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A Model for Determining the Classification, Vulnerability and Risk in the Southern Coastal Zone of the Marche (Italy)

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ABSTRACT

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A method is proposed for the classification of coasts with the aim of providing a tool for more correct planning and management of the coastline.

The 70-km long southern coast of the Marche was subdivided into 24 stretches, each of which were described by fifteen variables: three describe the hydrodynamic and energy characteristics of the coast; four describe the evolutionary trends of the beach; seven describe the morphological and sedimentological features of the exposed beach and of the sea floor; and one quantifies the degree of human intervention.

The matrix of the variables was processed using factor analysis and cluster analysis. The results of this investigation enabled us to determine the relationships between the variables and to group similar coastal tracts. This in turn allowed us to classify the coastal zones and to attribute a degree of flood vulnerability to each one.

Subsequently, by relating the vulnerability to the degree of urbanization, a risk level was defined for each of the coastal stretches.

ADDITIONAL INDEX WORDS: *Coastal classification, vulnerability, risk, Adriatic Sea, Italy.*

INTRODUCTION

The intense urbanization of the Marche coastline which started after 1950 has developed with often uncontrolled building even close to the shore. This has made it necessary to consider the beach not only as a bathing place but also as a natural defense against marine invasions. The latter has inspired the methodology which is developed in this work.

In the area under examination, even adjacent coastal stretches behave in quite different ways; this is the result of the notable variability of the sedimentological, hydrodynamic and human characteristics present. Along the coast, in fact, there are both pebble and sandy beaches which vary in width from between 1 and 100 meters. The adjacent sea floors have slopes of between 1% and 11% and have up to three bars. The energy flux of the waves is very variable and the direction of the net longshore transport rate is often inverted in correspondence to the mouths of the principal rivers. Furthermore, there are numerous ports and defensive structures of various types which have been constructed along the coast to counteract the marked retreat of some zones.

In this complex framework it was necessary to classify the coastline, subdivide it into stretches and group these on the basis of their characteristics. The aim was to provide a valid instrument for the proper planning and management of this coastline. The method proposed, in fact, allows provisions to be made from single tracts and for these to be applied to whole groups. This facilitates the choice and location of new defensive structures and the modification of pre-existing ones. Furthermore, it favours the experimentation of interventions in sample areas and reduces the cost of monitoring. In fact, it is reasonable to suppose that geomorphologically similar coastlines which are conditioned by human and physical factors of the same intensity will in the future behave similarly.

In the Adriatic Sea, there occur irregular phenomena of temporary flooding of the coast, as at Venice, for example. Phenomena of this type also occur on the Marche coastline, although with lesser intensity and frequency, causing great damage. Consequently, for a correct management of the coastline, it is useful to define the degree of vulnerability to flooding of the coastline. In this study,

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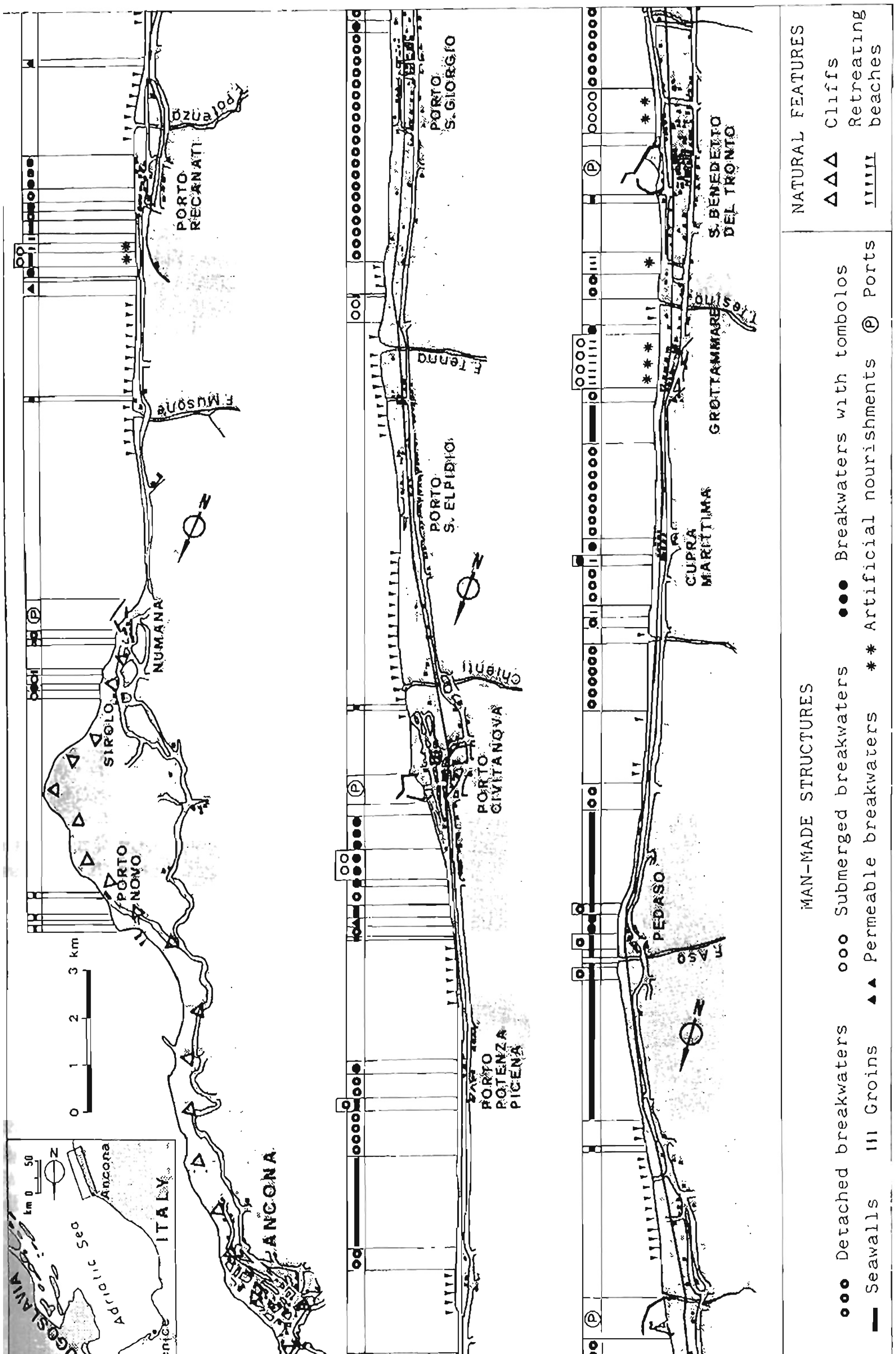

