



## Developing an Erosion Risk Map Using Soft Computing Methods (Case Study at Sifnos Island)

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**Abstract.** The erosional processes depend on various variables such as lithology, topography, drainage system, rock structure and climatic conditions. The quantitative evaluation of some of the above geological and geomorphological parameters is of primary importance for the purpose of developing erosion risk maps. These maps can become useful tools for developing appropriate strategies on environmental protection, hazard assessment and regional planning.

The island of Sifnos, in Cyclades, was chosen as a case study, where in the final map of the sub-basins of this island, erosion risk distribution is presented.

**Key words:** erosion, G.I.S., fuzzy, cyclades, soft computing

### 1. Introduction

Erosion, the result of surface water flow, is a very complicated process. Prior to the erosional stage, a physical or chemical rock alteration takes place. Products of this process are the soil and the weathered mantle. Since the beginning of erosion studies, five variables have been recognized as of major importance for weathering: climate, biological activity, topography, parent material and time (Jenny, 1941).

The erosion process carries away the soil and weathered material. There are many factors that control erosion. The first factor is the rainfall, the main eroding agent. Rainfall's erosivity depends on its duration, spatial distribution and intensity. The second factor is the morphology as it is expressed by the slope forms and the inclination. The third factor is the rock's and surface's deposit's properties. The above factors define the region's flow regime, the Hortonian or not runoff, and finally the critical time and the amount of erosion. The flow characteristics are controlled by microtopographic features, and produce either rills or sheet erosion (Emmett, 1978). The role of splash erosion, by raindrop impact, seems to be more important for the detachment. The rate of the soil erosion can be calculated by the distance of the divide, or the surface water flow discharge, multiplied by a power of slope gradient (Kirkby, 1978). In order to calculate a region's erosion risk, one must study its geological, geomorphological and hydrological variables.

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Erosion risk maps are land resource evaluations, as they classify basins of similar erosion risk degree. Various papers involve methods of evaluating erosion risk, based on many parameters, such as morphometric variables (Morgan, 1974; Jozefaciuk and Jozefaciuk, 1993), sediment yield information (Diaconu, 1969; Rooseboom and Annandale, 1981) and rainfall erosion indexes (Fournier, 1960; Hundson, 1981; Stocking and Elwell, 1976; Wischmeier and Smith, 1978).

Simple erosion risk scoring systems were previously proposed by Stocking and Elwell, 1973 and later by the European Union CORINE program (Briggs and Giordano, 1992), using morphometric variables and rainfall indexes but Morgan (1996) has criticized the results. Finally, different kinds of soil erosion rate models have been proposed (Wischmeier and Smith, 1978; Elwell, 1978; Morgan *et al.*, 1984; Knisel, 1980; Nearing *et al.*, 1989; Morgan *et al.*, 1997; Morgan *et al.*, 1994). Various soil erosion models have been developed (Giordano, 1986; Kirkby, 1995; Thornes *et al.*, 1996; Baturst *et al.*, 1996). All this activity indicates an expanding interest on the study of erosion and related processes to environmental changes, in the European Mediterranean (De Ploey, 1989; Poesen and Hooke, 1997).

## 2. Methodology

The development of erosion risk maps involves a series of different stages, as field work, air-photo stereo-observation, digitization of geological, topographical and drainage system maps, definition of the input and output variables, establishment of logical rules between the input and the output variables, analysis and visualization of the results. At some of the above stages, GIS technology and fuzzy sets theory were used (Figure 1).

Similar erosional or related to natural hazards problems, have been examined, by the use of different approaches (Brundsen *et al.*, 1975; Carrara *et al.*, 1977; Malgot and Mahr, 1979; Ives and Messerli, 1981; Carrara, 1983; Carrara *et al.*, 1991; Marinos *et al.*, 1997) and the recently used uncertainty factors and fuzzy sets (Binagli *et al.*, 1998) or probability networks (Stassopoulou *et al.*, 1998).

The principal variables used in this paper were:

- erodibility of the rocks,
- slope gradient of the morphology,
- drainage density.

The erodibility variable is very complicated as it depends on the physical and chemical composition of the rock and the existence of major (folds, faults) and minor (bedding, foliation and joints) tectonical structures. The mineral composition is critical as it has been proved that Olivine, Augite, Hornblende, Biotite and in general, dark-colored minerals are more susceptible to weathering than Orthoclase, Muscovite, Quartz, and other light-colored minerals (Sparks, 1965). Generally, the erodibility of the rock depends on the lithology, the process involved and the protective mechanisms. Lithology is connected to the hardness of the rocks and the resistance to erosion. This variable is difficult to be directly measured.

