Modelling Erosion in the Analyses of Degradation of Mediterranean Landscape

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Modelarea eroziunii în analizele degradării peisajului mediteranean. Principalul obiectiv al acestei lucrări este demonstrarea cum eroziunea poate fi modelată folosind Sistemul de Informaţii Geografice (GIS). Datele de pe Insula Brač în Dalmatia Centrală, Croatia, au fost utilizate în acest studiu de caz. Modelul eroziunii în Insula Brač s-a obţinut şi a fost evoluat pe baza varietăţii datelor mediului natural incluzând: modelul digital topografic şi pantele, precipitaţiile, geologia, pedologia şi utilizarea terenurilor, derivate din imaginile de teledetecţie.

1. Erosion in the monuments degradation context

The international multidisciplinary project called the Adriatic Island Project has been active in the research of central Dalmatian islands in Croatia for more than a decade (fig. 1). The main objective of the project is to understand contacts, colonisation and commerce in this region from earliest prehistory onwards, with special emphasis on analysing archaeological and historical sources. However, it soon became evident that extensive information on the natural environment and diverse processes in the environment are essential for understanding past human activity. The incorporation of natural environmental variables into monuments degradation research and advances in methods and theory may be demonstrated by several applications of geographical information systems. One important research topic within this broader concepts of landscape archaeology (which became feasible with GIS technology) is the analyses and modelling of the erosion processes.

Erosion is important in archaeological research from several different aspects. Erosion and deposition are two crucial elements in archaeological site formation (Harris, 1979). Erosion also has direct impact on the environmental resources providing basic circumstances for agriculture or other economies (Shiel and Chapman, 1988). Last, but not least, many sites and monuments in the region are continually being destroyed by it (Gaffney et al., 1997). The objective of this paper is to demonstrate how an erosion model can be made using GIS technology. In the case study we focused our research on the island of Brač in Central Dalmatia, Croatia. We hope that the results of the erosion model could, despite limitations, be used in monitoring the impact of erosion on sites, leading to a better understanding of the processes of site formation.

In the paper we first briefly summarise the general characteristics of the island of Brač, with some information on geology and geomorphology. Then, after the general description of erosion models, the results of the study are presented. Finally, the model is evaluated with special emphasis on its future and possible improvements.

2. The island of Brač

The island of Brač is the third largest island in the Adriatic Sea. It has an elliptical shape with a maximum east-west length of 36km, a maximum north-south width of 12km, and a total surface of 395 sq. km. The orientation of the island is E-W and is different from the general orientation of the Adriatic coast, which is NW-SE. The reasons for this difference in orientation are still not known.