Figure 1. Typology and location of the man-made structures; location of the currently retreating beaches and of the cliff.

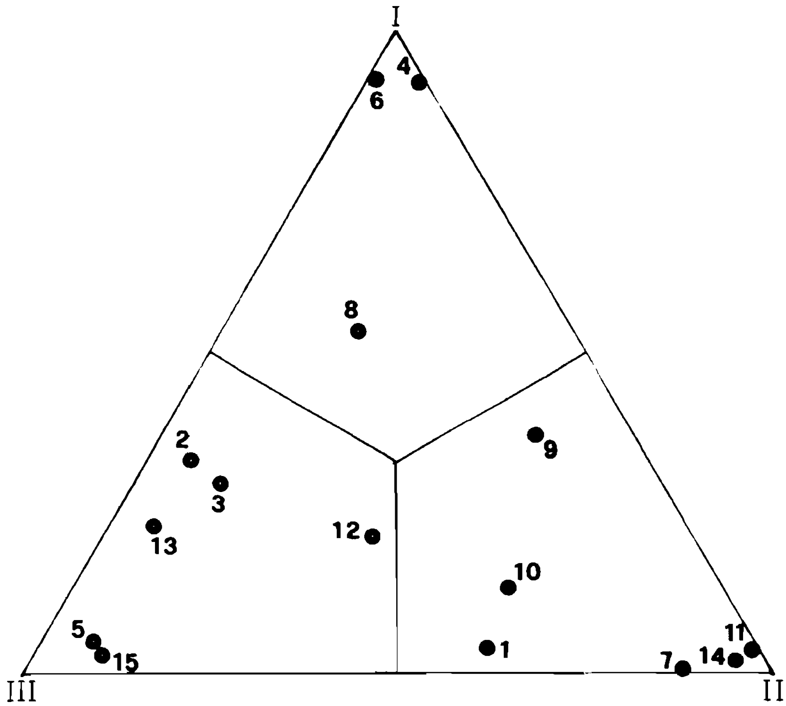

Figure 2. The plot normalized factor components of the fifteen variables. The R-mode factor analysis highlights the main groups. For the definition of the variables, which are defined by the numbers, see text.

the degree of vulnerability was determined as a function of the stability and of the characteristics of the beach, resulting in a classification of the coastal tracts.

Finally, the association of this vulnerability to the degree of urbanization of the coastal strip furnishes an evaluation of the level of risk present in each single tract.

GEOGRAPHICAL AND MORPHOLOGICAL SETTING

The beaches investigated (Figure 1) of a length of about 70 km are located in the southern Marche (middle Adriatic). They form part of a coastal plain between the Apennine mountain chain and the sea which ranges from several hundred meters to several kilometers in width. The thinness of alluvial sediments of the plain and their gravelly nature indicate that subsidence is slight and as such does not influence the evolution of the coast.

In contrast to the beaches further north which border the Po plain, their development is essentially conditioned by the sea, given the scarce solid material transport by the rivers which feed them (Dal Cin and Simeoni, 1993).

The coastal zone is densely urbanized, as is demonstrated by the degree of building of the first 200 m starting from the edge of the beach. The presence of houses, coast roads, structures for bathing stations, dunes, agricultural and forested land characterizes this limit. These areas show an average degree of urbanization (the urbanized surface with respect to the total surface) of about 44%. The areas of coast with the highest density of urban development are located between Porto Potenza Picena and Porto Civitanova (70%), Grottammare and San Benedetto del Tronto (60%), and San Elpidio and Porto San Giorgio (55%) (Figures 5 and 6).

Along the coast, gravel beaches represent the majority (69.0%); sandy beaches constitute 17.3%; and sandy-gravel beaches 13.7% (Figure 5). They are primarily fed by terrigenous supplies from the rivers and by material coming from the erosion of the river mouths.

