Definition of scale, nature and characteristics of the threatening event (Hazards) for a given area and a given time period (risk analyse, *Hazard*) • Evaluation of the affected urban, social and economical sphere in function of the occurrence of a given threatening event (vulnerability analysis, *Vulnerability*).

Table 3. – Definition of Risk Assessment according to CoPraNet and EUROSION.

In the present study, the analysis of the Risk (R) is evaluated by the following relation:

$$R = VrE$$

where Vr = real Vulnerability and E = economical value of the littoral.

The Economical value (E) may represent an evaluation of the social, economical, natural value of the exposed zones or the cost in monetary terms of the directs and/or indirect impacts. Because the procedure for an economical evaluation is complex, a rapid and effective methodological approach is used to determine E.

In order to use an effective and fast methodological approach in the risk assessment, the variable E has been codified in classes (tab. 4) that are function of the typologies of land use along the coast. Therefore, the effects of the direct impacts (like the temporary land loss), and of the indirect ones (socio-economical aspects related to the effects of the land loss) are considered.

Class	***Charactersitics of identification***
Natural zones	without habitation and uncultivated, protected natural zones
Scattered houses and agricultural areas	houses scattered in the territory at a such distance between them that do not constitute inhabited nucleus
Inhabited center and camping	groups of contiguous or near houses with at least 5 families and interposed limited continuity solutions, areas dedicated to equipped camping
Village, Urban centre	association of contiguous or near houses with interposed roads, public squares and similar, equipped with infrastructures of permanent service

Table 4. – Codification of the economical value of the littoral (E) according to the soil use.

In any case, it is necessary to highlight that the risk associated to each stretch has to be exclusively considered in a comparative manner. Every stretch will be considered in comparison with the adjacent ones. That implies the necessary integrated evaluation either of the internal variables of the considered coastal stretch and especially the effects induced from possible human interventions. Such recommendations, in fact, do not only result from the evaluation of the described method application, but they are based on the Community indications regarding the management integrated of coastal zones.

1.6. STORAGE MODALITY OF THE PARAMETERS

The organisation of a coastal integrated management politics needs the creation of geographical database as tool for the knowledge and improvement of the territorial state. Especially the creation of a geodatabase is indispensable when studies on risk evaluation have to be performed. This database will be used to insert and elaborate all the needed parameters and indicators for the vulnerability definition.

The database is realised in order to be easily updated. The database is structured according to the parameters (variables) used for the definition of the risk. The structure of the GIS is realised in the ESRI® Arcgis environment for the management and analysis of the data and for the creation of the thematic cartography.

A first set allows to identify all the entities that, together with the parameters, constitute the database. Once the entities and the variable have been collected, the architecture of the database must be defined. According to a primary key, defined within every entity of single coastal stretch, all the information concerning the chosen morpho-sedimentary parameters are determined. The geographical definition of each stretch is defined through the Universal Transverse of Mercator projection system and the geocentric Datum WGS 84.

Then, all the geographic data relative to topography, aero-photo, bathymetry, and data coming from different institutional sources are acquired and inserted in the GIS. This allows to characterise the study area and to represent in one geographic window the different information layers useful for the definition of the morphodynamic state of the studied coastal zone. The values obtained for each variable are reported for all the coastal stretches delimitated during the subdivision. A ponderal weight on the base of the importance related to the risk mitigation has been therefore attributed to each variable.

The aerial images “Volo Italia” 1998/99 (IT2000) are used as topographical base.

2. *RESTITUTION MODALITY OF THE TERRITORIAL DATA: THE THEMATIC CARTOGRAPHY*

In order to obtain a general view of the used parameters variability for the vulnerability assessment of the studied coastal zone, some elaboration will be realised. The representation of the results consists in a chart where the morphological, sedimentological parameters, the land use and the defence structures are represented (see legend).

For each stretch, the parameters are represented with a non-conventional symbology.: the typology for the defence structures and the classes of land use; the values or the classes of each parameter related to the emerged or submerged beach; the mean diameter of the beach sediment; the illustrated morphology of the hinterland through classes of elevation coming from the elaboration of a digital model terrain; the evolution of the shoreline.

A particular territorial informative level, resulting from the analysis of the impacts of the submersion scenarios at short, medium and long term, will furnish (in phase C) an estimation of their incidence on the socio-economical pattern of the coastal zone. These scenarios, based on the modelling of the extreme wave height on the coast, will be elaborated for each homogeneous stretch in order to “quantify” the coastal potential criticity for specific “morpho-types”.

At long-term the sea level rise represents the climatic factor used for the evaluation of the submersion phenomenon. A “multi-scenario” approach will evaluate the potential incidence of more sea level rise scenarios on the coastal zone, considering the climatic (global) and geological (local) causes of the phenomenon.

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