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# SLOPE STABILITY STUDY BASED ON GIS ALGORITHM

BY

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**Abstract.** Based on the SINMAP model our study presents the implementation and development of an ArcGIS macro for determining the most probable trigger points of landslides.

**Key words**: GIS, slope, landslides. algorithm.

## 1. Introduction – the SINMAP Model

The study of a phenomenon can be made on quantitative or qualitative manner, using direct or indirect methods. The indirect methods based on GIS are used especially for larger areas [1]. For studying slope stability the data driven or process driven methods are both convenient, but in case of historical data lack the last methodology is suitable. The infinite slope model is used on SHALSTAB [2] and SINMAP submodels. While SHALSTAB neglects the root cohesion [3] SINMAP takes account also this aspect. The SINMAP stability index used to study the phenomenon is determined on the basis of the following formula

$$\mathrm{SI} = \frac{C + \cos\theta\left(1 - wr\right)\tan\phi}{\sin\theta}, \tag{1}$$

where:

$$C = \frac{C_s + C_r}{h\rho_s g}; \qquad w = \frac{h_w}{h}; \qquad r = \frac{\rho_w}{\rho_s};$$

$C_s$ – force of soil cohesion
$C_r$ – roots cohesive force
$h$ – coating soil thick
$h_w$ – water layer thick of the soil
$\rho_w$ – density of water
$\rho_s$ – density of soil
$\theta$ – region slope
$\varphi$ – friction angle

One of the advantages of the method is that the value of index is categorized into the meanings what it defines. Another advantage is that for some parameters is possible to define a value frame, through removing the necessity of time costing exact measurements. Another advantage is that for the analysis is not necessarily to have a historical database of landslides.

**Table 1**
*The Appreciation of the Value Index of Stability*

| SI value | Stability | Influences |
|---|---|---|
| > 1.50 | Stable | Instability may occur due to major factors of destabilization |
| 1.50…1.25 | Moderately stable | Instability may occur due to medium factors of destabilization |
| 1.25…1.00 | Slightly stable | Instability may occur due to minor factors of destabilization |
| 1.00…0.50 | Lower threshold of instability | Instability without external factors |
| 0.50…0.00 | Higher threshold of instability | The stability is due to the presence of stabilization factors |
| < 0.00 | Instable | Stabilization factors are required |

Interpreting the sense of stability factor (Table 1) as the ratio between the forces who oppose to landslide and those favoring sliding, when the value factor is above 1, the area can be considered stable.

## 2. Case Study – the SINMAP Extension and the Necessary Data

Although there are several possibilities for the study the chosen method was SINMAP for several reasons. Firstly the results provided by this methodology are directly interpretable, and may constitute inputs for a possible further analysis, and secondly the existence of a program (ArcView/ArcGIS extension) allows an easy approach to the analysis.

SINMAP extension is freely available in two variants for ArcGIS and ArcView respectively (Fig. 1). The possibilities offered not differ significantly, and neither the way of calculation.