The most important rivers are the Chienti, Potenza and Musone, each of which is characterised by a drainage basin ranging between 600 and 1,300 km^2. The Aso and the Tenna rivers have drainage basins of 300 and 500 km^2, respectively. There is also a series of creeks, such as the Ete Vivo, Menocchia and Tesino.

The amount of riverborne material reaching the sea is less than 15,000 m^3 per year for the Ete Vivo, Menocchia and Tesino rivers. The riverborne sediment for the remaining rivers ranges between 20,000 and 40,000 m^3 per year (AQUATER, 1984). These sediment flows are 30% to 70% less than those recorded before 1966. The main reasons for this reduction are: the excavation of sand and gravel; damming; the withdrawal of large quantities of water; and changes in the geometry of the river beds.

As a result of this decrease in sediment flow, extensive coastal erosion has started (DAL CIN *et al.*, 1984), which has been countered by the construction of numerous defensive structures. At present, 55% of the beach has been protected by various engineering devices; of the remaining beaches, two-thirds are currently eroding (Figure 1).

During the winter, the wave action in this area is quite intense and comes from the southeast and northeast, while in the summer it comes from the north. The strongest wave action is most frequently associated with a southeasterly direction; however, the most intense storms originate from the north.

The most common wave heights during the year are those lower than 0.5 m (59%); the occurrence of waves which are higher than 2.5 m is proportionately very low (0.9%). The average tidal range is about 0.7 m.

METHODOLOGY

In the literature, there are many studies on the classification of coasts, based either on descriptive geomorphology (FISHER, 1982), on tectonic and morphological concepts (INMAN and NORDSTROM, 1971) or on coastal processes (NUMMEDAL *et al.*, 1977; NUMMEDAL and FISHER, 1978; HAYES, 1979; DAVIS and HAYES, 1984).

Considering the aim of this study, the classification proposed here is based on a series of variables which allow the resistance to erosion of the coast, the historical shoreline changes, the morphology of the shore, the presence of defensive structures and coastal processes to be evaluated.

The coast has been subdivided into 24 stretches (Figure 5), each ranging in length between 2 and 3.5 km. Wherever possible, the boundaries between adjacent segments were drawn to coincide with important morphological or human features, such as river mouths and harbors. In some cases, the boundaries were drawn to coincide with the end of protected areas or with locations where the type of defensive structure changes considerably.

Each of the 24 coastal stretches has been described by 15 variables (Table 1) which are considered to most strongly influence beach dynamics (DAL CIN and SIMEONI, 1987). These variables, which are listed below, fall into four groups: hydrodynamic and energy-related (variables 1 to 3), evolutionary (4 to 7), morphology and sedimentology of the beach (8 to 10) and seafloor (11 to 14), and human intervention (15).

(1) Mean energy flux per unit of coastline (kw/m).
(2) Net longshore transport rate (10^3 m^3/year).
(3) Gross longshore transport rate (10^3 m^3/year).
(4) Mean shoreline accretion between 1892 and 1951 (m/year).
(5) Mean shoreline retreat between 1892 and 1951 (m/year).
(6) Mean shoreline accretion between 1951 and 1990 (m/year).
(7) Mean shoreline retreat between 1951 and 1990 (m/year).
(8) Width of the backshore (m).
(9) Elevation of the backshore (m).
(10) Mean size of the beach sediments (mm).
(11) Slope of the sea floor between 0 and -3 m (%).
(12) Mean size of the sea floor sediment between 0 and -3 m (mm).
(13) Number of bars on the sea floor.
(14) Percentage decrease, with respect to the period before 1960, of the contribution of the material transported along the river beds.
(15) Defensive structures and ports.

The energy flux (variable 1) in the surf zone was determined on the basis of the characteristics of the waves in the breaker position (*Shore Protection Manual*, 1973) and represents an average annual value.

The longshore transport rate was calculated (AQUATER, 1984) using the formula of the *Shore Protection Manual* (1973) and modified to take into account the mean size of the sediments and the mode of breakage of the waves according to the relationships suggested by SWART (1976) and

Table 1. *Average values for the variables measured in each coastal stretch. See text for the identification of the variables.*

