ACTA Geographica Szegediensis Tomus XXXI. 1993. pp. 89-98.

Remote sensing methods in soil erosion assessment in the Mátra Mountains, Hungary

Dr. Gábor Mezősi - Dr. László Mucsi

Abstract

In the test site, which is situated in the northern part of Hungary in the Mátra Mountains there are various lithological and morphological conditions together with special land uses. In the test area, the importance of relief, plant cover characteristics and the physical properties of the soil types can be emphasized by examining the degree of soil erosion caused by water. Different field measurements based on soil mapping were performed to assess the erosion intensity of the area. Landsat digital data were used to calculate the C and K factors of the Wischmeier-Smith formula. These results were compared with field measurement data. The factors of USLE were stored and processed using a GIS. The field measurement results and the values of soil erosion estimated by the Wischmeier-Smith formula were compared. An estimate of the intensity of soil erosion by distinctive composition of Landsat TM images was calculated. This was also compared with the USLE values.

The results show that the punctiform measured data can be extracted regionally but that remote sensing methods are not enough for an estimation of soil erosion and must be used in conjunction with field measurements. Surface areas which have to be protected against soil erosion were identified together with potential sites which may be destroyed by this process in the future.

Introduction

About 30 % of the cultivated area of Hungary is affected by soil erosion. The soil erosion lessens soil capability and upsets the dynamic ecological equilibrium of the soil system. Because of the changes in land ownership as a result of privatization, there has been a significant transformation in land use, agricultural technology and the area of farms. The big cooperatives and governmental soil conservation services were defuncted and consequently, new owners are short of information concerning the soil erosion risk.

