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USING FUZZY LOGIC TO MAP SOIL EROSION. A CASE STUDY FROM THE ISLAND OF PAROS

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Summary: This paper introduces the study of the phenomenon of soil erosion and the parameters affecting the erosional processes; both environmental factors and causes induced by human factor in Paros Island. The research focuses primarily on the modelling of erosion risk in a GIS environment; the input variables of the model are vulnerability of rocks, slope values, drainage density and the soil distribution. A derivative map for each factor is being produced and classified, while logical rules are formulated so as to transform input to output variables. An erosion risk index for the study area is, then, generated along with a corresponding thematic map. The methodology is applied in Paros island, located in southern Cyclades, in Greece.

Introduction

Soil erosion is a natural process where particles of soil, surficial sediments and rocks are carried away by water or wind. It depends on a number of factors such as climatic elements, vegetation cover, slope angle, soil type, topography, human intervention and natural disasters.

The direct factors that cause erosion are the climatic elements such as rain and wind (or even ice in some areas). The role of the rest of the factors is to simply accelerate or decelerate the process, which involves:

- dislodging, where soil particles are detached due to heavy rain or wind,
- transport, where the particles are transferred by flowing water or wind and
- deposition, where the soil particles are deposited as sediments to another location.

Estimation the amount of soil loss highly depends on input parameters (e.g. rainfall intensity, soil erodibility etc.). Higher slope angle and low plant cover can cause severe dislodging and material transfer, increasing the amounts of soil that are eroded (CENTERI 2002, CENTERI and PATAKI 2005).

The vegetation cover is another important factor since it generally stabilizes soil and controls run off, through the plants, roots. Erosion begins to decrease as rainfall reaches the level covered by grasslands, because the grass roots anchor the soil and resist erosion. Erosion occurs rarely in natural forests, quite often in croplands and the more frequently in cleared areas (COCH 1995).

The soil structure also affects erosion since the arrangement of soil particles and their cohesion determines the soil's resistance to dislodging. The soil structure also determines the rates of infiltration and the infiltration capacity; big infiltration capacity reduces water runoff, thus reducing material transfer. Soil types with abundance in organic material appear high infiltration capacity, as well as strong particle cohesion and, so, they are considered to be well resistive to erosion.

The morphology of an area is of major importance concerning the intensity of the erosional processes. For example the length, the angle and steepness of a slope affects the velocity of runoff water and generally steeper slopes appear increased surface water-flow velocity thus aggravating the rates of material transfer.

Soil erosion can be accelerated by human activities, the major of which are:

- Overcultivation, which refers mainly to plowing which causes the soil to lose its cohesion and to remain exposed to wind and water. After plowing, the soil remains bare before the newly planted crop grows. After the harvest, the soil is again exposed to erosion.
- Overgrazing, which mostly affects grasslands. The land may become barren when the grass production fails to keep up with consumption and that leads to wind and water erosion and desertification.
- Deforestation, which comprises another major issue. Forests are extremely useful, among others, for holding and recycling nutrients and for absorbing and holding water (WRIGHT 2005). Logging activities or land reclamation at forest areas, are leaving the soil exposed. The topsoil becomes saturated with water from rain and slides off into waterways exposing the subsoil, which continues to erode. Soil loss complicates reforestation or plant re-establishment, which are some of the means that are used so as to prevent further erosion.

Furthermore, natural events such as droughts and fires may increase erosion, since they reduce the vegetation cover. Climatic changes such as unexpected storm periods or the establishment of drier periods increases water and wind erosion, respectively. Soil erosion is an important social and economic problem and research on land and water management is essential. Monitoring of soil erosion is necessary in order to predict the progress of the phenomenon and mitigate it. Prediction models estimate rates of erosion. During the last decades, corresponding algorithms are being developed such as the Universal Soil Loss Equation, the Water Erosion Prediction Project model, and the European Soil Erosion Model. Modeling requires input data and validation. The input data includes meteorological data, soil characteristics, topography, land use and land management data. In view of a long-term preservation mechanism, continuous measurements of soil erosion is of necessity; in parallel, geomorphological mapping and comparative analysis of sediment transport and deposition rates are of essence.

Measures for combating erosion refer to sections such as agriculture, livestock, grazing and forestry. They include practices concerning sustainable management of agricultural land and improvement of soil properties, control of the rate and the duration of grazing and minimizing afforestation (VAN-CAMP et al. 2004).