	Variables														
								Morphology and Sedimentology							Human Int.
	Hydrodynamic			Evolutionary				Beach			Seafloor				
Stretches	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.0	1.6	41.4	0.2	0.0	0.0	0.5	53	3.5	2.36	5.6	0.14	0	30	0
2	0.8	1.1	74.9	0.8	0.0	0.0	3.2	43	3.7	3.43	10.0	0.21	0	50	25
3	0.9	0.4	77.4	0.9	0.0	0.0	3.5	42	2.9	3.75	11.5	0.17	0	40	191
4	0.9	2.1	81.1	0.4	0.0	0.0	2.3	36	3.0	2.42	6.5	0.13	71	40	5
5	1.0	2.2	49.2	0.0	0.3	0.0	2.0	5	0.8	2.10	6.8	0.21	100	0	362
6	0.9	1.7	93.7	0.0	2.3	0.0	0.8	36	1.7	1.64	1.7	0.14	118	0	271
7	0.8	0.0	91.8	0.0	1.0	0.1	0.0	39	2.5	1.18	1.6	0.16	150	0	0
8	0.8	1.3	117.9	1.0	0.0	2.3	0.0	56	2.1	0.50	1.6	0.16	122	0	245
9	0.8	0.9	63.7	1.4	0.0	2.9	0.0	54	2.5	8.39	2.4	0.11	100	16	100
10	0.9	1.3	72.2	0.0	0.8	0.0	3.5	20	2.3	6.08	2.7	0.16	100	50	0
11	0.7	2.8	103.9	4.0	0.0	1.4	0.0	41	2.1	4.88	2.8	0.15	129	0	0
12	0.8	0.8	83.9	0.6	0.0	0.0	2.9	31	2.0	10.20	2.9	0.16	100	48	0
13	0.8	2.9	107.5	0.0	1.0	0.0	2.9	18	1.9	7.25	2.4	0.13	180	22	62
14	0.7	3.0	128.4	0.0	0.0	0.0	0.5	53	2.1	1.69	1.4	0.15	232	0	200
15	0.8	2.8	126.4	0.0	1.0	0.0	1.7	67	2.0	0.20	1.2	0.16	150	0	265
16	0.9	0.1	88.1	0.0	1.0	0.0	3.1	24	2.1	6.50	2.9	0.14	100	20	11
17	0.7	0.7	93.1	0.0	0.6	0.0	3.2	5	0.8	13.60	6.5	0.14	17	30	409
18	0.9	2.5	70.3	0.0	1.9	0.0	1.0	5	0.8	5.05	3.2	0.15	114	32	408
19	0.8	4.3	97.9	1.1	0.0	0.5	0.0	23	2.2	7.20	1.6	0.14	119	20	80
20	0.9	3.6	82.2	0.5	0.0	0.0	0.5	24	2.2	6.71	1.4	0.15	100	0	162
21	0.7	4.3	112.9	0.0	0.4	0.5	0.0	17	1.7	6.60	1.2	0.15	134	0	221
22	0.7	3.7	134.3	0.4	0.0	0.8	0.0	23	1.4	4.10	1.6	0.15	150	20	272
23	0.8	2.8	129.2	1.0	0.0	0.0	0.5	30	2.1	3.70	1.6	0.15	177	0	120
24	0.8	5.5	110.3	0.0	0.5	2.9	0.0	62	2.3	0.20	1.1	0.22	96	0	257

by KAMPHUIS and READSHOW (1978). Net longshore transport (variable 2) was used because it furnishes information on the sedimentary budget, while gross transport (variable 3) gives an indication of the mobility of the surface sediments on the sea floor.

For the quantification of the variations of the shoreline (variables 4–8) based on the existing cartography, 1951 was chosen as a boundary between the two periods because it was, above all, in the 1940's and 1950's that intense erosive processes started to manifest themselves (DAL CIN *et al.*, 1984).

The seawards limit of the sea floor (variable 11) has been situated at −3 m, since it is at this depth that the most frequent line of the breakers is located. Furthermore, on the sea floors examined, one generally finds a change in the slope at around 2.5–3 metres.

The presence of bars on the sea floor (variable 13) is important because it reduces the energy of the wave breakage (DAVIS and FOX, 1972; SONU, 1973; KOMAR, 1976; WRIGHT *et al.*, 1979; WRIGHT and SHORT, 1984). In order to quantify their presence, a value of 100 was assigned to each order of bars which extends over the entire coastal stretches.

For the quantification of the effect of the diminution of material transport in the coastal tracts (variable 14), the littoral tract that benefits from fluvial transport was first identified for each river. Therefore, a percentage value as a function of the diminution of material transports since 1960 was assigned to every river. The diminution in material transport was then calculated for every tract in proportion to its distance from the river mouth (DAL CIN and SIMEONI, 1987).

The man-made structures (variable 15) have been quantified on the basis of their capacity to defend the coast from floods and high waters. Different values were assigned to each type: (1) to the submerged breakwaters, harbor moles and groins; (2) to the emerging breakwaters; (3) to the breakwaters emerging too close together and next to the shore with formations of tombolos; (4) to the sea walls. These values were then multiplied by the percentage length of the protected coast; in the cases in which there was the contemporary presence of more than one defensive structure, the values were added.

The values of the variables were subsequently normalized and subjected to factor analysis and cluster analysis. The factor analysis attempted to determine the minimum number of independent dimensions needed to account for most of the information in the table of similarity coefficients (RUMMEL, 1967; DAVIS, 1973; JORESKOG *et al.*, 1976; TEMPLE, 1978). The most common forms of factor analysis used in the natural sciences are R-mode and Q-mode. The first investigates interrelationships in a matrix of correlations between variables; whereas in Q-mode factor analysis, the role of samples and variables is reversed.

The use of these techniques yielded good results in similar investigations carried out along the Adriatic coast (DAL CIN and SIMEONI, 1987, 1989, 1991; DAL CIN, 1989; SIMEONI, 1992), and along the coast of Provence in France (BLANC and FROGET, 1979; BLANC, 1980).

RESULTS

Grouping of Variables Affecting Beaches

The shoreline is the result of the joint action of different natural and human factors acting on it. In order to establish how the variables under consideration can be grouped and thus contribute to determine a certain situation of the shoreline, factor analysis in R-mode was applied. From this it was established that only three factors (eigenvalues) explain 80.1% of the total variance. In general, the communality exceeds 0.8 and is always above 0.7.