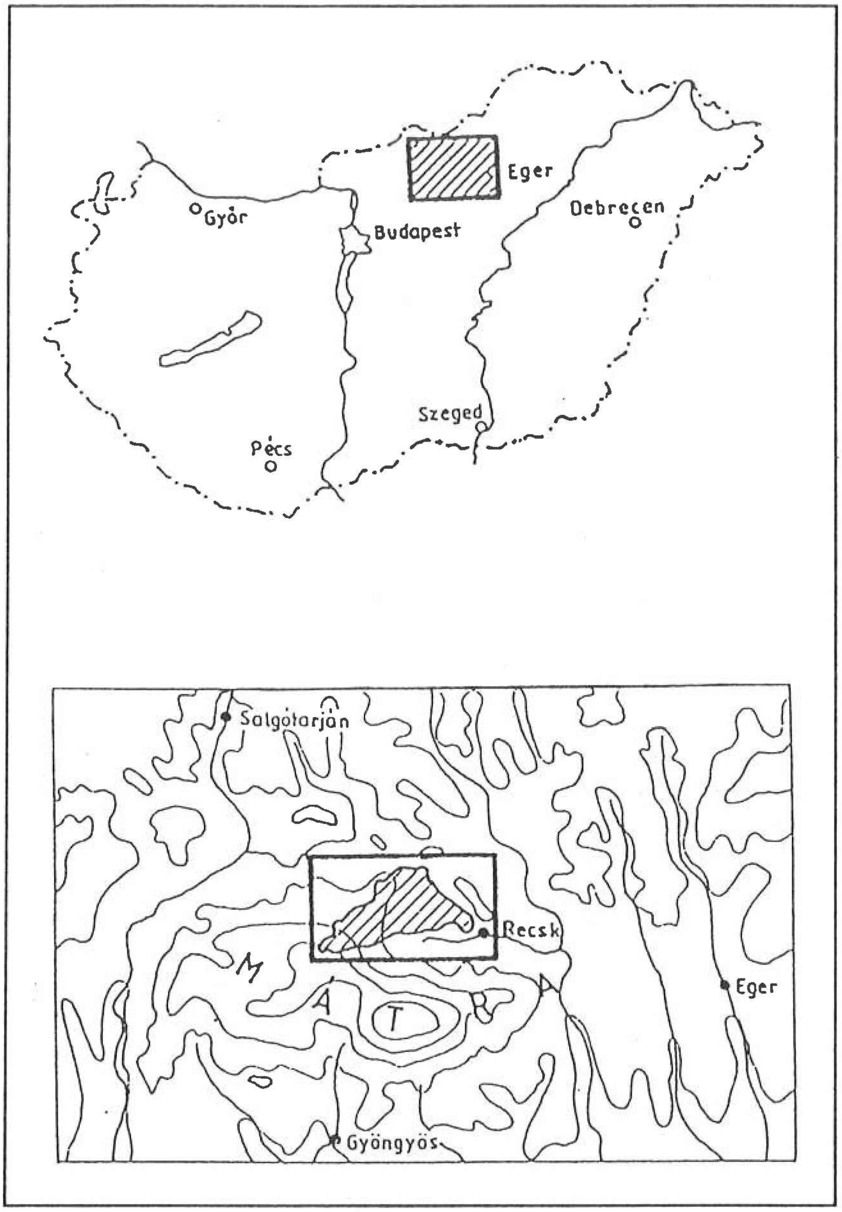

Figure 1 The situation of the catchment area in Hungary

The basic ecological conditions are not modified by the changes in ownership and th erefore a catchment area (Fig. 1) was chosen as the test site unit. Considering this fact, the USLE formula was applied to the catchment area. The main aim of the study was to locate those areas which are endangered by soil erosion independently of the borders of land parcels and to find areas in which the dynamic equilibrium is upset.

METHODS

In the investigation the unified soil loss equation (USLE -Wischmeier, W.H.-Smith, D.D. 1978) was used. The USLE is an erosion model, which assesses the soil loss for a given site as the product of six major factors, whose most likely values at a particular location can be expressed numerically. The soil loss per unit area is (A):

$$A=R*K*Ls*C*P$$

where R - the rainfall and runoff factor (most important part is the rainfall erosion index), K - the soil erodibility factor, Ls - slope length and steepness factor, C - surface covering and management factor, P - support practice factor. The two complicated factors K and C were controlled with the help of remote sensing methods. The K factor was simultaneously experimentally measured in the field using a field-plot rainfall simulator. The K factor depends mainly on soil type and texture, which allows the use of remote sensing methods. There are a lot of formulae to express the NDVI or the biomass value of a surface by measuring the vegetation cover characteristics and from these, the regional differences of the C factor can be assessed. The C value was also calculated from the suggested tables in Wischmeier and Smith (1978). All bands of the Landsat TM image recorded on 7 July, 1987 were used because the rainfall intensity (EI) and the predicted soil erosion give the highest rate in this early summer period. The LS values were measured using field methods. The maps were digitized in AutoCAD and the results were transferred to IDRISI v. 4.O (Eastman, J.R. 1992). In IDRISI the vector database was converted into a raster database, and stored in GIS. The rasterized database was then used to compare field measurement data with the remotely sensed data. The best composite of different TM bands which substitute the slow process of the experimental field measurement data can then be distinguished.

RESULTS

Some factors in the USLE formula can be easily calculated or, owing to the insignificant differences, the factor value can be constant. For example, the P factor is equal to 1 for the entire catchment area because there was no special soil conservation management.

Other factors, such as L and S, were measured at the test site: the value of steepness of land slope ranges from 10 to 12 %, while the length of land slope ranges from 300 to 500 m. The LS values therefore, are more than 3 and less than 5. It may also be deduced that the steepness of the land slope is greater in the western part of the catchment than on the cultivated eastern part.