Materials and methods

Both the erosional procedures and the deriving depositional processes depend on the type and the distribution of soils. The study of the phenomenon of erosion entails various tasks (Figure 1.) so as to generate the results and the derivative maps:

- Realization of fieldwork so as to obtain primary and accurate topographical data with the use of GPS.

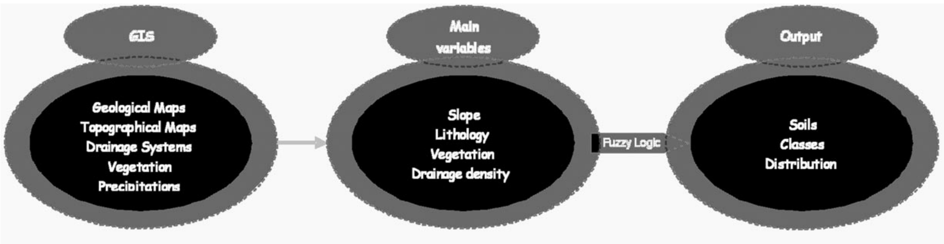


Figure 1. Flow diagram of the followed procedure
1. ábra Az alkalmazott eljárás folyamatábrája

- Correction and photo interpretation of aerial photographs and satellite images.
- Gathering analogue maps (geological, topographical, physico-geographical, hydrological).
- Digitization of the aforementioned maps and creation of the information layers attributing geological, altitudinal, geomorphological, hydrological and environmental data.
- Definition of input and output variables that will determine the erodibility of the area.
- Specifying logical rules apt to transform input variables to output ones.
- Creation of derivative erosion risk maps, visualization of areas at erosion risk and analysis of the results.

The input variables applied at the study area are:

1. Erodibility of rocks
   The erodibility of the rocks results from many variables in combination; the physical and chemical composition of the rock, its structure and discontinuities, the existence of a protective vegetative cover which contributes in the increasement of the infiltration capacity and limits the runoff flow, the intensity and the duration of precipitation, its spatial and time distribution and, finally, its raindrop size (GOURNELOS et al. 2004) are all factors affecting the rock.
2. Slope values and angles
   The morphological slope gradient is another imperative factor with regard to erosion, since the steeper the slopes are, the higher the gravitational movement of sediments is. The aspect (slope angle) of the area defines the orientation towards which the sediment moves.
3. Drainage density
   Drainage density declares the ratio of the total stream length to the drainage basin's area. This factor is associated to the water's runoff quantity and substratum's permeability. Drainage density is, usually, high at basins of weak impermeable rocks and low in basins of resistant and permeable rocks. In 1973, Gregory and Walling found that drainage density increases in correspondence to the basin's average slope. Moreover, drainage density of rills is greatly linked to the slope gradient (SCHUMM 1977).
4. Soil distribution and characteristics
   The type and the thickness of soil along with its spatial distribution, also, affect the susceptibility of the area to erosion.

Target area

Paros belongs to southern Cyclades and it is located between Naxos and Sifnos in a distance of 90 miles from Piraeus (Figure 2.). The island has an area of 196 km^2 and it is the third largest island of the Cyclades, after the islands of Naxos (428 km^2) and Paros (374 km^2). The village of Paros or Parikia is both the capital village and the most important port of the island. The island of Paros has an ellipsoid shape with axes NE-SW 22 km and NW–SE 14 km. The coast is indented in the northeastern part, where the Bay of Naousa is formulated, and, in the northwestern part, at the Bay of Paros (Parikia). The biggest part of the coast is steep and rocky, while just a small percentage of it is sandy.

The vegetation of Paros island is poor. Flora is met only at the mountainous mainland of the island, where water exists. The climate is mild, typical of an island and representative of the climate with yearly winds in the central part of Aegean.

Various researchers have studied the geology and the geomorphology of Paros island (TRIKKALINOS 1950, PARASKEUOPOULOS 1960, PAPANIKOLAOU, 1978, EVELPIDOU 1996). The geology of Paros is characterized by a complicated structure consisting of different units. Lithological formations are, mainly, metamorphic rocks (amphibolites, gneisses, mica schists and marbles), granite and pegmatitic intrusion. Another unit overlies, discordantly, the previous one and it consists of serpentinites, limestones (from upper chalk) and neogene formations (conglomerates, marls, sandstones). Finally, quaternary formations are, mainly, present in coastal areas.