Factor I (21.4% of the variance) groups the high values of variables 4 and 6, and to a lesser extent 8 (Figure 2). Factor II (29.8%) joins variables 7, 11 and 14 and, subordinately, 1 and 10. Factor III (28.9%) groups variables 5 and 15 and, to a lesser extent, 2, 3 and 13. Variables 9 and 12 do not fall within one factor.

This investigation shows that the conditions of the highest stability of the beaches can be associated with the variables of Factor I. In general, these had positive evolutionary trends (variables 4 and 6) and also, at present, show generally wide beaches (8).

The grouping around Factor II highlights situations of extreme vulnerability. In fact, they are associated with coastal stretches which have been built and maintained by fluvial supplies (14) and, once riverborne sediments decreased, they have started to erode (7). Furthermore, the steeper slope of the sea floor (11) and the particular exposure have created such conditions that the highest flux of energy (1) is discharged on these coastal segments. All of this justifies and determines an increase of the mean size in the beach material (10).

This grouping clearly indicates that the fundamental cause of the retreats which took place after the 1950's can be ascribed to the decrease of contributions from the rivers. Furthermore, as the beach starts to erode, there is a corresponding increase of the nearshore slope.

Factor III characterizes the erosional beach prior to 1951 (5) which has resulted in major engineering defenses (15). The sea floor of these coastal sections is much more dynamic (2 and 3), resulting in one or more bars (13) (SIMEONI, 1989).

The high mean sizes of the sea floor sediments (12) is associated predominantly with Factors II and III. The elevation of the beach (9) is loaded on both Factors I and II. This variable can be considered to be indicative of the stability associated with wide beaches, which are predominantly sandy and tend to be stable (Factor I) or unstable, especially when attributed to narrow gravel beaches undergoing erosion (II).

Coastal Zoning

The grouping of the 24 stretches described on the basis of the 15 variables was established by means of factor analysis in Q-mode and by cluster analysis.

The three factors explain 83.1% of the total variance (Table 2). The triangular diagram in Figure 3 shows that Factor I (36.0% of the variance) groups together beach segment numbers **7**, **8**, **9**, **11**, **14**, **15**, **19**, **21**, **22**, **23** and **24** and to a lesser extent **20**. Factor II (27.6%) aggregates sections **1**, **2**, **3**, **4**, **10**, **12** and, subordinately, **16**. Factor III (19.5%) groups together segments **5**, **17** and **18**. Coastal segment number **6** loads equally on Factors I and III at the same time, and that of stretch **13** to Factors II and III.

The dendrogram of Figure 4, which was obtained by cluster analysis, allows us to evaluate the classification and relative hierarchy. A total of five clusters are recognized. The groupings with the highest degree of similarity, with a correlation coefficient ranging between 0.88 and 0.71 are: **14**, **21**, **22** and **23**; **2** and **3**; **10**, **12**, **13** and **16**; **1** and **4**; **8** and **24**; and **19** and **20**. The associations are not always formed by adjacent stretches. This suggests that the characteristics of the shoreline can show strong variations also within short distances.

In conclusion and taking into consideration the

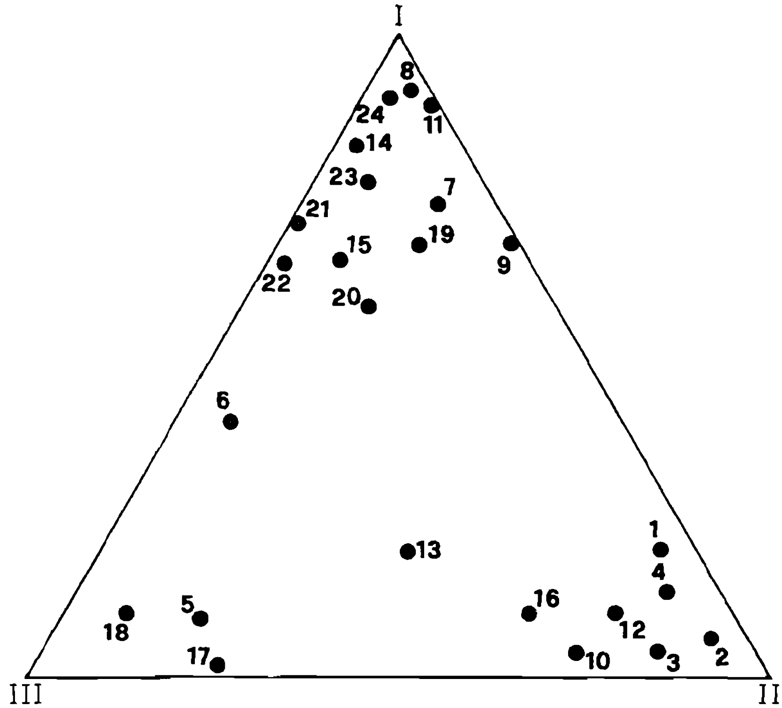

Figure 3. The plot normalized factor components of the twenty-four coastal stretches. The Q-mode factor analysis highlights the main groups and the weights of the latter on the three factors. For the location of the coastal stretches identified by the numbers, see Figure 5.

correlation between the variables, the results of the factor and cluster analyses indicate that the 24 coastal stretches can be grouped into three homogeneous groups: A, **B** and C. Through more careful evaluation, groups A and **B** can be subdivided into two subgroups: **A1** and **A2**, and **B1** and **B2** (Figure 2).