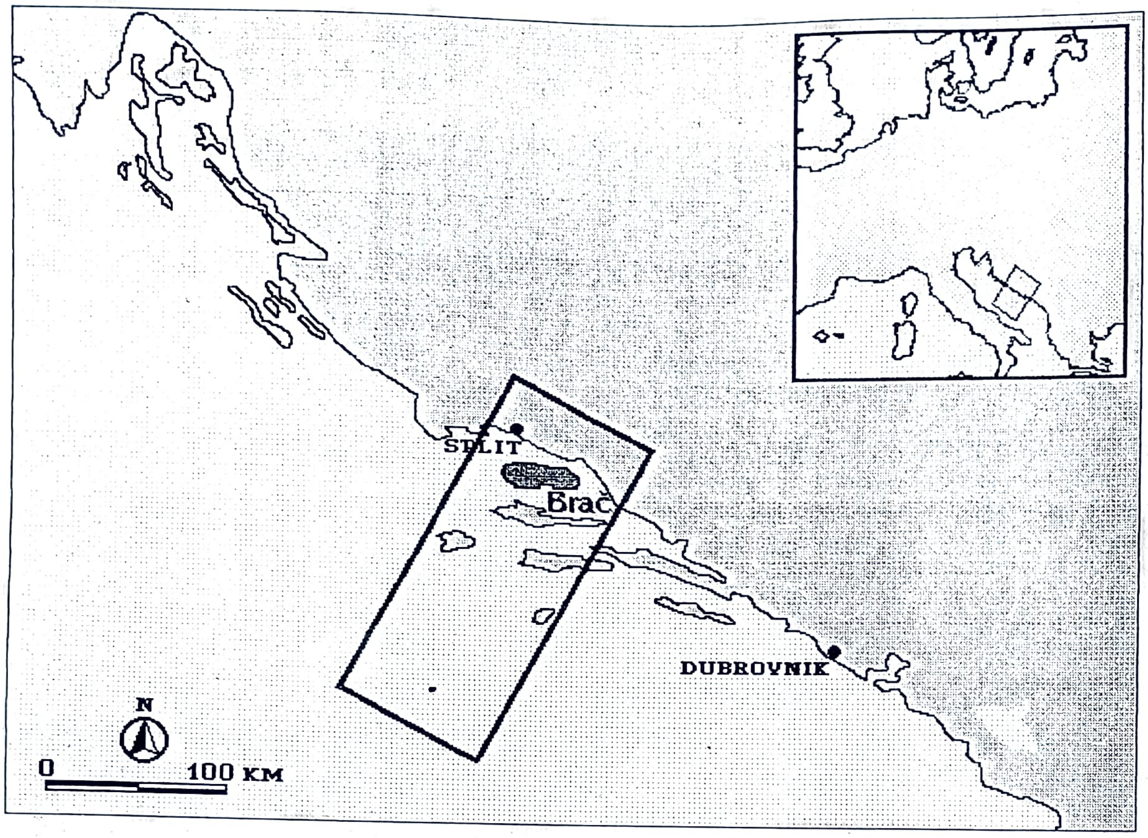

Figure 1. The Adriatic Island Project study area.

From a geological perspective Brač is an anticline with an east-west strike surrounded by synclines; the Brač Channel is on the north and the Hvar Channel is on the south. Brač is also characterised by especially dramatic relief. The highest peak on the island, Vidova gora, rises 778m above sea level and is the highest peak on all the Adriatic islands (fig. 2). The depth of the channels is over 80m in some places. The core of the anticline which forms the mountainous spine of the island is composed of dolomites and limestones of the Lower and Upper Cretaceous.