Intense and various morphological features are present in the island of Paros due to the lithological composition and the tectonic structure of the island. The relief is low in the biggest part of the island. The relief reaches 100 m perimetrical to the island, while it increases in the inner part, mainly in the central area to the southern part, except for the northwestern part of the island. The highest altitudinal values are met, primarily, on marbles and, secondary, on gneisses, whereas lower altitudinal values (up to 100m) are met on clastics and schists. The drainage basin is, also, greatly affected by the tectonic and the lithological characteristics of the island.

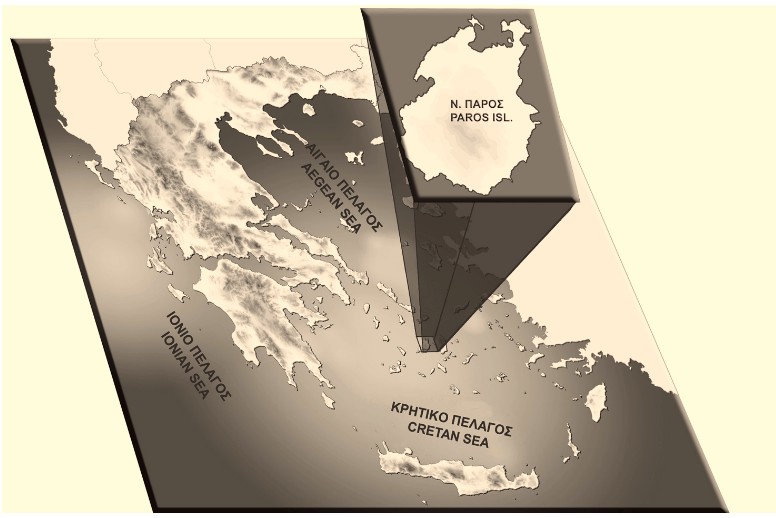
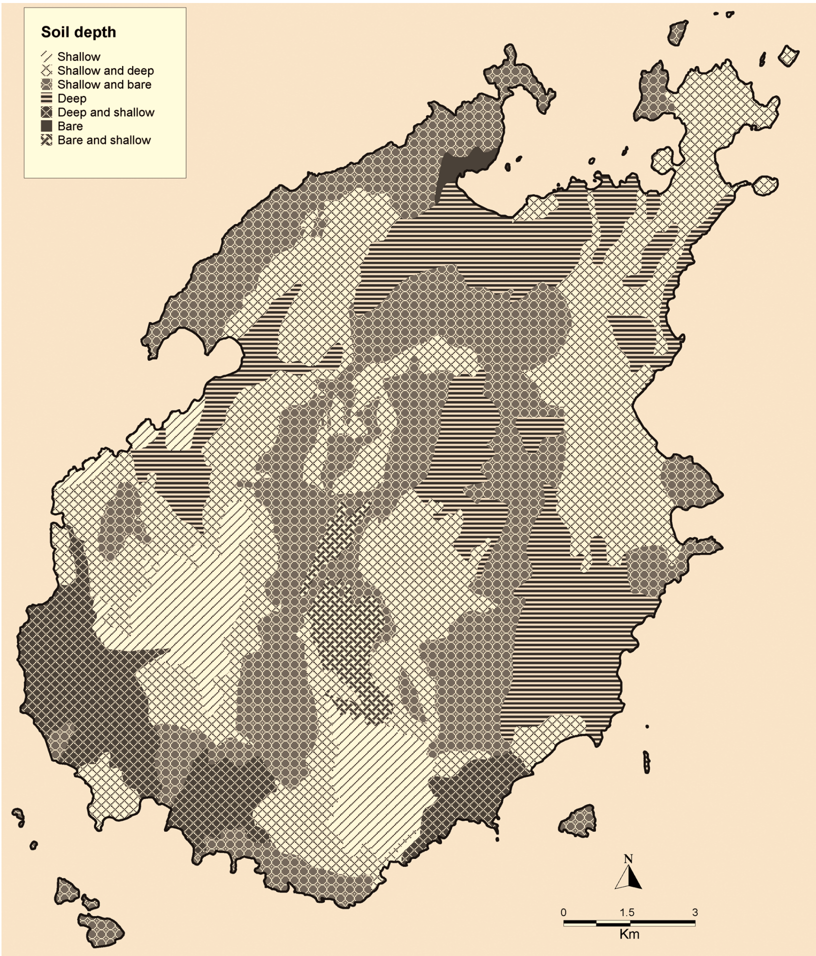