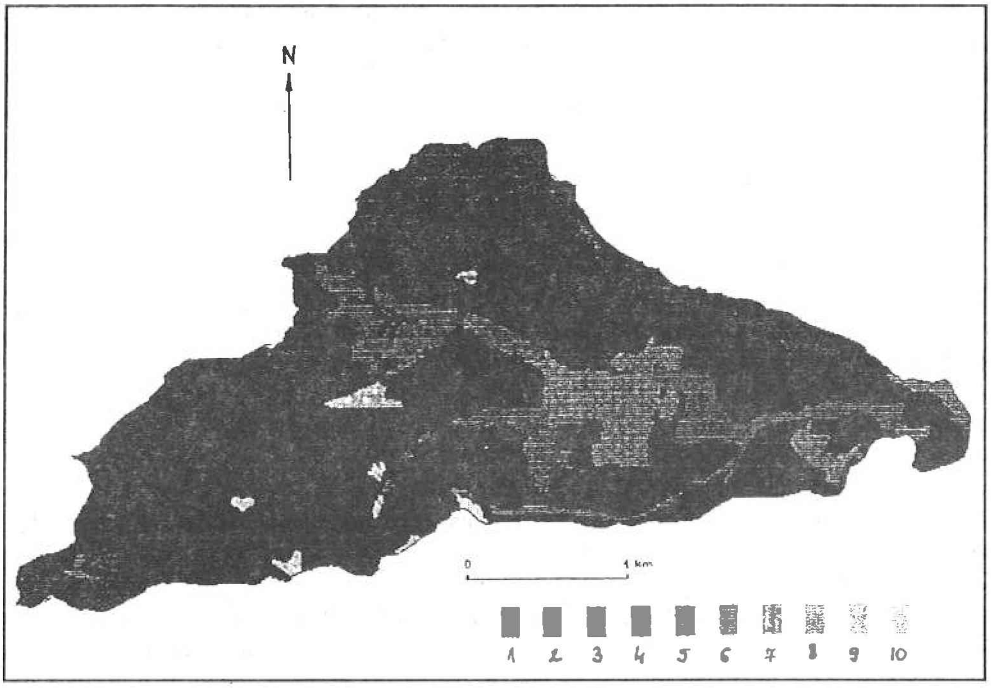

Figure 2 Map of soil erodibility factor (K) on the catchment
1 - 0.11; 2 - 0.18; 3 - 0.25; 4 - 0.26; 5 - 0.28;
6 - 0.29; 7 - 0.3; 8 - 0.32; 9 - 0.35

The soil erodibility factor (K) must be evaluated independently of the effects of the other factors. The K factor in the USLE is a quantitative value which is experimentally determined. The calculation of this factor is difficult and requires measurement, but with the help of the soil erodibility nomograph the approached value can be calculated if the soil's sand content, the amount of organic matter, the structure and permeability are known. A map of K factors for the entire catchment area was constructed. In spite of the fine resolution there are no significant differences between the K value of the patterns, and it ranges between 0.1 and 0.3 in 95 % of the area (Fig. 2). In the transitional zone between the cultivated area (meadow, grassland, pasture, orchard) and the uncultivated area (forest, deciduous forest, acacia grove, hydrophyte association), small patterns occur and it is here that greater differences between the K values are found.

A TM image or image composition, which can represent the same conditions as the map of the K factor, was determined. However, the calculation of the K factor is difficult and it is not the same as soil erosion, therefore there is not a single image which can take the place directly of the original method. On the 742 (RGB) TM composite the important