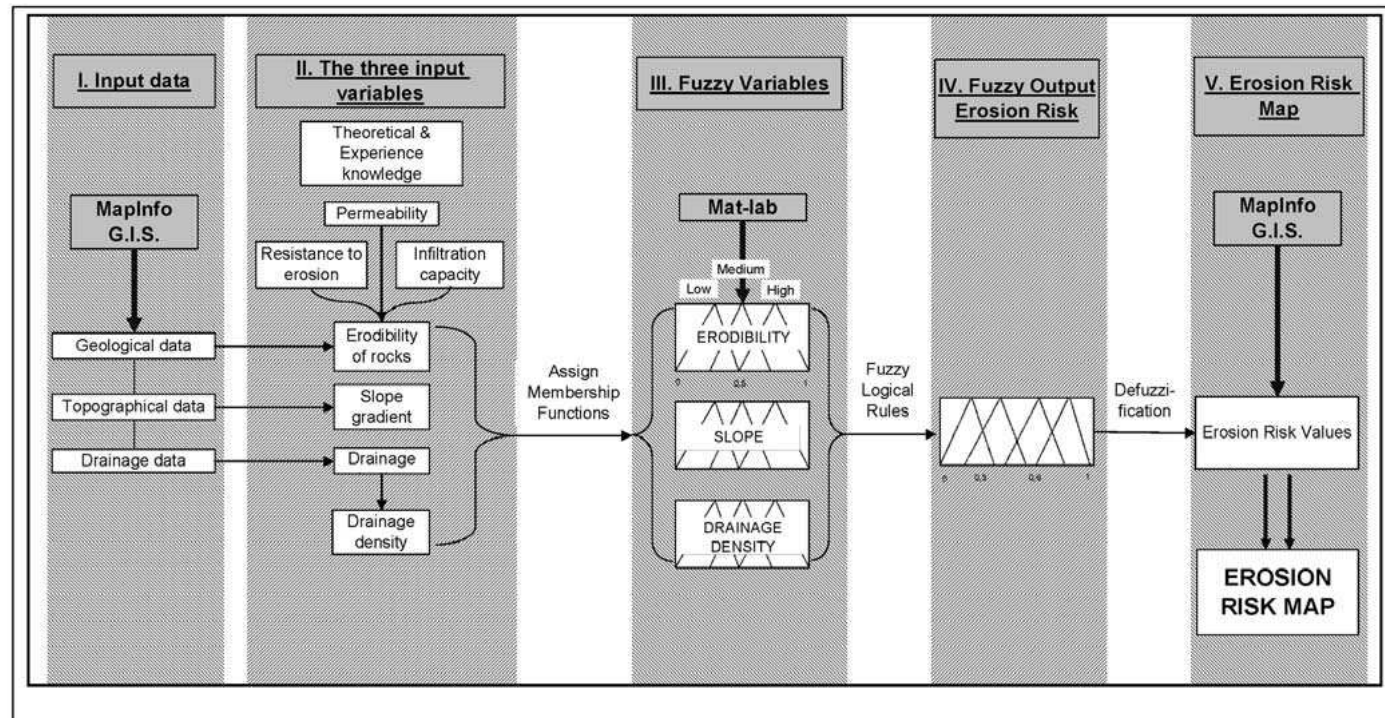


Figure 1. Flow diagram for the production of the erosion risk map.

Some observations on the resistance of rocks to abrasion have resulted in a rock list with decreasing resistance to erosion (Kuenen, 1956). On the other hand, Selby (1987) has proposed a rock mass strength classification and rating, to express the resistance to erosion. In the above classification limestones are more resistant to erosion than schists. The first attempt to assign erodibility values on different rock types was made by Jensen and Painter, (1974). Erodibility is a function involving rock's hardness, permeability and infiltration capacity. Marbles and blueschists are considered to be more resistant to erosion, while alluvials, soil and weathered mantle more prone to erosion.

The grain's form and size defines rock's permeability. This variable controls the quantity of the runoff water, which is the dominant erosion factor. Three categories of permeability values can be distinguished: very low ( $10^{-12} - 10^{-8}$  m/s), low to medium ( $10^{-8} - 10^{-5}$  m/s) and high ( $10^{-5} - 10^{-2}$  m/s) (Bolton, 1979). Metamorphic schists are considered to have a very low permeability while marbles and surface rocks are quite permeable formations. The amount of runoff and underground water depends on surface deposit's infiltration properties. In general, deposits with coarse grain present high infiltration rates. The infiltration capacity of the surface deposit (Horton, 1945; Kirkby, 1969) strongly influences erosion. Concerning the above, one may say that erodibility is the factor of rock's resistance to erosion (hardness of the rock), permeability and infiltration capacity. Finally the existence of vegetation acts as a protective mechanism to erosional processes.

The second variable that has been processed is the morphological slope gradient of each drainage basin. Apart from the slope gradient, form (convex, concaves), aspect and extent are also important factors. It is obvious that slope steepness is critical to the erosional intensity. Schumm (1977) proved that there is an exponential relation between average slope and sediment-yield.

Finally the last input variable was drainage density (ratio of the total stream lengths to the drainage basin's area) which is highly related to water's runoff quantity and substratum's permeability. In general, drainage density is high at basins of weak impermeable rocks and low in basins of resistant and permeable rocks. It was found that drainage density increases according to basin's average slope (Gregory and Wallig, 1973). Furthermore, drainage density of rills is highly related to slope gradient (Schumm, 1977).

The development of the drainage system reflects the interrelations between different geological and hydrological variables. Drainage basin is the smallest autonomous hydrogeological unit. All the above-discussed variables have been calculated for each Sifnos sub-basin. This means that there is one ordered value triad corresponding to each sub-basin. Using these variables, thematic maps to visualise them were produced.

The next step was to formulate proper logical rules in order to produce the final erosion risk values and map. Logical rules, mainly based on empirical knowledge, were applied on all input variables to deduce degrees of erosion risk.

In such problems, two kinds of inexact knowledge are present: the boundary vagueness and the relative spatial imprecision of most input variables. For this reason the fuzzy set theory was applied (Zadeh, 1965; Zadeh, 1987; Yager *et al.*, 1987; Dubois and Prade, 1980; Zimmermann, 1991; Klir and Yuan, 1995). Burrough (1989) and Burrough *et al.* (1992) have proposed a fuzzy methodology for land evaluation of soil profile observations. In our case, triangular functions have been adopted. All the above variables were characterized by fuzzy set values, and expressed by a corresponding membership function. In the present study, “low”, “medium” and “high” define the different degrees of rock’s erodibility. The erodibility value of each formation was based on empirical and theoretical data (Kuenen, 1956; Leopold *et al.*, 1964; Spark, 1965; Bolton, 1979; Selby 1987). The same gradation was used for the relief’s slope, and the drainage density. Output variable was characterized by “Very Low”, “Low”, “Medium” and “High” erosion risk degrees. In order to combine data layers, all the original data have been normalized dividing them by their maximum value. All normalized values are presented in Table I.

Based on the above variables, a fuzzy model was developed. The fuzzy inference process that was used, is known as Mamdani method (Mamdani and Assilian, 1975) and is characterized by its fuzzy outputs. The last step was the defuzzification of fuzzy outputs, using the centroid technique.

### 3. Case Study

The island of Sifnos (Figure 2), located at the northwestern part of the Cycladic Archipelagos, belongs to the Attic-Cycladic geological unit, which is mainly characterized by metamorphic rocks, crystalline limestones and schists. This island has been chosen as a case study, as different sources of geological and geomorphological data were available. Moreover, it has a similar morphostructural evolution with the entire surrounding Cycladic islands, presenting a typical and very attractive Cycladic landscape, with a unique type of architecture.

Davis (1966) and Gournellos (1980) have studied the geology of Sifnos (Figure 3). The lithostratigraphy of Sifnos island, corresponds to a depositional environment of a continental margin. The main sequence contains three carbonaceous and two clastic formations. Recent sediments are found in a few coastal areas and are mainly alluvial or dilluvial. The soil deposits and the weathered mantle, are overlaying alluvials and schist formations and appear in a discontinuous way. Vegetation cover is very limited.

The tectonometamorphic evolution of this island, is the result of many deformational phases. Both the first and the second folding phase were isoclinal, while the later ones had vertical axial planes (Gournellos, 1980). The final deformation phase is the discontinuous neotectonic one, which is responsible for the island’s fracturing.