Figure 2. Paros island
2. ábra Parosz szigete

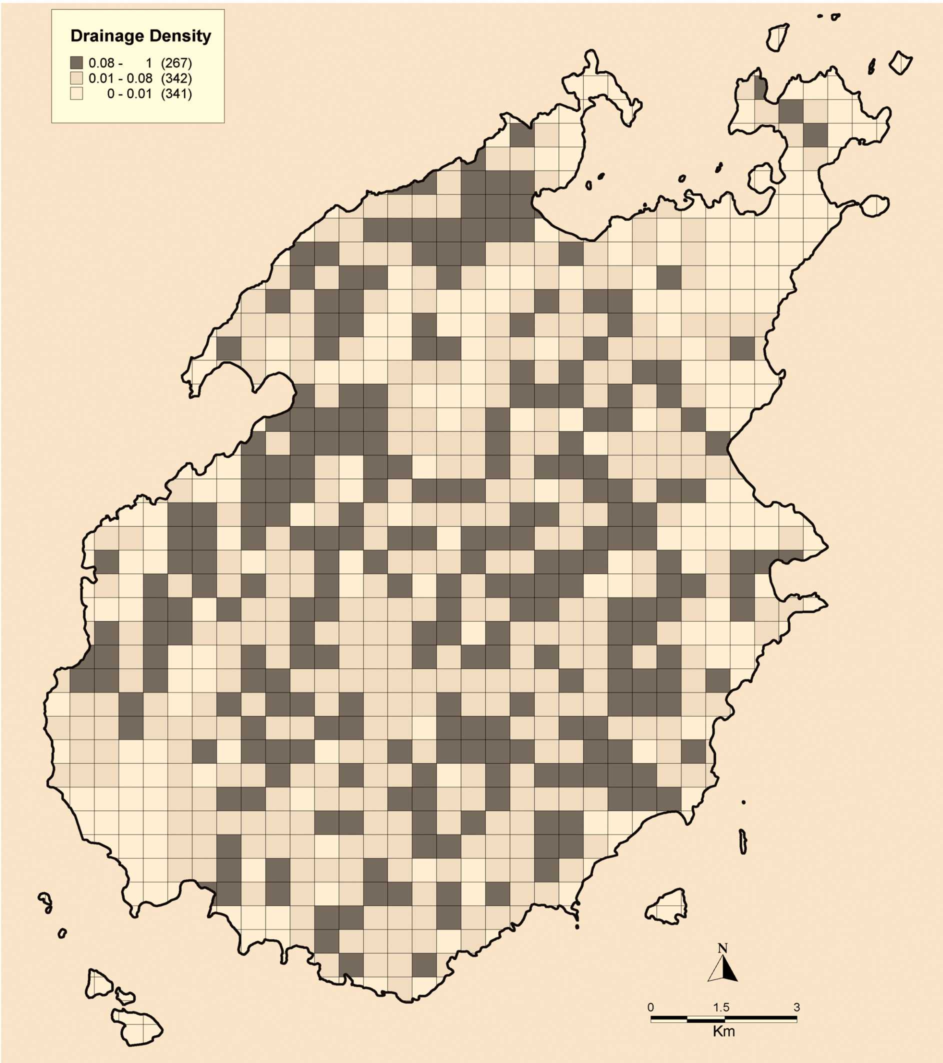
The climate of Cyclades, though relatively dry (366,8 mm per year), is also characterized by few storm events, especially, during wintertime (THEOCHARATOS 1978).

Focal aim of this research was the study of erosion in the island of Paros; both the erosional processes and the result, the depositional material at footslopes deriving from upslope erosion, have been studied.

For the aims of the study, the topographical and geological maps of scale 1:50000 have been digitized and imported in a GIS environment. Information layers presenting the altitude, the drainage basin and the geological formations have been created. The aerial photographs of scale 1:33000 and the satellite images have been photo-interpreted and, along with primary data gathered through fieldwork, have been also imported in the spatial database; the derivative information layers concern geomorphological data such as diaclaces and discontinuities, land use data and distribution of weathered mantle which overlay the unweathered metamorphic basement. In specific, soil depth map (Figure 3.) depicts the geographical distribution of the soil mantle. This map has been created from data both from Ministry of Agriculture (Forest Service) and from extensive field work.