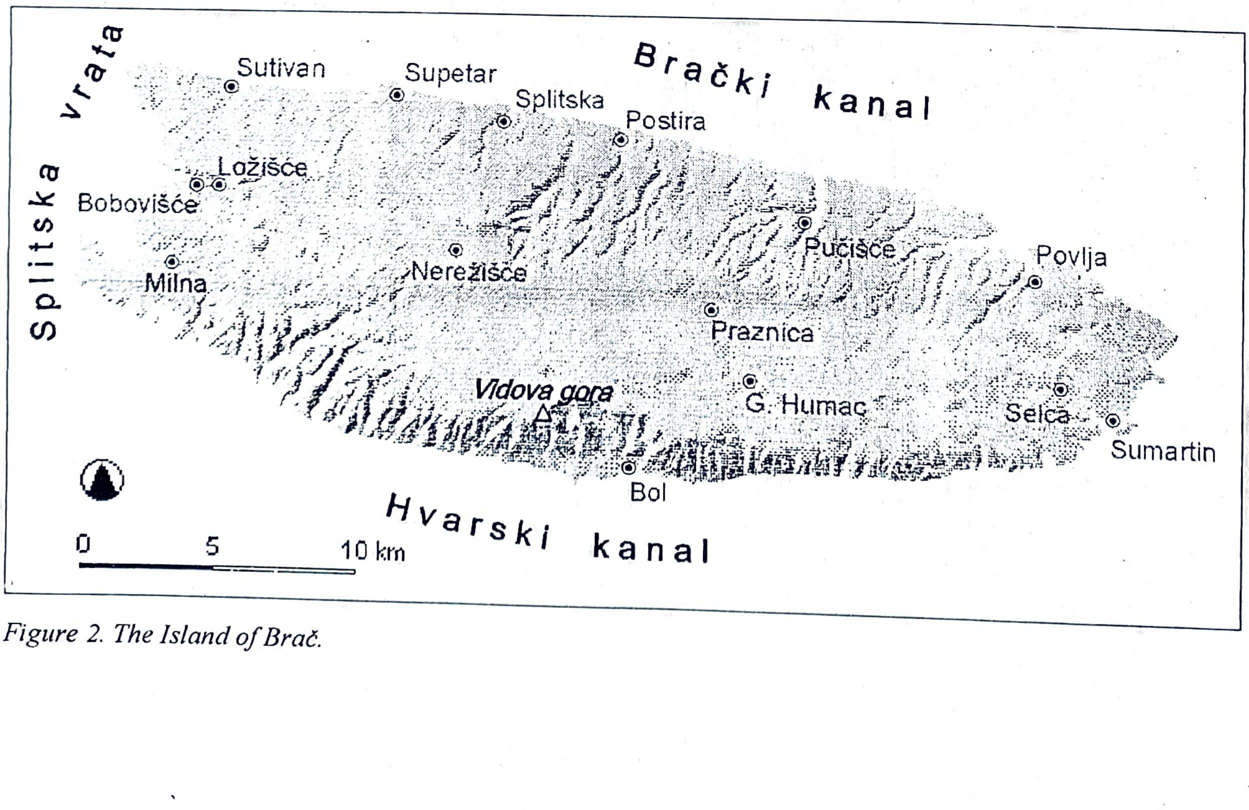

Figure 2. The Island of Brač.

The anticline is asymmetrical and is much closer to the southern coast of the island. The relief is therefore asymmetrical - from the anticline the terrain drops dramatically to the southern coast.

The coast is within 1km, measured in a straight line, of the highest peak. To the north, three plateaux can be distinguished. The highest plateau extends from the peak to an elevation of 700m; the second plateau is lower, with a minimum elevation of 400m. Finally, the lowland extends from sea level at the coast to an elevation of c.170m (Derado 1984). Due to the asymmetrical shape of the island most of the slopes are north facing.

The island is also characterised by numerous dry valleys, especially in its lower parts. Most of these valleys are tectonic in origin, although some are of fluvial origin. The valleys are often very deep and with very steep slopes. Valleys on the southern coast are the most impressive, especially in the proximity of Bol: Dubov dolac, Vodica and Nova staza. Some valleys are canyon-like: Juras-potok near Ložišće, Babin laz near Supetar and the Radovnja valley south of Sumartin. Most of the valleys on the northern coast have thick Pleistocene deposits and are very suitable for agriculture. Some typical examples are the Povaljski dolac, Pučiški dolac, dolac Lovrečine, dolac Trestena and Postirski dolac. The majority of these valleys were closely related to one of the major settlements on the island.

Due to its limestone geology some typical karst structures are present. The karst polja at Nerežišće and Dračevica are two examples of large fertile karst valleys filled with terra rossa. Some smaller karst fields are Veštačko polje, Gračiško polje and Vejak. Another example of karst landscape are ponikve, which are smaller than polja and usually more closed. The most dominant examples are Duboki dolac, Vica and Praznički dolac.

The dynamic relief of the island can be seen in the numerous coastal bays. The total length of the Brač coast is circa 175km (Derado, 1984). The southern coast is very steep but the northern is less dramatic and more accessible.

3. Physical background of erosion modelling

Erosion is the process by which the surface of the earth is worn away by the action of water, glaciers, winds, waves, etc. These processes of surface drifting might be mechanical, chemical or biological and depends on natural and anthropogenic factors. A model of the action of water erosion has been evolved for the island of Brač. Areas of different degrees of erosion and accumulation on the island were determined in order to perceive changes in the natural environment and to investigate examples due to current environmental conditions.

Erosion has particularly interesting effects in karst areas, which cover most of the surface of the island of Brač. In karst landscape typical phenomena that are formed mostly by chemical activity of water are: sinkholes, karst fields, estavelles, chasms, caves, etc. (Gams, 1982). The level of the erosion may be defined as a function of natural and anthropogenic parameters:

$$E = f(EP, R, L, P, V, W, H),$$

Where are:

EP – erosion potential,

R – relief,

L – lithology,

P – pedology,

V – vegetation and animals,

W – weather (climate),

H – human activities.

Among these parameters the biggest influences on erosion are: relief, lithology, weather, climate and human activity.