*Table I.* The initial data of the three input variables (Drainage density, Slope, Erodibility) and the derived output variable (Erosion risk index)

a/a	Density km <sup>-1</sup>	Normalized density	Slope (%)	Normalized slope	Erodibility	Erosion risk index
1.1	1.91	0.25	2.48	0.07	0.33	0.138
1.2	1.31	0.17	3.11	0.09	0.77	0.667
1.3	2.79	0.37	1.16	0.03	0.55	0.666
1.4	4.07	0.54	0.28	0.01	0.41	0.293
1.5	3.53	0.46	0.55	0.02	0.46	0.158
1.6	4.64	0.61	0.00	0.00	0.59	0.481
2	3.32	0.44	29.28	0.85	0.39	0.573
3	4.76	0.63	26.11	0.76	0.47	0.63
4	3.84	0.51	29.79	0.86	0.38	0.568
5	3.42	0.45	31.67	0.92	0.37	0.563
6	2.31	0.30	34.49	1.00	0.41	0.591
7	3.76	0.49	32.65	0.95	0.35	0.225
8	1.93	0.25	30.96	0.90	0.33	0.537
9	1.27	0.17	23.74	0.69	0.29	0.477
10	2.84	0.37	34.02	0.99	0.29	0.511
11	3.00	0.39	30.62	0.89	0.29	0.511
12	3.53	0.46	25.22	0.73	0.31	0.503
13	3.51	0.46	21.94	0.64	0.78	0.692
14	3.06	0.40	21.46	0.62	0.88	0.688
15	2.87	0.38	17.64	0.51	0.88	0.67
16	3.37	0.44	17.34	0.50	0.87	0.5
17	2.46	0.32	16.58	0.48	0.66	0.666
18	3.91	0.51	19.14	0.55	0.62	0.677
19	2.81	0.37	18.12	0.53	0.68	0.674
20	2.79	0.37	17.69	0.51	0.79	0.67
21	2.56	0.34	14.41	0.42	0.67	0.667
22	2.70	0.36	18.36	0.53	0.69	0.674
23	3.50	0.46	19.04	0.55	0.88	0.677
24	4.16	0.55	16.50	0.48	0.88	0.592
25	3.40	0.45	19.01	0.55	0.87	0.677
26	2.54	0.33	23.18	0.67	0.78	0.696
27	2.71	0.36	27.75	0.80	0.75	0.709
28	2.91	0.38	24.21	0.70	0.60	0.678
29	3.13	0.41	26.88	0.78	0.29	0.509
30	1.77	0.23	25.08	0.73	0.29	0.494
31	2.47	0.33	28.23	0.82	0.29	0.511
32	1.03	0.13	18.47	0.54	0.29	0.294
33	3.45	0.45	22.19	0.64	0.29	0.445

Table I. Continued

a/a	Density km <sup>-1</sup>	Normalized density	Slope (%)	Normalized slope	Erodibility	Erosion risk index
34	3.21	0.42	27.26	0.79	0.29	0.511
35	3.31	0.44	26.52	0.77	0.29	0.506
36	3.55	0.47	25.73	0.75	0.29	0.5
37	3.68	0.48	26.76	0.78	0.29	0.509
38	3.80	0.50	27.73	0.80	0.29	0.511
39	3.76	0.49	28.24	0.82	0.30	0.518
40	2.26	0.30	22.22	0.64	0.30	0.45
41	3.22	0.42	18.89	0.55	0.42	0.435
42	3.04	0.40	17.01	0.49	0.51	0.665
43	2.72	0.36	17.74	0.51	0.44	0.47
44	2.52	0.33	18.68	0.54	0.33	0.316
45	1.69	0.22	21.51	0.62	0.54	0.67
46	4.54	0.60	27.52	0.80	0.78	0.72
47	3.81	0.50	22.25	0.65	0.56	0.672
48	1.89	0.25	13.80	0.40	0.42	0.151
49	1.80	0.24	16.93	0.49	0.62	0.665
50	2.82	0.37	17.56	0.51	0.88	0.67
51.1	3.13	0.41	0.97	0.03	0.82	0.667
51.2	0.00	0.00	7.24	0.21	0.87	0.667
51.3	1.68	0.22	0.29	0.01	0.56	0.667
51.4	2.09	0.27	0.41	0.01	0.85	0.667
52	2.19	0.29	15.02	0.44	0.88	0.667
53	2.59	0.34	12.96	0.38	0.88	0.667
54	2.87	0.38	9.91	0.29	0.88	0.667
55	3.14	0.41	15.71	0.46	0.88	0.666
56	1.99	0.26	14.15	0.41	0.85	0.667
57	1.64	0.22	13.42	0.39	0.88	0.667
58	2.17	0.29	14.79	0.43	0.85	0.666
59	2.41	0.32	12.27	0.36	0.80	0.667
60	2.13	0.28	13.92	0.40	0.77	0.666
61.1	2.60	0.34	1.26	0.04	0.86	0.667
61.2	2.38	0.31	0.00	0.00	0.82	0.667
62	2.75	0.36	14.21	0.41	0.71	0.667
63.1	2.09	0.27	1.27	0.04	0.66	0.667
63.2	3.12	0.41	3.13	0.09	0.73	0.667
64	3.98	0.52	13.24	0.38	1.00	0.668
65	2.91	0.38	20.81	0.60	0.47	0.594
66	3.80	0.50	16.71	0.48	0.44	0.154
67	4.03	0.53	13.28	0.39	0.42	0.376

Table I. Continued

a/a	Density km <sup>-1</sup>	Normalized density	Slope (%)	Normalized slope	Erodibility	Erosion risk index
68	3.83	0.50	20.66	0.60	0.32	0.423
69	3.58	0.47	20.46	0.59	0.41	0.49
70	5.21	0.69	19.14	0.56	0.29	0.477
71	3.81	0.50	18.75	0.54	0.29	0.294
72	2.84	0.37	20.11	0.58	0.29	0.378
73	3.20	0.42	21.77	0.63	0.29	0.437
74	2.92	0.38	20.95	0.61	0.29	0.417
75	2.64	0.35	17.88	0.52	0.45	0.372
76	2.49	0.33	0.00	0.00	0.29	0.132
77	2.28	0.30	15.71	0.46	0.38	0.145
78	3.53	0.46	16.65	0.48	0.49	0.163
79	2.88	0.38	19.65	0.57	0.35	0.401
80	3.89	0.51	19.72	0.57	0.36	0.409
81	2.87	0.38	23.68	0.69	0.29	0.477
82	4.92	0.65	22.77	0.66	0.55	0.671
83	2.51	0.33	20.02	0.58	0.49	0.634
84	2.96	0.39	20.24	0.59	0.29	0.393
85	5.20	0.68	19.91	0.58	0.29	0.472
86	7.60	1.00	21.21	0.62	0.29	0.511
87	2.48	0.33	22.21	0.64	0.45	0.581
88	2.52	0.33	21.14	0.61	0.49	0.642
89	3.31	0.44	21.67	0.63	0.45	0.576
90	3.93	0.52	18.80	0.55	0.57	0.677
91	4.12	0.54	16.78	0.49	0.80	0.619
92	3.86	0.51	15.34	0.44	0.70	0.627
93	3.45	0.45	13.77	0.40	0.58	0.667
94	4.18	0.55	19.42	0.56	0.73	0.679
95	2.83	0.37	16.59	0.48	0.34	0.139
96	5.67	0.75	23.01	0.67	0.29	0.501
97	3.08	0.41	22.03	0.64	0.42	0.544
98	3.25	0.43	17.57	0.51	0.39	0.218
99	4.23	0.56	15.73	0.46	0.36	0.393
100	2.60	0.34	25.47	0.74	0.46	0.617
101	2.90	0.38	24.84	0.72	0.60	0.677
102	4.43	0.58	25.27	0.73	0.55	0.67
103	2.32	0.30	24.82	0.72	0.41	0.565
104	2.82	0.37	24.49	0.71	0.31	0.496
105	4.21	0.55	24.14	0.70	0.29	0.481
106	3.30	0.43	25.09	0.73	0.30	0.498