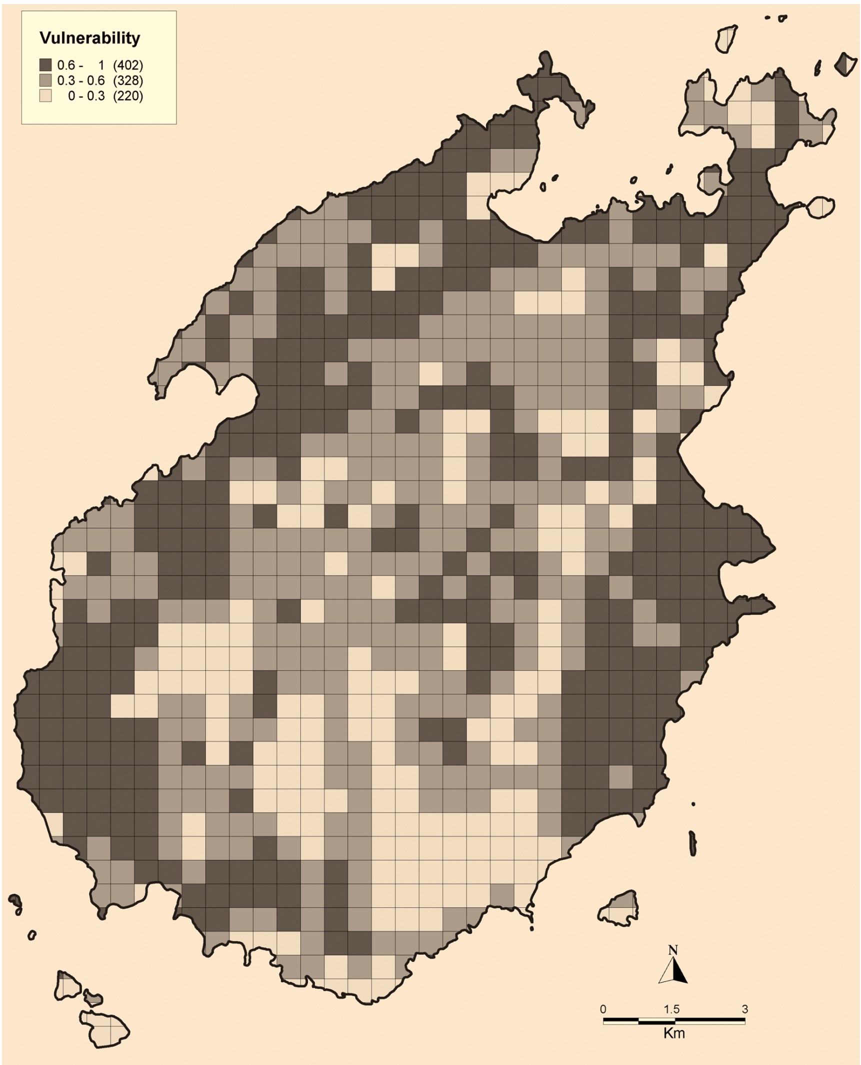
From these initial data, the drainage density, the vulnerability and the slope inclination values (Figure 4., 5. & 6.) have been derived. These variables are considered to be the most important ones for the erosional processes. The next step was treating the above variables as fuzzy variables assigning to them the corresponding membership functions. The first input variable was the vulnerability of the rock, which is the most complicated factor and 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; it has been proved that dark-colored minerals are more susceptible to weathering than light-colored minerals (SPARKS 1965). Generally, the vulnerability of the rock depends on the lithology, which is related to the hardness of the rock and the resistance to erosion, the permeability, the infiltration capacity, the process involved, and the protective mechanisms (e.g. the existence of



vegetative cover). Marbles and schists are considered to be more resistant to erosion, while alluvials, gneiss, soil and weathered mantle more prone to erosion.

Three normalized classes were distinguished and formations of low, medium, and relatively high vulnerability are marbles, blueschists–schists, alluvial and weathered mantle, correspondingly. The second input variable was the gradient of morphological slope, which was calculated through the digital elevation model. In this case three normalized classes were distinguished as well. Finally, the drainage density variable, which reflects the distribution of the runoff and the underground water, was distributed into three classes.

Next step was to formulate logical rules, which would conclude to the erosion risk index.