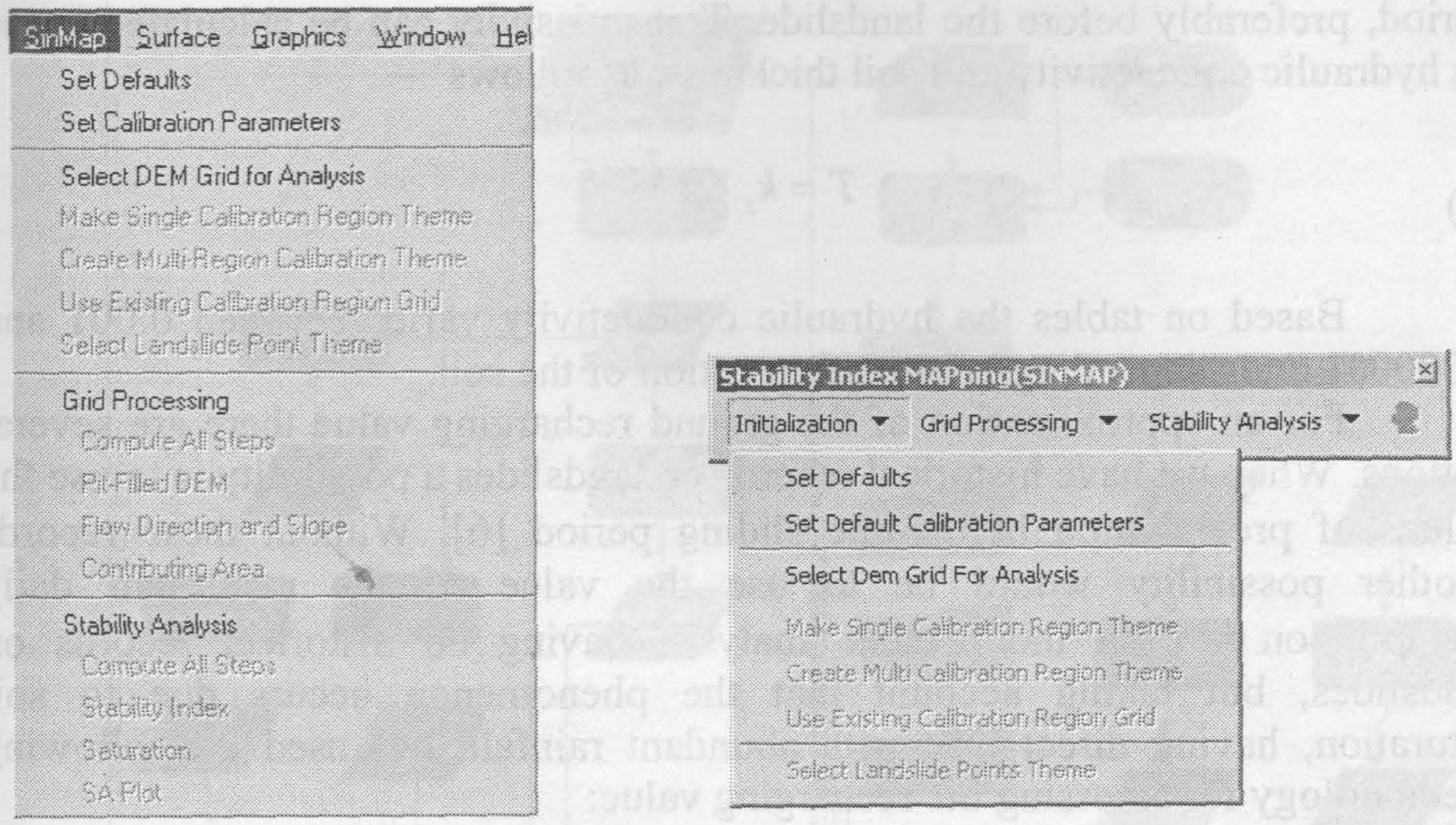


Fig. 1 – Interface of SINMAP extension in ArcView3.2 and ArcGIS9.2.

The performed steps of the analysis using these extensions are:

a) the selection of digital elevation model;
b) the decision on the type of study areas (zone unit or multi-zone);
c) defining the parameters for each area of analysis;
d) the removal of imperfections of elevation model;
e) calculating the slope and drainage maps;
f) determining the drainage areas;
g) calculating the stability map.

It's not necessary to include the rock type in the study as the SINAMP model doesn't models rock falls, just landslide [4].

Steps remembered are absolutely necessary to carry out the study regarding the slope stability. However the system offers other possibilities, such as specifying the location recorded landslides.

The SINAMP extension comply with the idea of automatic spatial analysis, since-as after defining the entry parameters with two mouse clicks the whole analysis is carried out automatically, thus allowing the rerun of the full analysis (and possibly reuse partial results which are not amended – ex. slopes map) with different parameters.

Parameters relating to the properties of the soil in the area were approximate with values of similar studies and soil tables [5].

Based on the calculation formula of stability index the cohesion is without measure, since-as they relate to the product of density, gravity acceleration and soil depth. Also the cohesion should contain the root cohesion. For this latter amount initially a range between 0…5 kPa was considered.

Another requested parameter of the SINMAP model is the *T/R* report, where *T* is soil transmissivity and *R* is the rate of ground recharging for a short period, preferably before the landslide. Transmissivity can be calculated based on hydraulic conductivity and soil thickness, as follows

$$T = k_s \cdot H \tag{2}$$

Based on tables the hydraulic conductivity varies between 0.001 and 0.000001 cm/s depending on the composition of the soil.

For an approximation of the ground recharging value there are several options. When we have historical records on landslides a possibility is to use the values of precipitation before the sliding period [6]. Without these records another possibility would be to use the value of the maximum daily precipitation [7]. In the present analysis, having no historical records on landslides, but taking account that the phenomenon occurs due to soil saturation, having direct link with abundant rainfall, has used the following methodology for assessing the recharging value:

a) interpolating the precipitation recorded at meteorological stations in the area based on the study of multiple regression;

b) determining the percent of minimum and maximum daily precipitation over annual rainfall taking account all meteorological stations;

c) for each study zone (determined based on the soil type) the average interpolated precipitation is calculated;

d) based on the percents determined in the previous step to determine the two limits (minimum and maximum) of recharge value ($R$) is calculated .