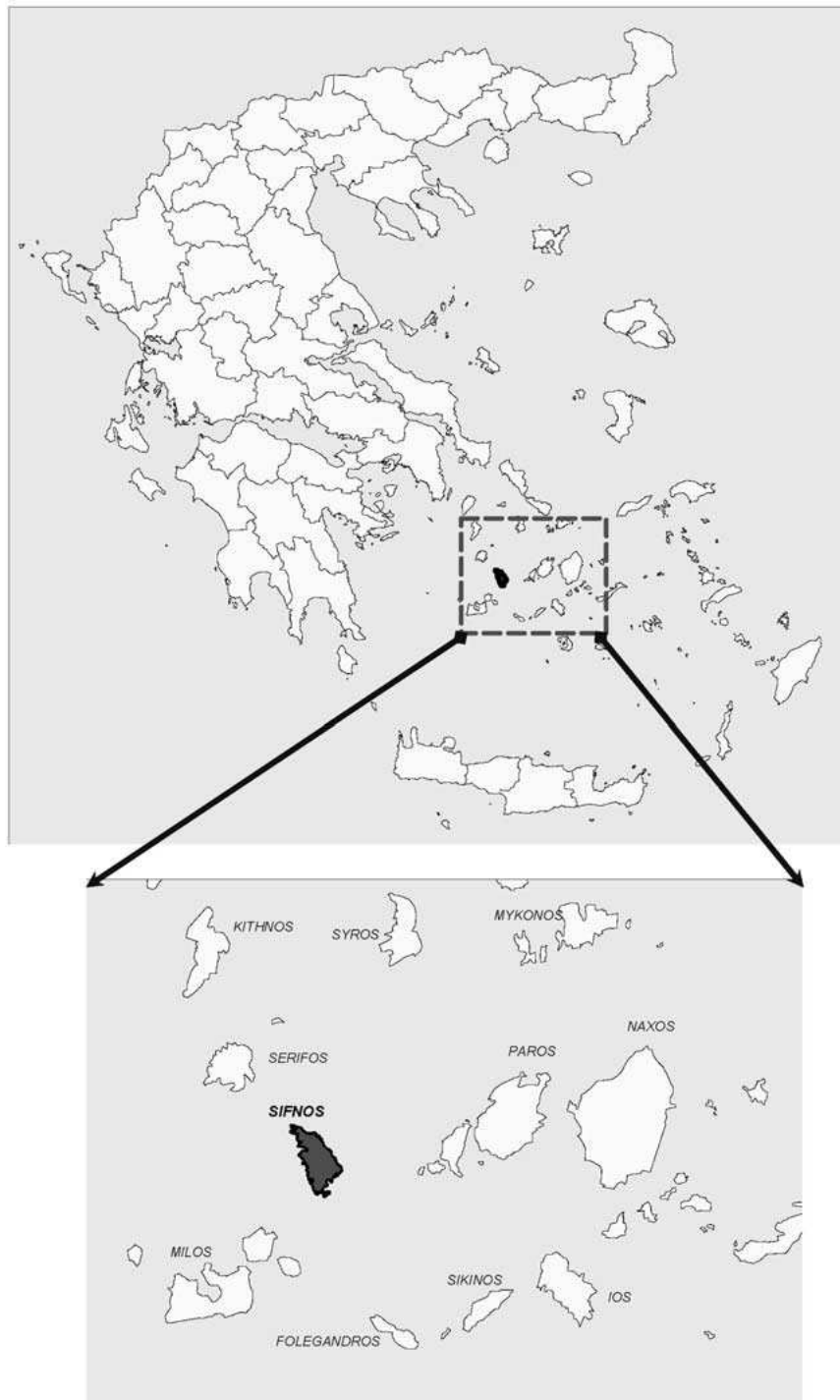
Table I. Continued

a/a	Density km <sup>-1</sup>	Normalized density	Slope (%)	Normalized slope	Erodibility	Erosion risk index
107	2.52	0.33	26.71	0.77	0.34	0.531
108	2.48	0.33	25.45	0.74	0.29	0.497
109	3.25	0.43	31.00	0.90	0.29	0.511
110	5.12	0.67	33.22	0.96	0.29	0.511
111	4.05	0.53	32.37	0.94	0.29	0.511
112	5.47	0.72	33.55	0.97	0.29	0.511
113	3.11	0.41	31.52	0.91	0.29	0.511
114	3.35	0.44	26.37	0.76	0.32	0.517

Sifnos' topography is dominated by the presence of two mountainous areas in the central part of the island, ranging from northwest to southeast. The climate of Cyclades though relatively dry (366.8 mm per year), is also characterized by a few storm events, especially during winter time (Theocharatos, 1978).

The working scales for the topographical and geological maps are 1:50.000 and 1:25.000 respectively. The interpretation of air photos was achieved at a 1:33.000 scale.

The first step of this methodology was the digitization of the geological, topographical and drainage system maps. The marbles originating from limestones are very susceptible to acid waters, which continuously widen the existent discontinuities (joints, bedding), increase the permeability of the rock and consequently reduce the runoff waters. In schists the existence of the schistosity and the joint system influence the disintegration of the rocks in parallel fragments and facilitate erosion. In Sifnos we can distinguish the weathered mantle overlay in the unweathered metamorphic basement. From these initial data, we derived the erodibility, the slope inclination and the drainage density values and the corresponding thematic maps (Table I, Figures 4, 5, and 6). The next step was treating the above variables as fuzzy variables assigning to them the corresponding membership functions. The first input variable that was used was the erodibility of the rock. In order to characterize the erodibility of the rocks, a 0–1 scale was adopted. This means that 0 erodibility values indicate non vulnerable, and 1 highly vulnerable to erosion rocks. At Sifnos case formations of “low” (0–0.5), “medium” (0.25–0.75) and “high” (0.75–1) erodibility were distinguished that are represented by Marbles, Blueschists – Schists, alluvial and weathered mantle, respectively. The second input variable was the slope gradient of the relief, the calculation based on the digital elevation model and representing the angle of the surface with the horizontal plane. Three classes of normalized values of slopes are used: low (0–0.5), medium (0.25–0.75) and high (0.75–1). The last input variable was drainage density. Some small coastal basins



*Figure 2.* General location of the studied area, Sifnos, Greece.