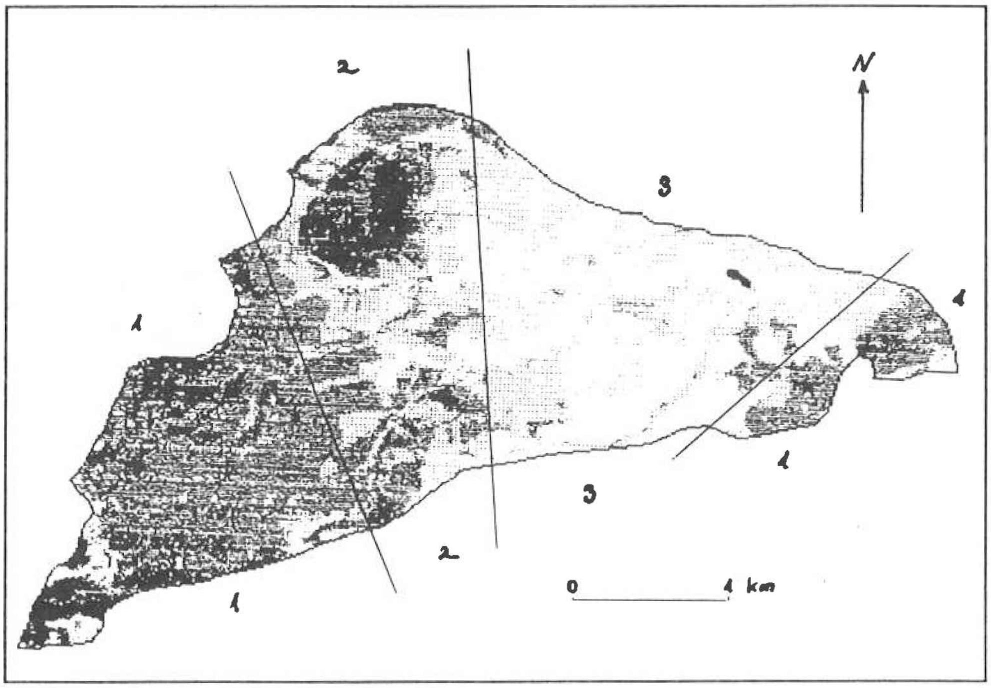

Figure 3 7,4,2 (RGB) Landsat TM color composite of the catchment
(Black & White representation)
1 - forested area
2 - transitional zone
3 - cultivated area

patterns which appear on the map of the K factor may be found. The transitional zone is apparent on the composite but there is a difference between the anticipated and the cultivated area, which is the result of the distinctive reflection of the plants (Fig. 3).

Before calculating the C factor value, the plant cover map of the area together with the map of series of succession of plant associations had to be constructed because the latter is very closely connected with land development and soil erosion. Environmental factors control the rate of development. The development of the succession can be divided into three phases: the initial phase (I), the optimal phase (II) and the degraded phase (III). The development is progressive from phase I to II and regressive from II to III. Since the bulk of the area is under cultivation, the majority of the patterns belong to the degraded phase (Fig.4).