A relatively recent [8] research makes further analysis seeking those points at which is most likely the launch of landslide can appear. The trigger besides that must have a classification of instability based on SINMAP analysis must be along the drain canal.

To determine these points in a GIS system, Tarolli proposes the following principle:

a) determining the minimum values of stability index along the drainage channels with downstream spreading;

b) determining the minimum values of stability index along the drainage channels with upstream spreading;

c) those cells that have equal stability index under a certain fixed threshold, are the most vulnerable points where they can trigger the landslides.

Tarolli noted that the algorithm was implemented in C programming language, in a recurring way. Given that, recursivity is a programming method that require significant resources of calculation (memory capacity and calculation power) and that any approach to a recursive problem has an iterative solution, the study proposes to develop a not recursive implementation of the basic algorithm, using the statistical system in R and Borland Delphi [9].

The two raster layers containing the propagated stability index in both directions (downstream and upstream) boots with the original stability index.

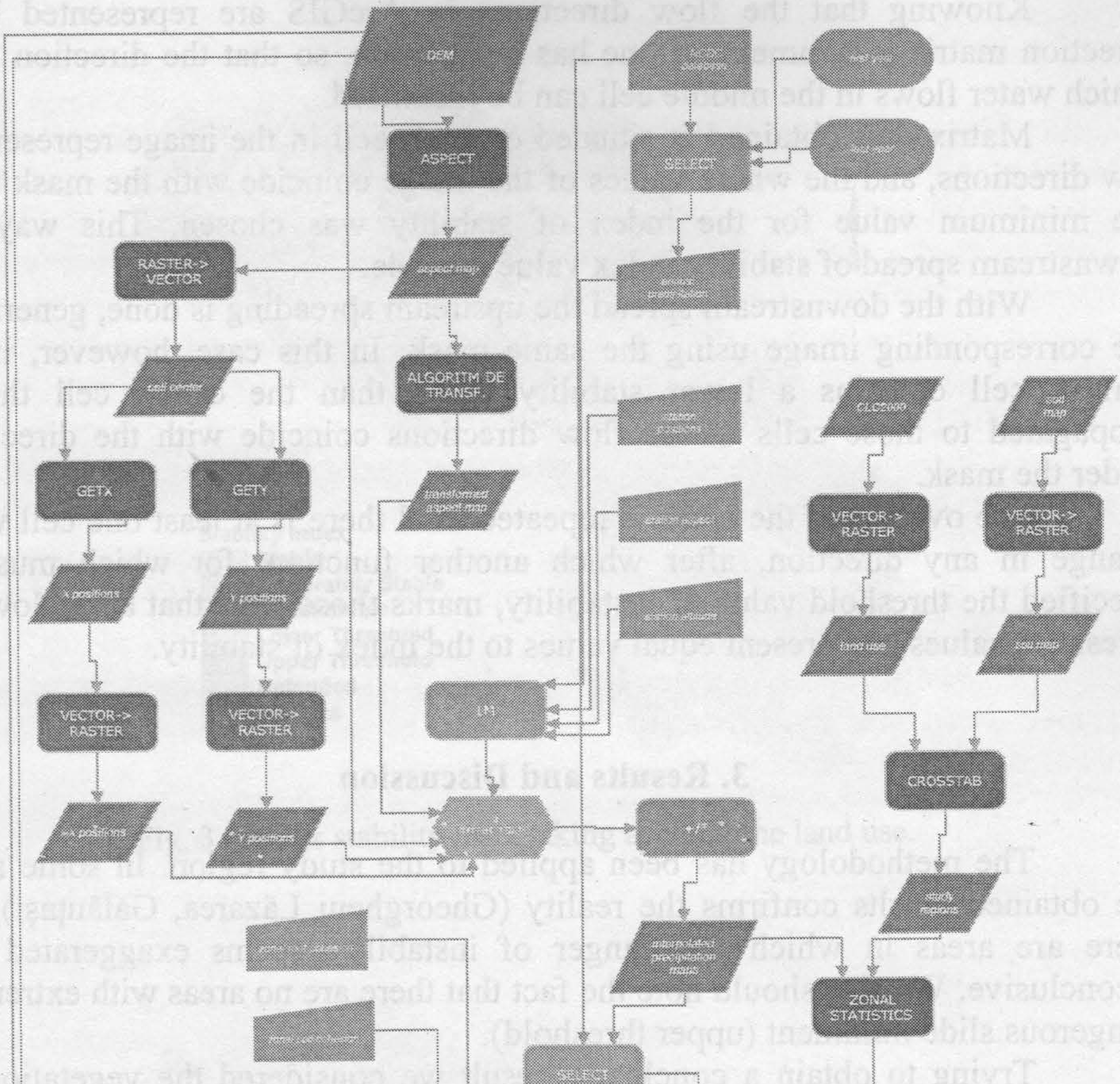


Fig. 2. – The algorithm used in the study of slope stability.

Knowing that the flow directions in ArcGIS are represented by a direction matrix a symmetrical one has been made, so that the direction from which water flows in the middle cell can be identified.

Matrix thus obtained is situated on each cell in the image representing low directions, and the where values of the image coincide with the mask there the minimum value for the index of stability was chosen. This way the downstream spread of stability index value is made.

With the downstream spread the upstream spreading is done, generating the corresponding image using the same mask. In this case, however, if the current cell contains a lower stability index than the center cell this is propagated to those cells whose flow directions coincide with the directions under the mask.