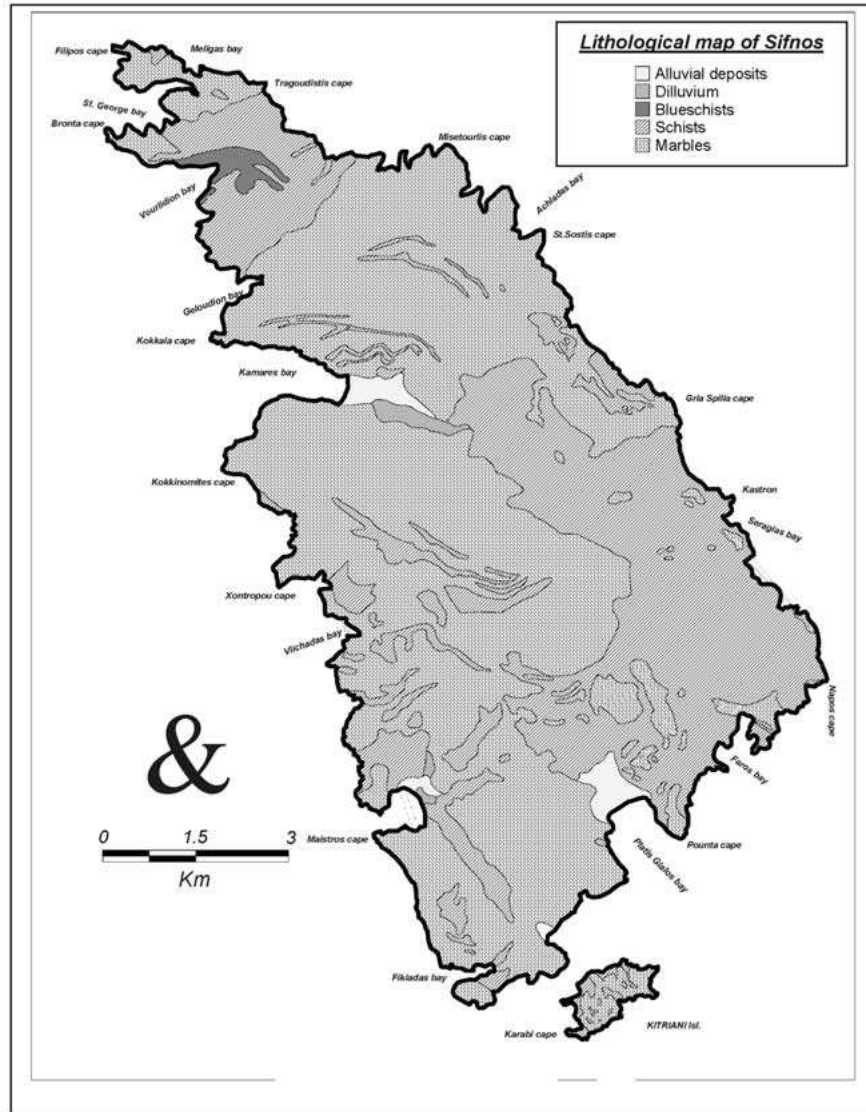


Figure 3. The lithological map of Sifnos.

have not been processed due to lack of wave action erosion rate data. The same classes as before have been used for this variable: low (0–0.5), medium (0.25–0.75) and high (0.5–1). The input variables were automatically processed, by routines programmed in MapInfo's programming environment (MapInfo, 1999; MapBasic, 1999). Figures 7, 8, 9 and 10 present the basin's area distribution, erodibility values, slope inclination and drainage density values.

Table II. The fuzzy logical rules used to derive the erosion risk index

If	ERODIBILITY	IS	High	&	SLOPE	IS	High		Then	Erosion Risk Index	Is	High			
If	ERODIBILITY	IS	High	&	SLOPE	IS	Medium	&	Drainage Density	IS	High	Then	Erosion Risk Index	Is	High
If	ERODIBILITY	IS	High	&	SLOPE	IS	Low		Then	Erosion Risk Index	Is	Medium			
If	ERODIBILITY	IS	Medium	&	SLOPE	IS	High		Then	Erosion Risk Index	Is	Medium			
If	ERODIBILITY	IS	Medium	&	SLOPE	IS	Medium	&	Drainage Density	IS	High	Then	Erosion Risk Index	Is	Medium
If	ERODIBILITY	IS	Medium	&	SLOPE	IS	Low	&	Drainage Density	IS	High	Then	Erosion Risk Index	Is	Low
If	ERODIBILITY	IS	Low	&	SLOPE	IS	Low		Then	Erosion Risk Index	Is	Very Low			