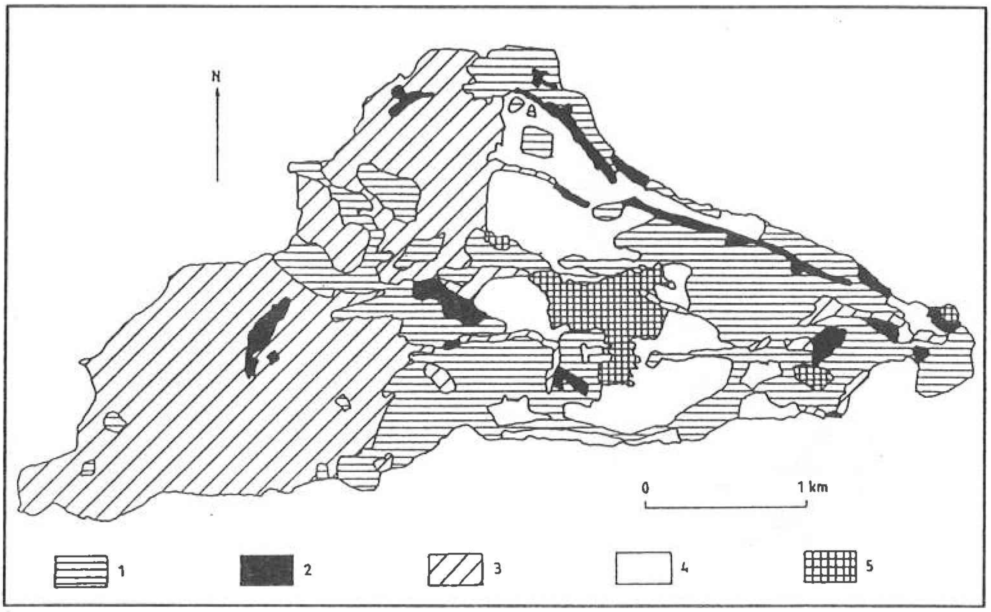

Figure 4 Series of succession of plant assotiations on catchment
1 - degraded; 2 - initial; 3 - optimal; 4 - cultivated area; 5 - settlement

The acacia groves and the mixed deciduous forest with pine are situated between the optimal and the degraded patterns and their development may be either progressive or regressive. The initial plant associations appear as narrow ecological corridors between degraded and optimal associations. At present these areas are in the regressive phase. If human activity decreases in these areas then progressive development will be possible. The optimal association is oak forest with hornbeam as well as submontane beeches situated on higher ground. Alder forest on wet surfaces and grassy associations on slopes as optimal associations were also considered. The pattern of the area shows that the former homogeneous biotopes of plant associations were divided into smaller spots isolated from each other. This process is called "fragmentation" in ecology. Usually, fragmentation is unfavourable for the development of living beings in a given area and the earlier series of succession have less stability than that of the climax phase. However, the stability may be high if successions promote a natural development. Instability is always a consequence of some kind of intervention of natural processes.

The value of the C factor is determined by many factors such as the ratio of plant cover as it changes as a result of plant growth and crop management. Major variables that can be influenced by management decisions include crop canopy, residue mulch, tillage, land use residual, etc. For an evaluation of the C factor six crop stages are distinguished from tillage to harvest. As C is a very complex factor, it was not expected to create a composite of TM bands which reflect the C value correctly. Instead, it was supposed that the most significant factor is the density of vegetation cover (the morphometrical characteristics of the catchment are similar). The NDVI is used for the assessment for crop production. This volume increases as vegetation gains chlorophyll and becomes greener. In this study the density of plant cover is more important and consequently the band4/band3 relationship was used (Fig. 5).