The mechanical activity of water is more noticeable after heavy rains when small stone fragments are washed down hill and the water erodes by the action of material carried by it. However, erosion potential depends more on the chemical action of the water. For limestone ($CaCO_3$) the process can be written with the following equation (Gams, 1974): $CO_2 + H_20 \cdot H_2CO_3$, $H_2CO_3 + CaCO_3 \cdot Ca^+ + 2HCO_3^-$. A similar erosion process can be observed in dolomite ($CaCO_3 \cdot MgCO_3$). The products of chemical erosion by water are carbonates. The residual 3% of these carbonates are impurities represented as earth minerals (Miloš, 1984). It is known that chemical erosion has lowered the surface by approximately 30cm since the Holocene in some karst areas (Gams, 1982). Nowadays carbonate surfaces are being lowered more than approximately from Holocene, by 0.02 to 0.14mm per year. For Brač it has been estimated that due to chemical erosion the mean ground level is 0.07mm lower each year. Thus, on average, $70m^3$ of rock is lost per year per square kilometre!

Relief is the most important erosion parameter. It is generally known that for surfaces whose inclination is below 5% erosion is not present and in some advantageous cases eroded material is accumulated (Lazarević, 1982). However, because of the specifically karst base of the island of Brač, accumulation is usually not present.

Lithology is a very important erosion parameter. If the rock is impervious then surface streams could be present and mechanical erosion could be present. In the case of the island of Brač, surface streams are not permanent. Chemical erosion dissolves the rocks and water carries the material under the ground or to the valleys. Besides lithology, tectonics and orientation of geological strata are also important. The power of erosion is usually greater along the strata than across them.

Pedology is a secondary parameter in the erosion model because it depends on the others parameters, mostly on lithology and relief. However, pedological data were used for the Brač erosion model. For the regions where soil is present, accumulation is anticipated, instead of erosion. Accumulation can be considered as "negative" erosion. Nevertheless we have to take in account the vulnerability of the Brač karst surface and for that reason the possibility of very rapid changes in soil cover.

Vegetation is very ill-defined in the Brač erosion model because of uncertain knowledge of vegetation distribution in the past. It is not known when fires have occurred. It is impossible to know on which areas and when the vegetation was present. Vegetation generally prevents soil erosion. Improper exploitation of forests (e.g. clear cuts) can cause extreme erosion and formation of the final stage of karst. However, in some cases vegetation may hasten erosion by mechanical activity causing rock decay. Human activities, such as causing fires and cutting bushes and trees, also have have a big effect on vegetation.

The weather has a very unpredictable influence on erosion. The most impressive paradox is that in areas with the highest precipitation erosion is not as strong as expected (Lazarević, 1982). At the same time rapid erosion is expected in arid areas when rain falls. The intensity of precipitation is thus more important than its quantity. Temperature oscillation also affects erosion. Most importantly, freezing decays rocks and enables mechanical and chemical erosion by water.

The last erosion parameter is the effect of human activities. These activities influence all the previously mentioned parameters. Unthinking human interventions in the environment have recently greatly increased erosion. In vulnerable karst areas we should be aware of the need to preserve the soil and be particularly careful with structural interventions.

4. Erosion modelling for the island of Brač

Until ten years ago, erosion models were mostly produced by taking erosion parameters in certain known areas and using them intuitively in areas imperilled by erosion. Modern approaches to erosion modelling are different. Most of the approaches use GIS as the principal tool, but the ways of deriving the erosion parameters are different. Erosion models may be represented by simple empirical equations or by complex mathematical models. The quality of some erosion factors in advanced models may be enhanced by experiments with rain simulators.

Some newer GIS approaches to erosion problems can be briefly summarised. In the Ukraine, a GIS approach concerns water erosion and soil renewal in an agricultural area. The result is a map that shows areas of soil deposition and erosion (Shvebs et al., 1995). A very complex erosion model has been developed for one of the most eroded areas in the world in Ethiopia (Eweg, 1995). Other good examples are a map of environmental sensitivity for the Central French Alps region (Bessenay and Etlicher, 1993) and a map of soil resistance to erosion in agricultural areas in the Rhain part of Switzerland (Dräyer and Fröhlich, 1994). All these erosion models use a digital elevation model (DEM) as the principal data layer, but other erosion parameters vary from example to example.

The erosion model of the island of Brač has been designed in a relatively modest way. Incidence of erosion E is defined as a function of individual erosion parameters:

$$E = f(R, D, L, P, V).$$

The symbols represent:

R – influence of terrain slopes,

D – influence of annual precipitation,

L – influence of the geological structure,

P – influence of the pedology,

V – influence of the vegetation.