The overlap of the mask is repeated until there is at least one cell value change in any direction, after which another function, for which must be specified the threshold value of instability, marks those cells that are below the threshold values and present equal values to the index of stability.

## 3. Results and Discussion

The methodology has been applied to the study region. In some areas the obtained results confirms the reality (Gheorgheni Lăzarea, Gălăuțași), but there are areas in which the danger of instability seems exaggerated and inconclusive. We also should note the fact that there are no areas with extremely dangerous slide imminent (upper threshold).

Trying to obtain a conclusive result we considered the vegetation on Corine Land Cover 2000, making a crosstabulation of two levels one with the content of clay, with the various coverings of vegetation. Four classes have been defined for vegetation coverage (lack of vegetation, agricultural crops, poor vegetation, forest area), for each giving the values of cohesion due roots.

The result obtained is more eloquent (Fig. 3). On the one hand it is noted a much clearer appreciation of dangerous areas, and the cells with high risk appears, particularly in the area of Sălard and Gălăuțași. It is considered as danger zones the lower river of and downstream of the lake Răstolița. The most likely trigger points are offered after running the own developed module (Fig. 4).

Taking account the probabilistic interpretation of stability index stability (values over 1 represents stable areas, and values below 1 the probability that in the specified location landslides will not occur), but also the method how to account values below 1 (using cumulative probability functions) the transformation of these probabilities has been made in return periods. This transformation has been achieved for both the stability index map obtained from the SINMAP analysis and for the map containing the most likely trigger locations for landslides.