Group A

This group is composed of the gravel and sandy-gravel beaches and almost all of the sandy beaches (variable 10). Until 1951, they were advancing (4); but as the contribution from the rivers decreased, erosion has set in (7). This in turn has prompted the construction of breakwaters (15) which now cover almost the entire coast. The beach fronting these sectors is predominantly medium to low energy (1), gently sloping (11), and with little sediment movement (3).

This group can be subdivided into two subgroups: **A1** and **A2**. The first includes segments **14, 15, 19, 20, 21, 22** and **23**. They are characterised by moderately wide beaches (about 35 m). The sections are protected predominantly by breakwaters, except for stretch **19** which is only partially protected. The location of these beaches is not close to river mouths.

The coastline classified as A2 (7, 8, 9, 11 and 24) has large areas without man-made protections. However, they tend to be stable because they are located upstream from harbor jetties (segment 9) or in areas between river mouths (7 and **11**). The beaches are very wide (averaging 51 m).

Group B

These are coasts located near river mouths and are fed by rivers. The reduced sediment from rivers (variable 14) has resulted in extensive erosion. However, this has not prompted the construction of defensive structures, except on the sea floor in front of Porto Recanati. At present, the shoreline is still retreating (variable 7) due to the high energy flux of the wave action (1). The beaches are composed of gravel (10) and have average widths (about 35 m) and elevations (2.8 m). The sea floor

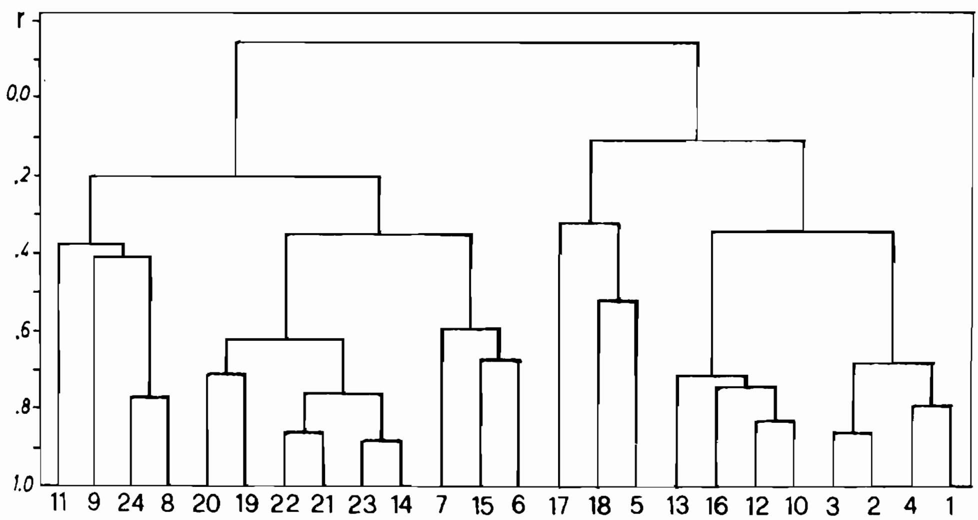

Figure 4. The dendrogram shows the coefficient of grouping of the pairs and groups of coastal stretches along the y-axis. For their location, see Figure 5.

is not characterised by a marked development of bars (13) because of the restricted mobility of the sea floor sediments (3).

The trends of some of the characteristics of the beaches and the sea floor suggest two subgroups: **B1** (stretches 1, 2, 3 and 4) and **B2** (10, 12 and 16). The beaches of the segments classified as **B1** are broader (on average 44 m versus 24 m), higher (3.3 m versus 2.1 m) and less coarse (mean size 3.0 versus 7.6 mm). On the sea floor, the steeper slopes (8.4% versus 2.8% and the lower number of bars are the parameters that differentiate most clearly **B1** from **B2**.

Group C

In this category, the coastal stretches (5, 17 and 18) which are completely endangered and which are located in areas where the energy flux of the wave action is the strongest (variable 1) are included. Erosion, which affected them in the past, has been opposed by the construction of a close, continuous seawall (15). This intervention preserved the sea cliff, but has almost completely eliminated the beach (8) which is now only 5 m wide. When present, the beach is composed of coarse gravel (10) with a mean size of 7.4 mm. This represents a typical example of unnatural coast where the balance has been completely changed by the intervention of man.