The incidence of erosion is a function of corresponding cell values in input raster data layers with cell size of 30 by 30m. Each cell in the input layers is assigned a weight corresponding to the strength of the particular erosion parameter. All the layers cover the entire island of Brač.

We consider that the most important and influential parameter in the Brač erosion model is held in the DEM layer. This was produced very carefully from 1: 25,000 maps. From these data, a layer of terrain *slope* inclination was generated. Seven classes were derived, corresponding to erosion influence. It was assumed that erosion could be present only on slopes of 5% and higher.

Precipitation data are less important than slope in the erosion model. Precipitation data for Brač exist only for 10 localities where meteorological stations have been present for a long period (Juras, 1984). From these available data and with the support of the DEM it was calculated that the amount of precipitation changes almost linearly from the coasts to the highest peak on the island, Vidova gora (778m). It was noted that precipitation on Vidova gora is double that in coastal areas. Based on these observations, the precipitation data layer, with an appropriate reclassification, was derived from the DEM.

From *lithological* data it has been determined that almost all the surface of Brač is covered with limestone or dolomite except a small area around the village of Bol. There is some Quaternary alluvium composed of flysch and breccia. These sediments are eroded more mechanically but less chemically than limestone. Using collected data and geological maps, weights were assigned for 13 groups of rocks (Derado, 1984).

For *pedological* data it was considered that good quality and thickness of the soil both have an influence which potentially reduces erosion. On good soils more vegetation is normally present and it is mostly level, so that water cannot run off quickly (Stritar, 1990). Weights for erosion model were assigned in the same range as for the precipitation layer.

There are no data for the past *vegetation* of Brač, but the present day vegetation cover is well known. Used with pedological data they could give us insight into vegetation in the past. The impact of vegetation has to be seriously taken into account and special care has to be used when selecting weighting values for different classes.

For the island of Brač it was not possible to obtain a vegetation map of suitable quality. The maps were mostly out of date or with very low spatial resolution and poor differentiation of vegetation types. Satellite image classification seemed to be an inexpensive and appropriate alternative. A Landsat Thematic Mapper (TM) quarter-scene (90 by 90km), acquired on July 31, 1993, was used to produce a land cover map. The image was georeferenced to the co-ordinate system of the GIS and pre-processed to improve the classification (Mather, 1989; Lillesand and Kiefer, 1987). After the initial unsupervised classification and field inspection four main classes were selected and identified on the image. These classes were:

- *open areas* (coastline, urban areas, quarries etc.) – spatially well defined, but spectrally mixed,
- *agricultural areas* (arable land and pastures) – spectrally mixed due to extreme polyculture of Mediterranean fields,
- *maquis* (with abandoned pastures and grasslands) – probably the most problematic class, since most of the maquis has developed on abandoned pastures, and
- *woods* (mostly red and white pine) – spatially well defined and clearly seen as darker areas in the infrared bands of the TM scanner.

The classification has been repeated several times with different learning samples to obtain satisfactory results. The vegetation map has been verified both by visual interpretation and field observation.