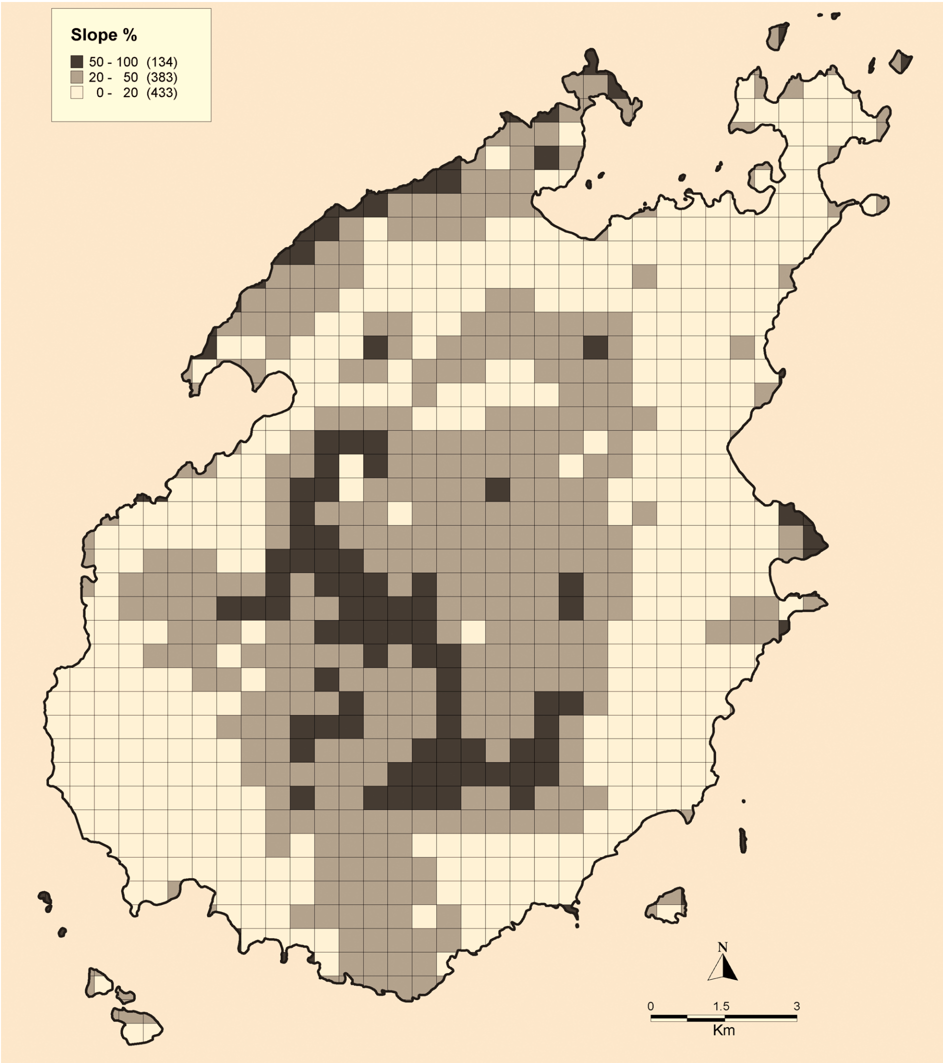

Slope %
50 - 100 (134)
20 - 50 (383)
0 - 20 (433)
N
0
1.5
3
Km

Table 1: The fuzzy logical rules used to derive the erosion risk index
1. táblázat A fuzzy logikai szabályok használata az erózióveszély indexének megállapításához

If	vulnerability	is	high	&	slope	is	high					then	erosion risk index	is	high
If	vulnerability	is	high	&	slope	is	medium	&	drainage density	is	high	then	erosion risk index	is	high
If	vulnerability	is	high	&	slope	is	low					then	erosion risk index	is	medium
If	vulnerability	is	medium	&	slope	is	high					then	erosion risk index	is	medium
If	vulnerability	is	medium	&	slope	is	medium	&	drainage density	is	high	then	erosion risk index	is	medium
If	vulnerability	is	medium	&	slope	is	low	&	drainage density	is	high	then	erosion risk index	is	low
If	vulnerability	is	low	&	slope	is	low					then	erosion risk index	is	very low

The logical rules, which were separately calculated for each drainage basin of the island and were used to transform input to output variables, are presented at Table 1. The implementation of these rules was achieved using Mat-Lab software package (MATLAB 2002).

The final step was the evaluation of the output variable (erosion risk index) and the development of the corresponding erosion risk thematic map, presenting the distribution of the erosion risk index over the drainage sub-basins of Paros.