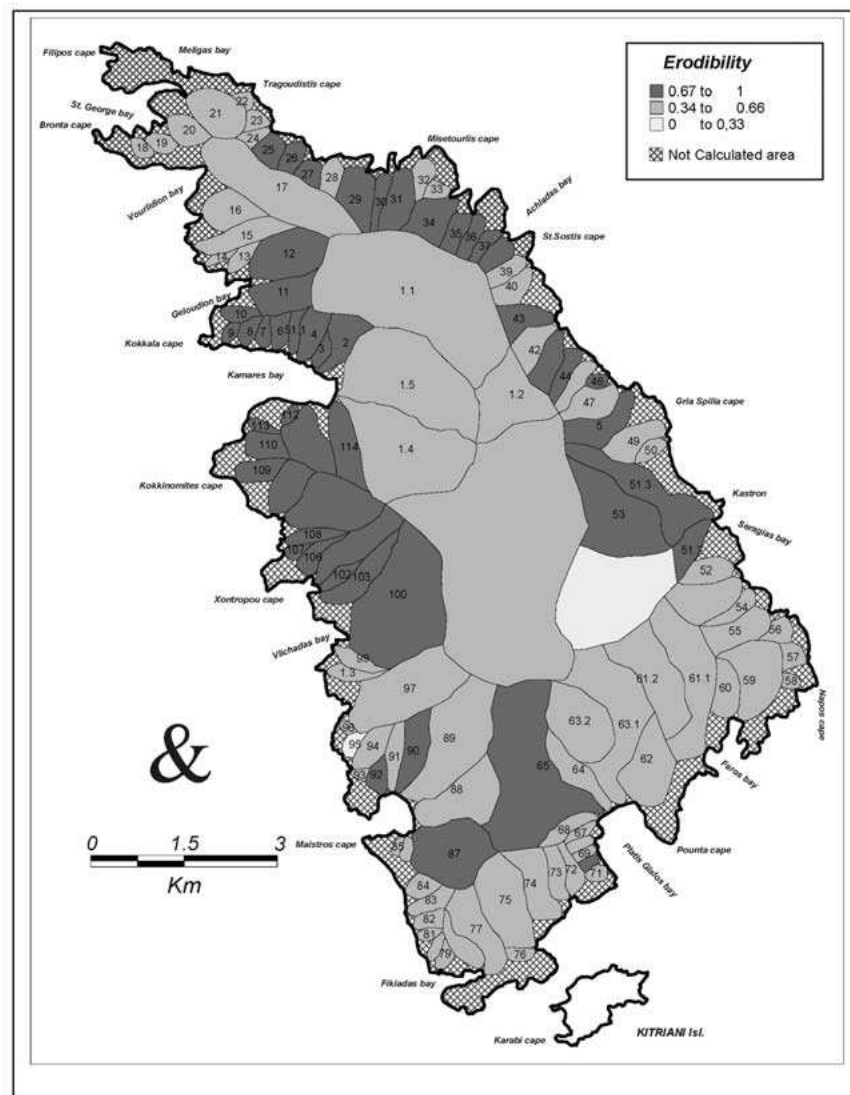


Figure 4. The erodibility map of Sifnos.

Next step was to formulate the fuzzy logical rules, that would transform the input variables to fuzzy numbers. The output variable was the erosion risk index, separately calculated for each drainage basin of the island. The fuzzy based rules that were used to transform input to output variables are presented at Table II. The implementation of these rules was achieved using Mat-Lab software package (Matlab, 1999). It is obvious from these rules (Table II) that we have constructed a fuzzy inference system: from a given set of input variables (drainage density, slope inclination, erodibility) there is a mapping to the output variable. This means that

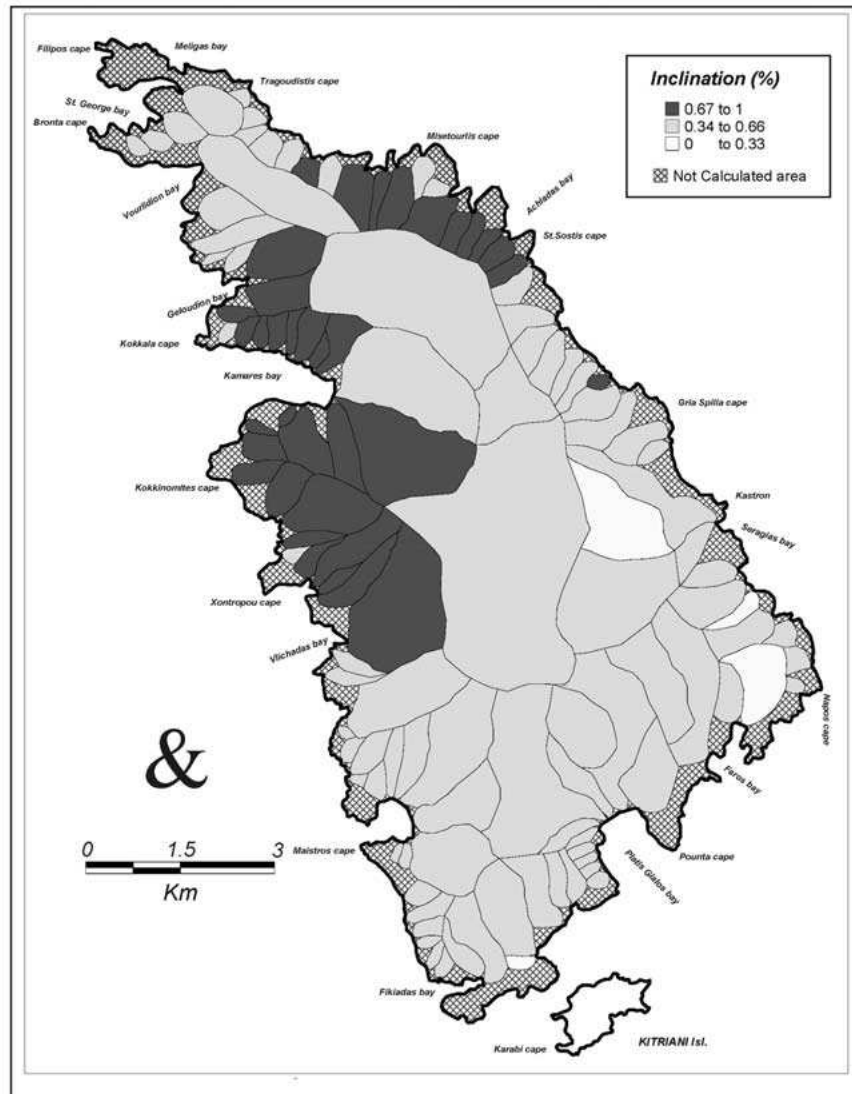


Figure 5. The inclination map of Sifnos.

firstly we have created in Matlab three fuzzy input variables with triangular membership function corresponding to the above variables. Secondly we have applied these rules using the Mamdani inferences style (1975) to produce fuzzy output and finally we have obtained the erosion risk values using defuzzification mechanism (Figure 1). The final step was the evaluation of the output variable (erosion risk index) and the development of the corresponding erosion risk thematic map (Figure 11), presenting the distribution of the erosion risk index over the drainage sub-basins of Sifnos. We consider the above variables as the most important for