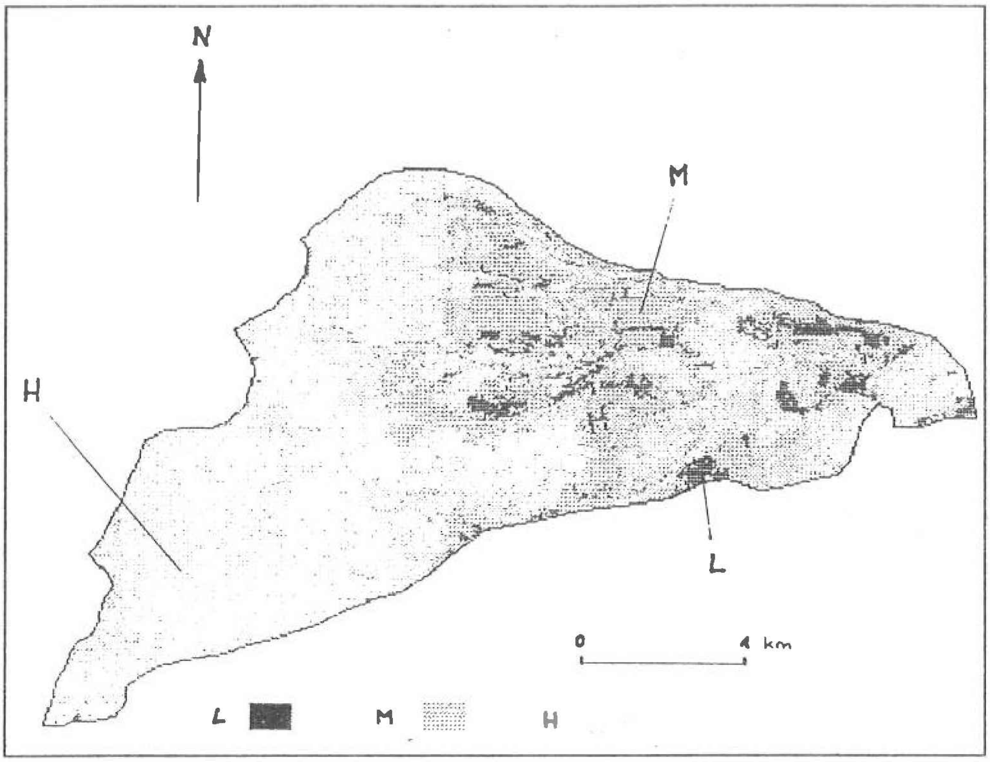

Figure 5 Biomass production on the catchment
(Landsat TM bands 4/3 ratio (B&W repr.)
L - low biomass production
M - medium biomass production
H - high biomass production

Comparing the composite with the map of potential vegetation, it can be deduced that the composite significantly reflects the differences of biomass distribution. In the western part of the catchment the dense homogenous forests are typical, while in the eastern part the different types of arable land show the condition of the surface in connection with the spatial differences in land use i.e. after harvest, in development, growing, the differences in residual mulch, etc. Large areas in which there is a distinctive plant cover may be delimited. For example, arable land, acacia grove - grassland and deciduous forest in the northern part of the test site.

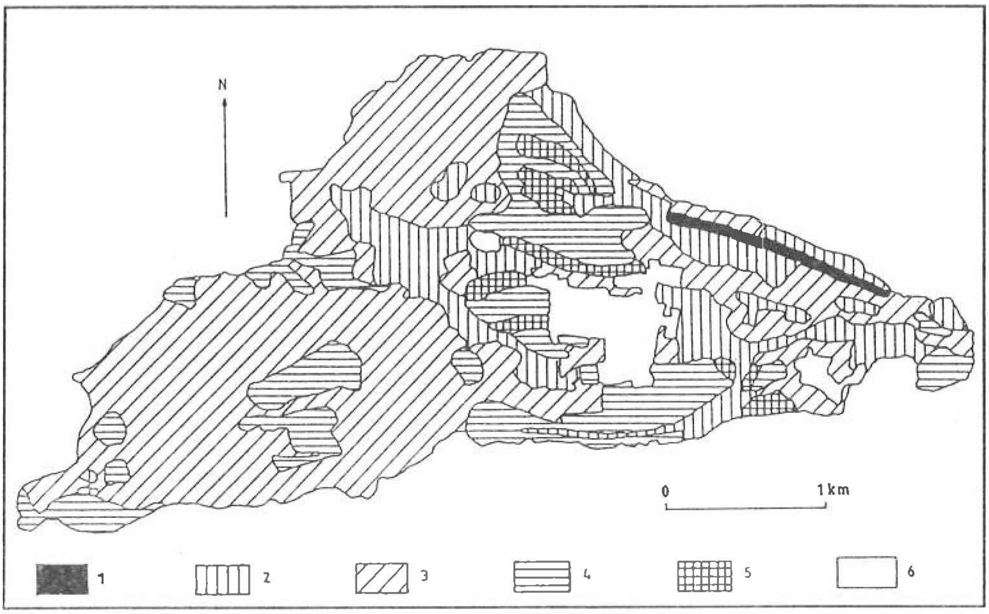

Figure 6 Map of soil erosion on the catchment area (t/ha/year)
1 - <1; 2 - 1-5; 3 - 5-10; 4 - 10-15;
5 - 15-30; 6 - settlement