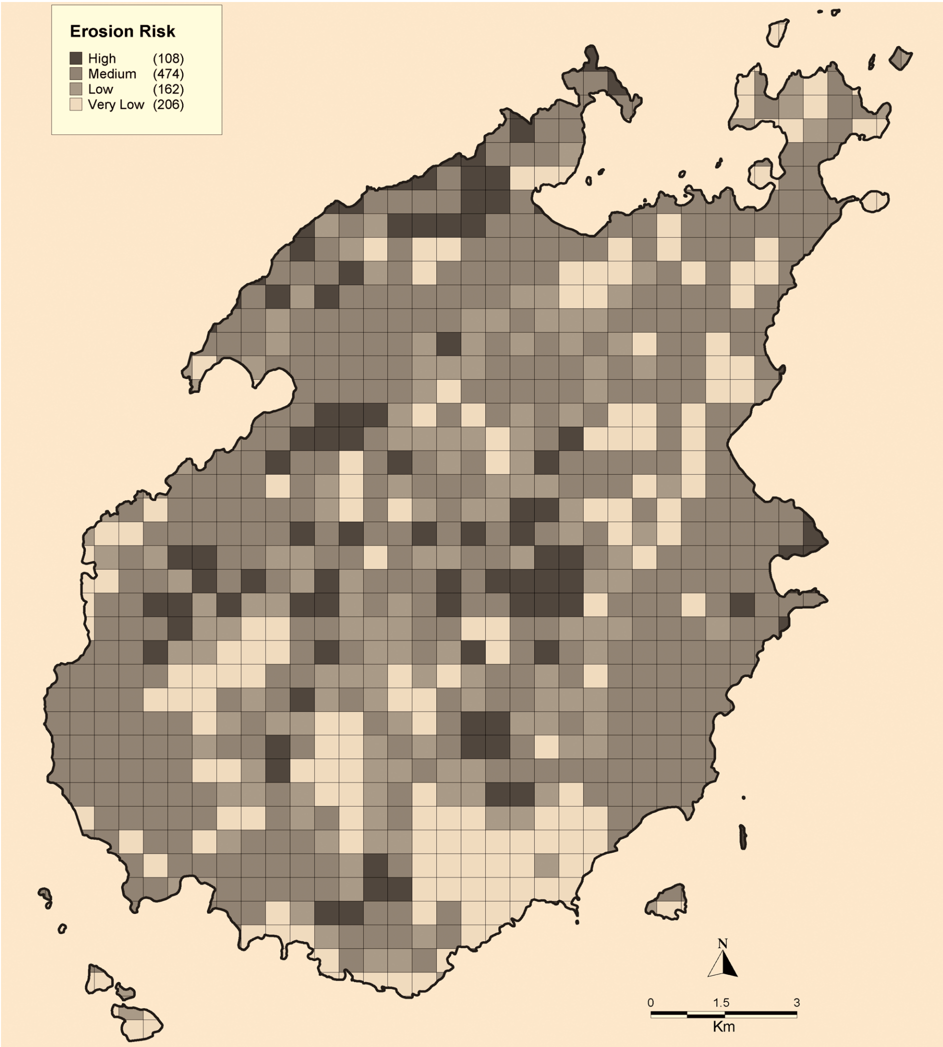
Results and Discussion

The erosion risk map indicates the zones of Paros island which are more, less or not at all susceptible to soil erosion. The greatest part of the coastal areas along with the big part of the mainland (Table 2) are classified as areas with medium risk of erosion, while there are few spots with high slope, vulnerability and drainage density values that are, eventually, in high erosion risk.

Table 2: Quantitative distribution of erosion risk
2. táblázat Az erózióveszély százalékos eloszlása

	Count	*%*
High	108	11,38
Medium	474	49,89
Low	162	17,05
Very Low	206	21,68

In specific, there are some areas in the north-western part of the island with high erosion risk values. Dispersed spots in the central-western part are, also, attributed with high erosion risk values. In contrast, in the south-eastern part there is the biggest area with very low risk towards erosion.



The erosion risk map gives the researcher an understanding of soil erosion conditions existing in the area and an implication of the overall environmental characteristics (slope, drainage density, vulnerability) of the island as a totality. Erosion risk maps enable an advantageous comparative analysis of neighboring areas or the holistic study of a group of islands. Such studies are, furthermore, of great assistance for the locals; spatial planning and environmental agencies of the local and regional authorities support their services with the use of such derivative maps. Controlling building activity and tourism expansion along with the protection of the landscape are all tasks entailing overview of the morphological characteristics of the area and its susceptibility to erosion.