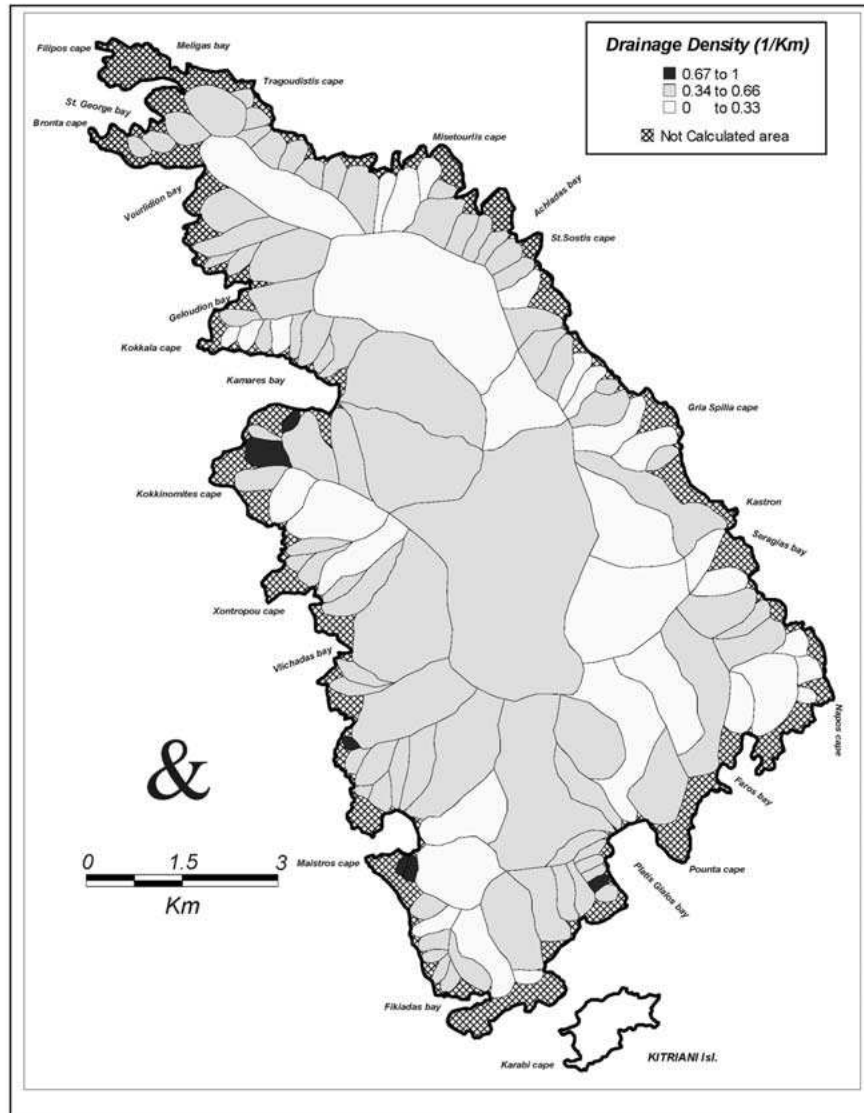


Figure 6. The drainage density map of Sifnos.

the erosional processes. Erodibility is related to lithological composition of the rocks, the slope inclination controls the flow regime of the running water and its ability to erode and finally the drainage density reflects the distribution of the runoff and the underground water. A sensitivity analysis was carried out, to test the model's behavior to minimal changes of the input variables. As it is expected small perturbation of the values of the three input variables contribute to no significant changes of the output variables (erosion risk index).

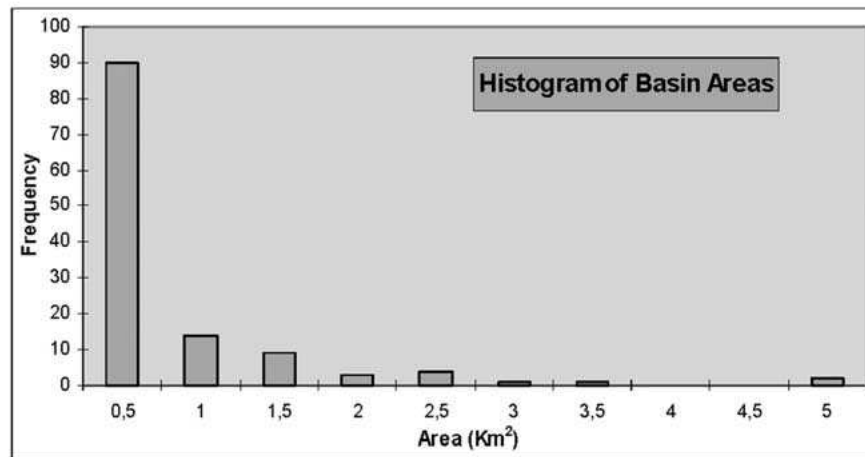


Figure 7. Histogram of the area of drainage basins of Sifnos.

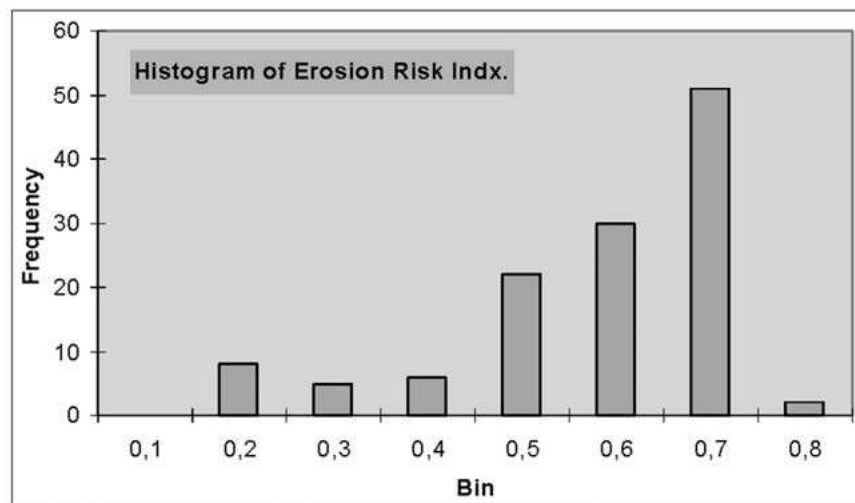


Figure 8. Histogram of the erodibility values of drainage basins of Sifnos.

#### 4. Conclusion

It is obvious (Figure 11) that some small coastal sub-basins of Sifnos at the northern and central parts present high erosion risk. Nevertheless, the largest part of Sifnos island is classified as medium degree erosion risk. This is mainly explained by the lithological and morphological characteristics of the island. We must note that Sifnos, like all the islands of Cyclades, presents high juxtaposition of resistant and permeable rocks (Marbles) against the moderate resistant and impermeable schists. In this substratum, soils and surface deposits are overlain with the absence of significant vegetation. The high vulnerability to erosion at all semi-arid

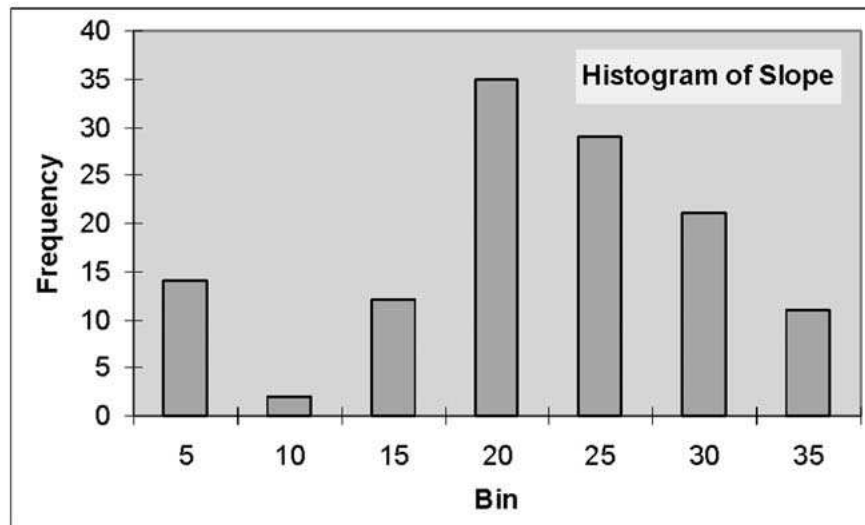


Figure 9. Histogram of the slope inclination values of drainage basins of Sifnos.