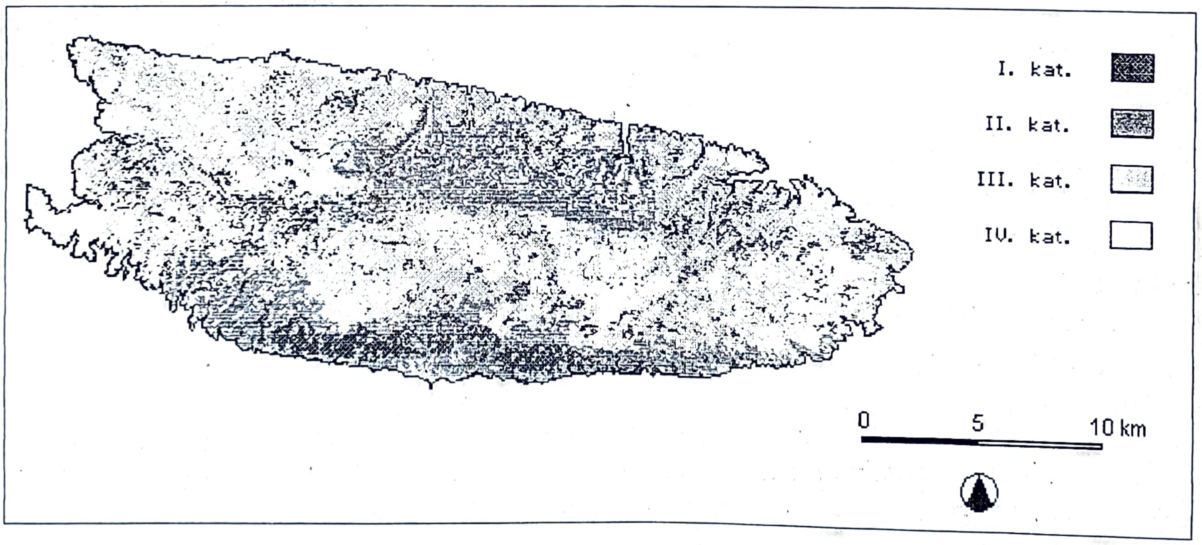

Figure 3: Four categories of erosion intensity for the island of Brač.

When all five thematic grid data layers had been created, with an appropriate weight for each 30 per 30 m cell in each layer, the final erosion layer was modelled. Values between 0 and 1 indicate possibilities of "negative" erosion, that is accumulation. The erosion layer was then reclassified into four categories (Figure 3). To category IV were classified areas with a little erosion or higher accumulation than erosion. The other areas, those vulnerable to erosion, were divided into categories III to I. Such areas vulnerable to erosion cover most of Brač (Figure 4).

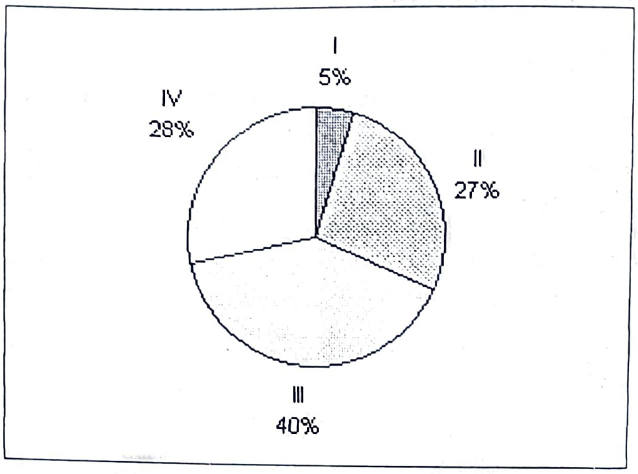

Figure 4. Island of Brač area divided into categories of vulnerability to erosion.

From the model is it could be determined that the areas most vulnerable to erosion are located on the southern side of the Brač anticline. Areas where we could expect low erosion or even accumulation are around Milna in the south-west, on the gentle slopes near Sutivan and Supetar in the north-west, in flat Nerežiško polje and the others between Povlja and Selca, and in some parts of the high plateau between Praznica and Gornji Humac.

5. Conclusions

This erosion model for the island of Brač gives only an approximate indication of the areas vulnerable to erosion during the last few millennia. Almost all of the surface is potentially vulnerable. The proportion of surfaces with very high erosion (categories: I, II, III) is more than three-quarters. Inspection of the data layers from which the erosion model was derived showed that almost all of the surface of Brač is vulnerable to erosion, according to the values of at least one of the five parameters.

The model could be improved by including more erosion parameters, better data, and a revised algorithm. The most significant improvements could be:

- Consideration of lengths of slopes, because the amount of water increases (on non-karst surfaces) with distance from the mountain peaks and ridges.
- A very different model in the case of strong cloudbursts when, even on the Brač's karst surface, superficial water streams are possible. In that case soil thickness could be an important factor in water retention.
- Much more complex data on chemical erosion.
- Incorporation of data on changes in vegetation over a longer period, covering several millennia.

We also need more data on the history of Brač's land surface. The strength of erosion in the past is unknown. Slow but continuous movements of the Earth's crust, landslides and faulting affect erosion. Intensity of erosion has also depended on the global weather pattern, which is well known only for the recent past.

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