Considering the environmental alterations taking place in an area together with the human activity directly affecting the landscape, it is advisable such a study to be revised after a period of time (few decades) for the same areas so as to sustain an integral perspective for erosion conditions.

References

CENTERI, CS. 2002: The role of vegetation cover in soil erosion on the Tihany Peninsula. *Acta* Botanica Hungarica. 44: 285–295.

CENTERI, CS., PATAKI, R. 2005: Soil erodibility measurements on the slopes of the Tihany Peninsula, Hungary. In. A. Faz Cano, R. Ortiz Silla & A. R. Mermut (eds). Advances in GeoEcology 36, p. 149–154.

CHRISTODOULOU, M., ZIANGAS, E., NAKOS, G. 1996: Soil Map of Greece, Land Resource Map, Dhitiki Iraklia. Ministry of Agriculture, Forest Service.

CHRISTODOULOU, M., ZIANGAS, E., NAKOS, G. 1996: Soil Map of Greece, Land Resource Map, Paros. Ministry of Agriculture, Forest Service.

CHRISTODOULOU, M., ZIANGAS, E., NAKOS, G. 1996: Soil Map of Greece, Land Resource Map, Nisos Despotikon. Ministry of Agriculture, Forest Service.

CHRISTODOULOU, M., ZIANGAS, E., NAKOS, G. 1996: Soil Map of Greece, Land Capability Map for Forestry, Naxos. Ministry of Agriculture, Forest Service.

COCH, K. N. 1995: Geohazards, Natural and Human by Prentice Hall.

EVELPIDOU, N. 1996: Geological and Geomorphological remarks in the island of Paros with the use of photo-interpretation techniques and GIS, MSc Thesis, Faculty of Geology and Geoenvironment, Athens.

GOURNELOS, T., EVELPIDOU, N., VASSILOPOULOS, A. 2004: "Developing an Erosion risk map using soft computing methods (case study at Sifnos island)", Natural Hazards, Kluwer Academic Publishers, 31: 39–61

MATLAB 2002: The Language of Technical Computing. 2002, Version 6p5. The Mathworks Inc., Natick MA USA.

PAPANIKOLAOU, D. 1978: Contribution to the geology of Aegean Sea. The Island of Andros, Ann. Geol. Pays Hellen., 29: 477–553.

PARASKEUOPOULOS, G. 1960: Deposits of Manganites ores in the area of Thapsanaon in Paros Island, AGPH, 11: 83–124.

SCHUMM, S. A. 1977: The fluvial system, A Wiley-Interscience publication, p. 338

SPARKS, B. W. 1965: Geomorphology, Longmans ed., p. 371.

THEOCHARATOS, G. 1978: The climate of Cyclades, Athens.

TRIKKALINOS, J. 1950: Tektonischen Untersuchungen in der osthellenischen Zone, Gebiet Lokris-Euboea, Ann.Geol.Pays hellen., 6: 142–144.

VAN-CAMP, L., BUJARRABAL, B., GENTILE, A-R., JONES, R. J. A., MONTANARELLA, L., OLAZABAL, C., SELVARADJOU, S-K. 2004: Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. EUR 21319 EN/2, 872 Office for Official Publications of the European Communities, Luxembourg.

WRIGHT T. R. 2005: Environmental Science: toward a sustainable future. Pearson Education Inc.

FUZZY MÓDSZER HASZNÁLATA A TALAJERÓZIÓ-TÉRKÉPEZÉSBEN – PÁROSZ-SZIGETI ESETTANULMÁNY

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Kulcsszavak: talajerózió, erózióveszély, modellezés, GIS, Fuzzy módszer, Párosz

Összefoglalás: A cikk a talajerózió és az azt befolyásoló környezeti és emberi tényezők bemutatásával foglalkozik a Párosz-sziget kapcsán. A kutatás során elsősorban az erózióveszély térinformatikai módszerekkel történő modellezése volt a cél. A bemeneti adatok között szerepelt a kőzetek érzékenysége, lejtőérték, lefolyássűrűség és a talajok kiterjedése. Mindegyik bemeneti tényezőre vonatkozóan készültek származtatott térképek, és megtörtént a vizsgált tényezők osztályozása is. Az osztályozás során logikai törvényszerűségek alapján készültek el a kiementi adatok. A mintaterület erózió veszélyeztetettségi térképe az így készült tematikus térképek alapján készült el. A módszert Párosz-szigeten alkalmaztuk, Görögországban.