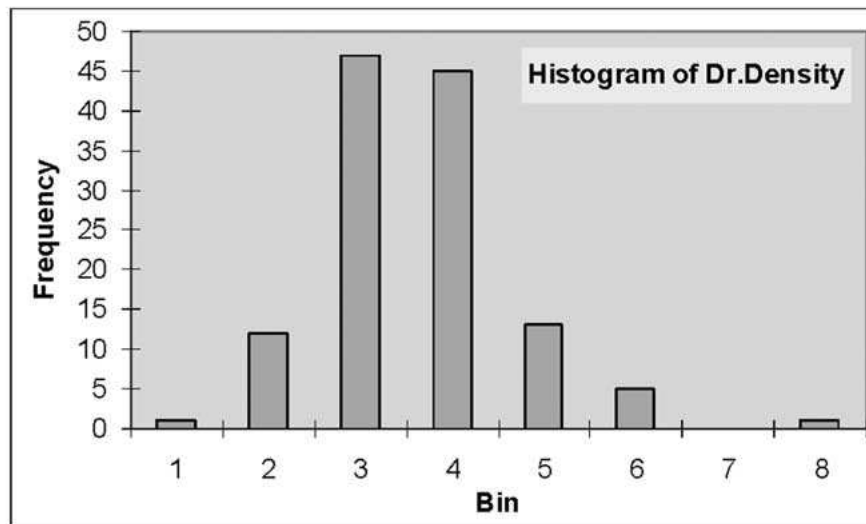


Figure 10. Histogram of the drainage density values of drainage basins of Sifnos.

regions including the Mediterranean region (Walling and Webb, 1983) is already known. Small drainage basins receive uniform rainfalls. The climate conditions, the existence of a long summer dry period and the appearance of rainfalls in the autumn-winter period, contributed to erosion. It was already noted that the sediment yield per unit area, increases as the drainage area is decreasing (Schumm, 1977) and that in general the Mediterranean climates present high erosion rates (Jensen and Painter, 1974). The model proposed by this paper cannot be easily

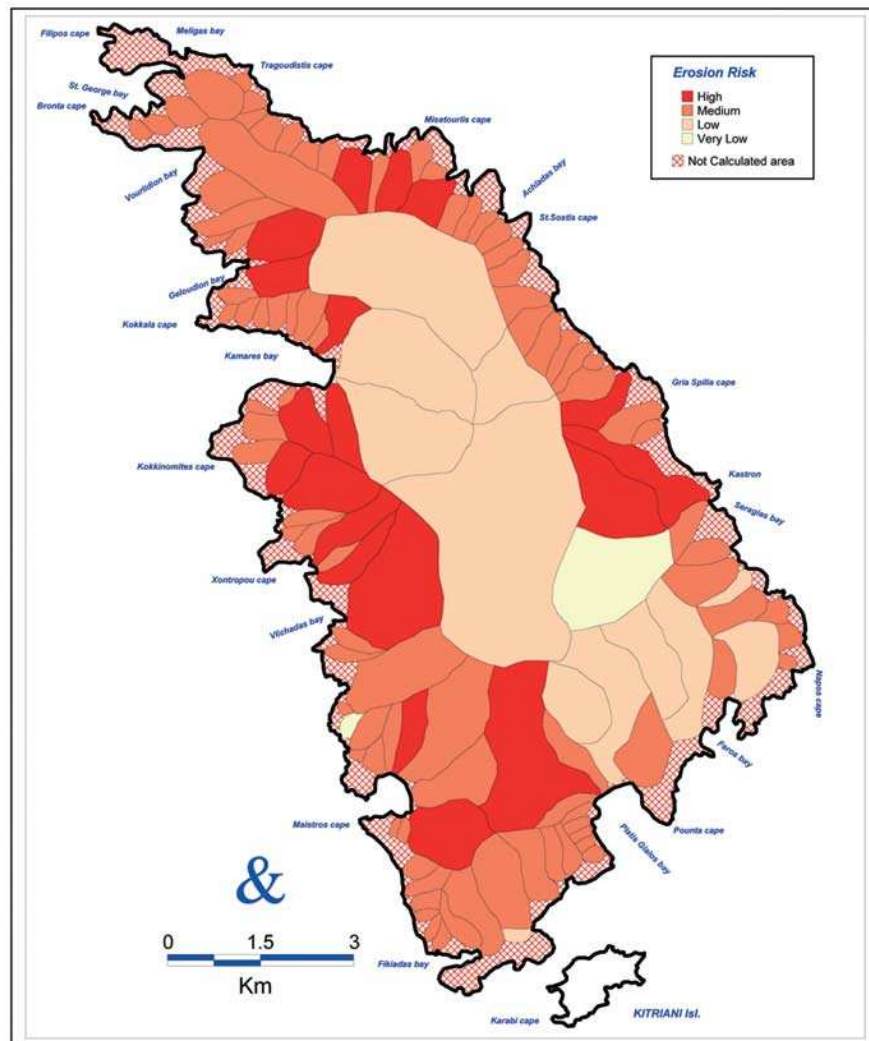


Figure 11. The erosion risk map of drainage basins of Sifnos.

cross-tested, however by observing the distribution of recent sediments we can realize that the erosional process is active.

The application of the fuzzy set theory on the development of erosion risk maps may be a useful tool in many cases. The nature of the input variables, having no sharp boundaries, and the complexity of their interrelations, makes the fuzzy set approach necessary in many problems. On the other hand, fuzzy based logical rules can be very easily developed. In the case study of Sifnos, which may be considered as a typical example of the Cyclades islands (Gournellos, 1980), the elaboration of the erosion risk map indicates those drainage basins of high erodibility degree. This allows the application of the right conservation strategy for controlling erosion.

This kind of data analysis should also be taken into consideration for both local and regional planning.

This GIS framework may be applied to all Cycladic islands to map erosional deterioration. This is a simple model, demanding only three variables and a few logical rules, making its use easy.

Modifications on the fuzzy rules and the membership functions should be made, when more quantitative and qualitative data are available, concerning the geodynamic process of the studied drainage basins.

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