By multiplying the above mentioned factors the soil loss value may be calculated (Fig. 6). Comparing these results with the plant cover conditions the following rules may be stated. If the plant cover is stable then soil erosion does not reach the value of 10-15 t/ha/y, while on the cultivated land soil erosion is always higher than the above mentioned value (25-30 t/ha/y). The reason for soil erosion on forested lands is the physical and genetic properties of the soils while on the cultivated test site it is the steepness of land slope and plant cover. Owing to the close connection between plant cover, soil and plant moisture and soil erosion, compositions in which these factors can appear have been chosen. It is known (Banninger, C. 1986; Crist, E.P. 1983) that wetness and plant cover densities can be expressed:

Greenness Index: 0.7243(TM4)+0.0840(TM5)-0.1800(TM7)
Soil Wetness Index: 0.3406(TM4)-0.7112(TM5)-0.4572(TM7)

According to the histogram of pixel values the area is divided into three categories: low (L), medium (M) and high (H) plant cover density and low (l), medium (m) and high (h) soil moisture. In considering soil erosion, the following combinations were selected:

low soil erosion : H,l + M,m + M,l
medium soil erosion: H,m + H,h + L,l
high soil erosion: L,m + L,h + M,h

This selection (Fig. 7) proved useful in assessing the degree of soil erosion and in locating those areas potentially affected by soil erosion.

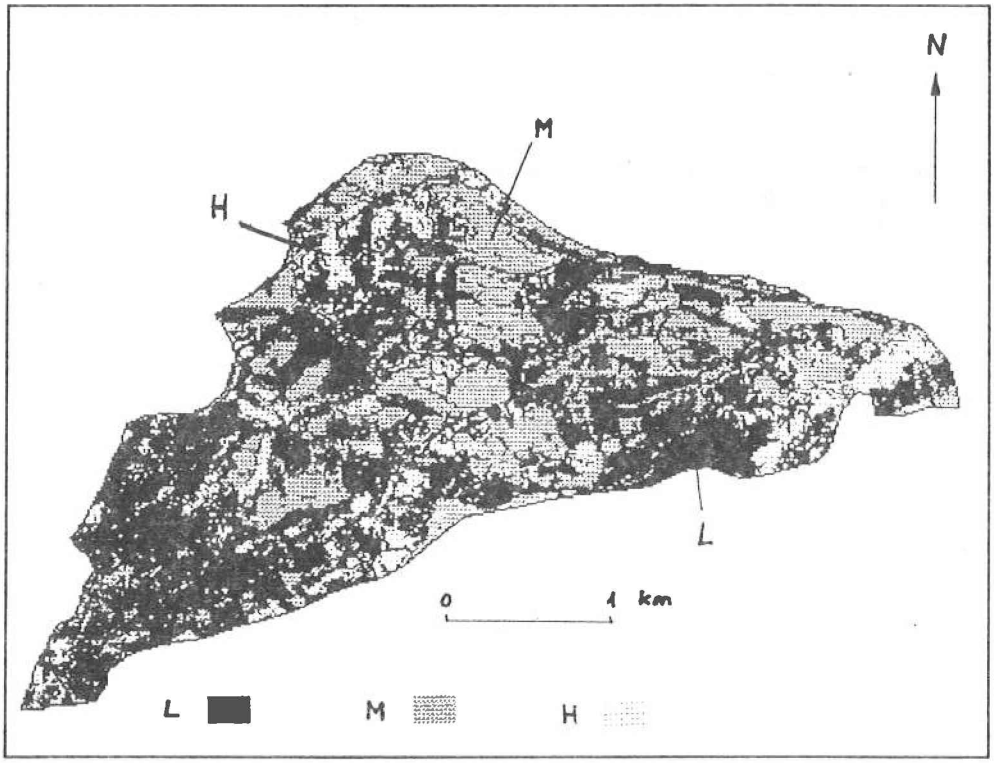

Figure 7 Soil erosion map of the catchment from the Greenness Index and Soil Wetness Index ratio (Black & White repr.)
L - low soil erosion
M - medium soil erosion
H - high soil erosion

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University of Szeged, Department of Physical Geography
Egyetem str. 2-6. PB. 653
H-6722 SZEGED
HUNGARY