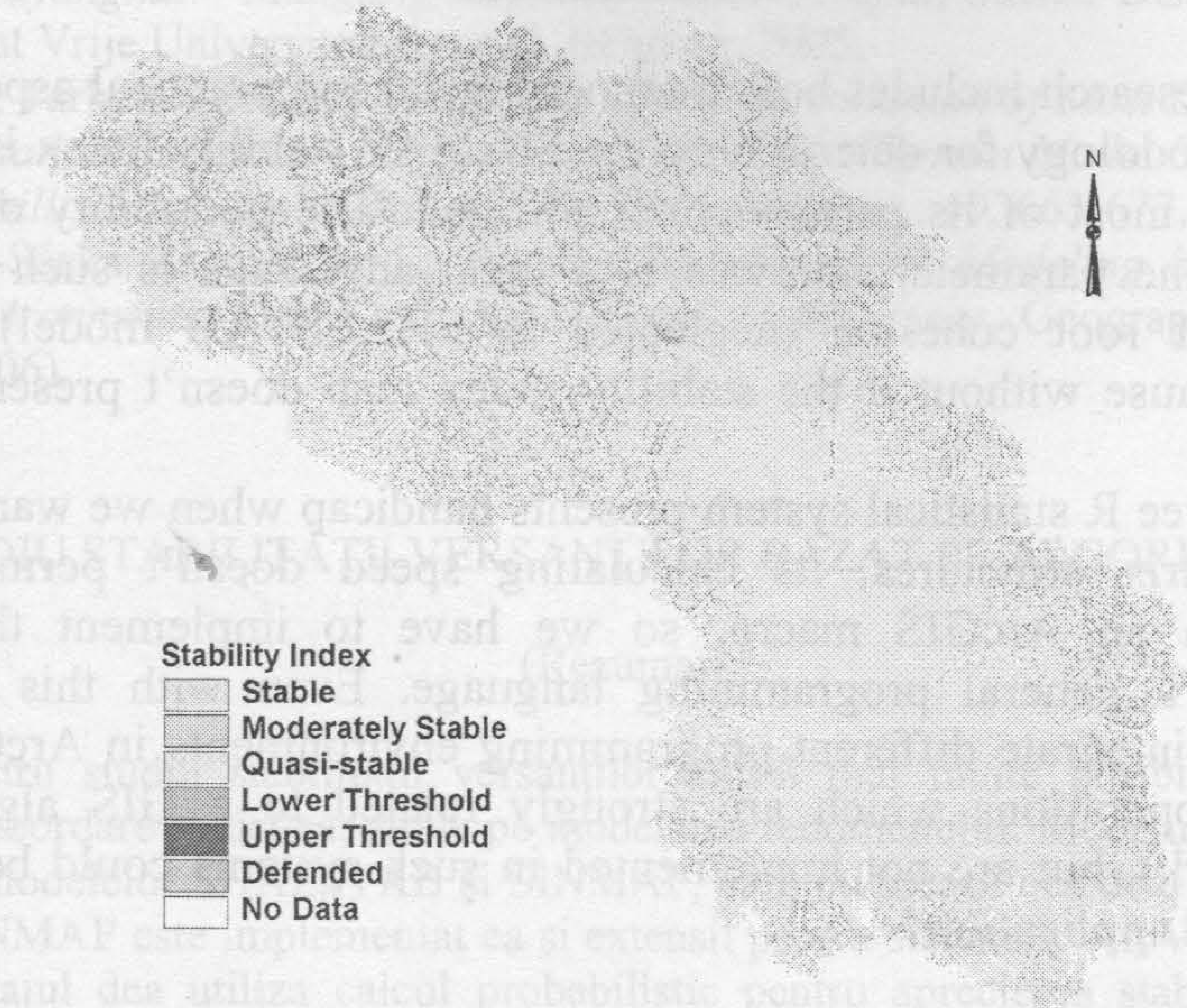


Fig. 3 - Index stability map, taking account the land use.


Fig. 4 - The most likely trigger points of landslides.

## 4. Conclusions

The research includes both methodological and practical aspect. Even if the base methodology for determining the SINMAP stability index is given, the calibration of most of its parameters is difficult. The possibility of SINMAP model to define parameter intervals is a great advantage is such cases. The importance of root cohesion (neglected in SHALSTAB model) is clearly revealed, because without it the stability index map doesn't presents obvious values.

The free R statistical system presents handicap when we want to operate on huge matrix structures, its calculating speed doesn't permit a useful integration in an ArcGIS macro, so we have to implement the Tarolli's algorithm in a general programming language. Even with this remark the possibility to integrate different programming environments in ArcGIS permits that special operations which are strongly related to a GIS algorithm (ex. statistical work), but are not implemented in such systems could be performed by specialized applications.

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## STUDIU STABILITĂŢII VERSANŢILOR BAZAT PE ALGORITM GIS

(Rezumat)

Pentru studiu stabilităţii versanţilor există mai multe posibilităţi, unele se bazează pe abordare statistică, altele pe modelarea fenomenului. Modelul pantei infinite stă la baza modelelor SHALSTAB şi SINMAP, care utilizează cea de a doua abordare. Modelul SINMAP este implementat ca şi extensii pentru sistemele ArcView şi ArcGIS, având avantajul dea utiliza calcul probabilistic pentru aprecierea stabilităţii. Studiul prezentat realizează o calibrare a parametrilor modelului SINMAP pentru Bazinul Superior al Mureşului, ţinând cont şi de coeziune solului datorată vegetaţiei, după care – pe baza unei extensii ArcGIS de dezvoltare proprie – determină cele mai probabile puncte de declanşare a alunecărilor, folosind atât harta indicelui de stabilitate cât şi harta direcţiilor de scurgere, conform algoritmului lui Tarolli. Pe baza rezultatelor se observă că locaţiile cu cel mai mare grad de periculozitate se află în special în zona localităţii Sălard şi Gălăuţaşi. Este considerată zonă periculoasă şi cursul inferior a râului Răstoliţa în aval de lacul Răstoliţa.