Stretch 6, which is located a long way from the

Table 2. *Normalized varimax factor components. The results here were obtained by subjecting the data regarding the coastal stretches (Table 1) to Q-mode factor analysis.*

Stretches	Communality	Factors I	Factors II	Factors III
1	0.82	0.20	0.75	0.05
2	0.88	0.07	0.88	0.05
3	0.88	0.05	0.82	0.13
4	0.94	0.14	0.79	0.07
5	0.71	0.10	0.19	0.71
6	0.75	0.40	0.08	0.52
7	0.71	0.74	0.20	0.06
8	0.86	0.91	0.07	0.02
9	0.72	0.68	0.32	0.00
10	0.91	0.04	0.72	0.24
11	0.79	0.90	0.10	0.00
12	0.86	0.10	0.74	0.16
13	0.84	0.21	0.41	0.38
14	0.88	0.83	0.03	0.14
15	0.85	0.65	0.10	0.25
16	0.87	0.10	0.62	0.28
17	0.73	0.02	0.25	0.73
18	0.87	0.10	0.09	0.81
19	0.85	0.68	0.19	0.13
20	0.82	0.58	0.17	0.25
21	0.91	0.71	0.00	0.29
22	0.86	0.65	0.02	0.33
23	0.92	0.77	0.08	0.15
24	0.80	0.89	0.05	0.06
Variance		36.01	27.61	19.49
Cum. var.		36.01	63.62	83.11

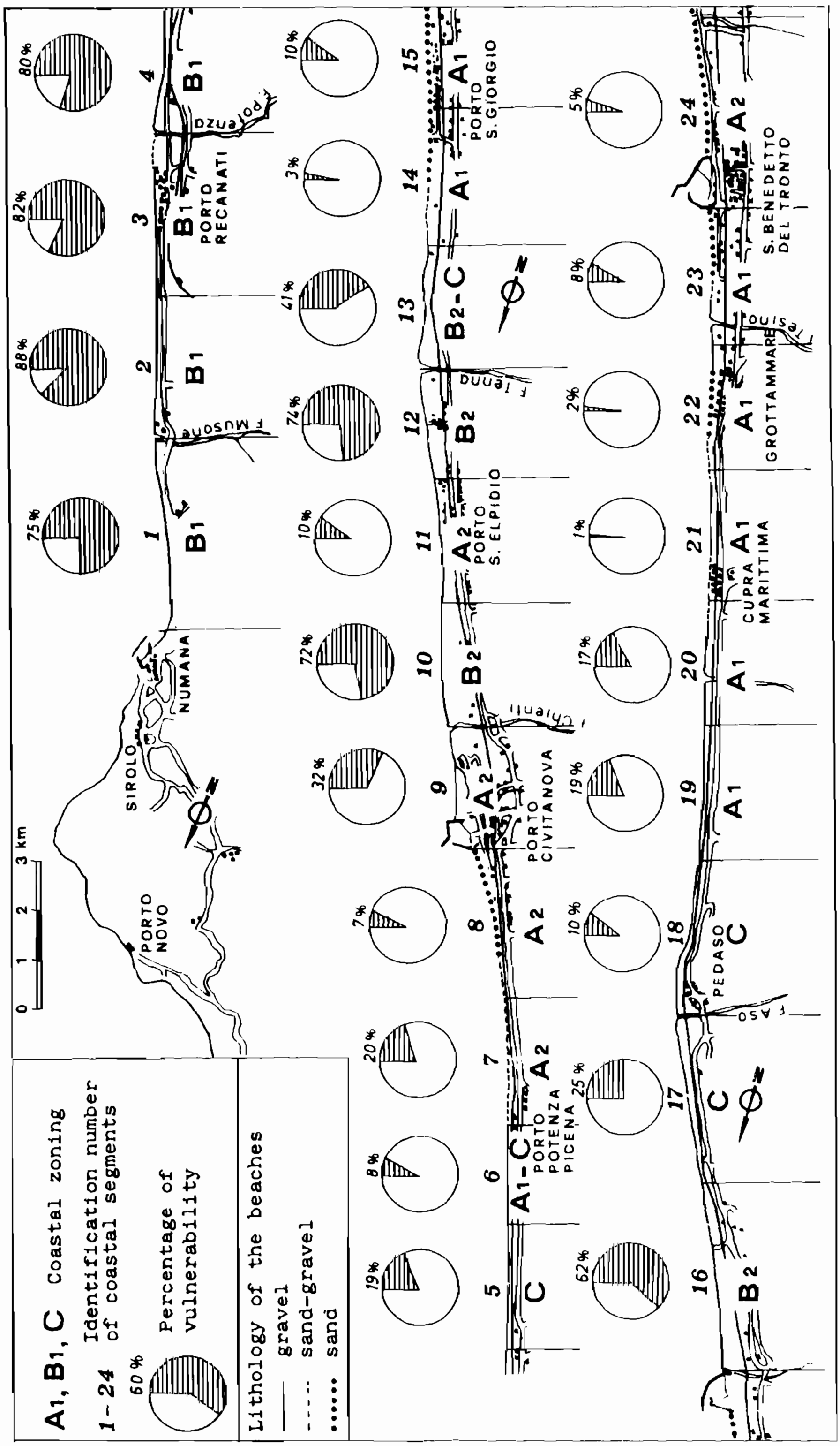

Figure 5. In this figure, the boundaries between the different stretches (numbered from 1 to 24) in which the coast is subdivided are delimited. The groups of similar coastal stretches according to the 15 variables are *identified* by the letters (coastal classification). The circular diagrams indicate the percentage of vulnerability to inundability of the coast. The lithology of the beaches is also shown.

river mouths, has sandy beaches which are quite wide but which have always been affected by erosive trends. Today, it is massively defended by man-made structures including seawalls. As its characteristics are intermediate between those of the identified groups and subgroups, it has been classified as A1–C. Similarly, stretch 13, which is located at the mouth of the river Tenna, has been classified as B2–C as a result of its peculiarities. In fact, it has moderately wide gravelly beaches, which are currently retreating and which are only partially protected by breakwaters.

Vulnerability and Risk

The definition of the indices of vulnerability and/or coastal risk can be determined, for example, as a function of the coastal erosion (CRANE, 1963; CHORLEY, 1973; MITCHELL, 1974; SWAN, 1975; KOMAR, 1979; BLANC, 1980; RICKETTS, 1986), of the variation of the sea level (GORNITZ and KANCIRUK, 1989), or of the ecological and cultural context (ROWNTREE, 1974; RICKETTS, 1989).

The investigation carried out tends to define the vulnerability as a function of the possibility of episodic flooding of the coast. The lower this index, the greater will be the security of the buildings next to the sea.

The results obtained from the coastal classification were used to determine the vulnerability. It was observed that high values of variables 4, 6, 8, 9, 13 and 15, and low ones of variables 1, 5, 7, 11 and 14 are characteristics indicating stability. This means that a beach can protect the area behind it when it is advancing or is stable, and when it is very wide and high. Other features indicative of stability are: a pronounced presence of bars and defensive structures on the sea floor; low values of energy flux and of retreat; a gentle slope of the sea floor; and a low decrease in the contribution of solid materials. The opposite behavior of the variables defines the degree of vulnerability.

By interpreting the coastal classification described in the previous section in terms of vulnerability, the following points stand out. Values of low vulnerability can be assigned to group **A** mainly due to favorable natural conditions of the beaches and to the presence of defensive structures. Group **B** tends to show conditions of high vulnerability due to the absence of natural or artificial protection. Finally, the stretches of group **C** have a low degree of vulnerability due to the strong presence of man-made structures. In conclusion, the closer the sections are to the vertex of Factor II (Figure 3), the more the vulnerability of the beach increases.

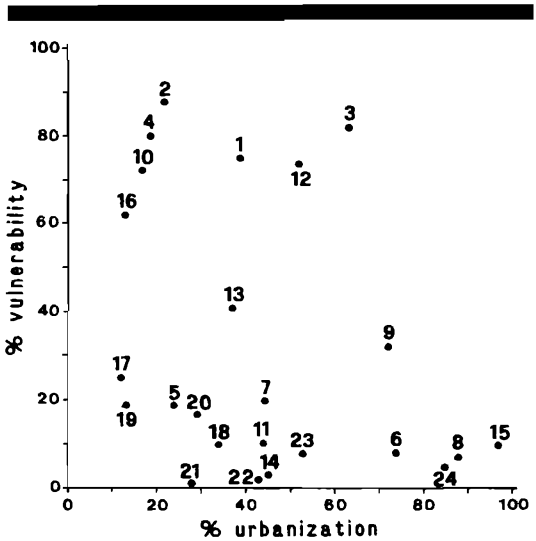

Figure 6. Percentage vulnerability to inundability versus percentage urbanization of the coast. The representation allows the evaluation of the risk of the coastal stretches.

The percentage weight of Factor II referred to the sum of the three factors allows the quantification, on a percentage basis, of the degree of overall vulnerability of the beaches (Figure 5).

The risk is given by the product of the vulnerability for natural hazard and for the value. In this particular case on the basis of historical data, one can consider the natural hazard of floods and high waters in the various coastal stretches to be constant. Now we add a concept of value to the percentage of urbanization of the first 200 m behind the beach. This limit has been chosen because given the configuration of the Adriatic Sea, the nature of the meteorological perturbations as a result of the tide, and storm surge and wave-setup, the rise in sea level at the waterline can present extreme values of circa 1.9 m (AQUATER, 1984). In the case examined here, the possibility of flooding does not exceed 200 m except in exceptional circumstances.

The combination of the vulnerability and the urbanization can thus give a relative estimate of the environmental risk (Figure 6).

We can therefore speculate that the stretches north of the Tenna river (12) and the area around

Porto Recanati (3) show the highest degree of risk. The least risky conditions are found in segments **21**, **22** and **19**.

CONCLUSION

The future evolution of the coastal area examined here is strongly conditioned not only by natural physical factors, but also by numerous man-made structures. The increase in pressure and the ever more intense and diversified use of the littoral have made a new approach to the management and defense of this environment necessary.

This study furnishes new tools for an optimization of the interventions by means of an objective and automatic classification of the physical and human characteristics. The proposed method is extremely flexible; both the type of variables and their number can change according to the data available and to the needs of the research. Certainly the quantification of some variables is susceptible to modification, and the introduction of variables that define more thoroughly the wave action and, in particular situations, the subsidence is advisable. Obviously, in cases in which the littoral is constituted by cliffs, it would be necessary to reconsider the variables used.

The validity of the results obtained with this method is limited to the area examined here. In fact, by changing the area, the values of the variables can be dilated and notably reduced, thereby modifying the characteristics of the single classes and making the results difficult to compare. It is also possible to assign different weights to the variables on the basis of their importance. However, this was not done because we did not consider it to be indispensable for the scope of the research, and we also sought to avoid introducing ulterior subjective evaluations in the absence of appropriate data with this regard. It is, however, the intention of the authors to investigate this theme in the future. Despite these limitations, studies carried out elsewhere in Italy have highlighted the high level of adaptability of the method to examples which are morphologically and dynamically different.

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