DEVELOPMENT OF A DATA BASE OF LAND CHARACTERISTICS AND COMPUTERIZED ANALYSIS OF ACTUAL AND POTENTIAL LAND DEGRADATION RISKS

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ABSTRACT

In this paper the development of a data base of land characteristics is described; both graphic and numeric data are memorized for the veoluation of land degradation risk.
In particular, the algorithms are described for the automatic overlay of thematic maps and for the synthesis of the results. Geographic data are stored and processed in vector form to achieve maximum output precision, although computer processing times are fairly long. The thematic maps involved in the application are: hydrography map, contour lines map, land-use map, soil map, geology and landslides map. Both cartographic and tabular output is described and the algorithms for the automatic evaluation of the rainfall erosivity index are also described.

INTRODUCTION

In the last ten years, several methodologies have been developed for the management of both graphic and factual data, and, in particular, much effort has been devoted to land data computerization.

The recent technological development in hardware and in the supports for software production have encouraged the implementation of increasingly sophisticated mathematical models. A principal scope of these models is to evaluate the parameters which result from the processing large amounts of data, managed by ad hoc data bases.

Most of the more recent studies and applications in resource planning and, more generally, in environment conservation, are based on an as complete and detailed as possible collection of all the necessary data.

The identification of the goals to be reached and of the models which can be applied is strongly dependent on data beeing available in a sufficient, consistent, homogeneous and processable form.

These conditions frequently constitute a limit to the application of complex models and even when it is possible to satisfy them to a certain degree, they contitute the most expensive part of the whole process.

Although the data collection is only made once, the costs remain heavy because of the large scale of many models and the scarce coverage of our country by a systematic data collection.

In this work we describe the data processing aspects of two models: LAPSE TIME ANALYSIS OF LANDSLIDE FORMS (LALF) and LAPSE TIME ANALYSIS OF EROSION HAZARD (LAEH) and the data base used for these models.

It is worthwhile mentioning that this data base contains much basic land data and could well be suitable for other models wich use similar types of data. The importance of the models which we will present for soil conservation and planning and their conceptual assumptions have been described in (Chisci, Tacconi and Biagi, 1985) and will be briefly summarized here.

In the first paragraph it will be described the general methodology of analysis and the conceptual assumptions of these models.

In the second paragraph the data base organization and content will be illustrated and the third one describes the algorithms for the basic data processing used to evaluate the models' parameters.

Finally, the results obtained from our models and their synthesis will be described in the fourth paragraph.

THE STRUCTURE OF THE LALF AND LAEH MODELS

The aim of these two models is to provide a means for the quantitative analysis of the processes of slope dynamics, i.e. to relate the various features of landslides (LALF) and the soil erosion hazard (LAEH) to the temporal evolution of the main factors affecting them (i.e. land use & management).

With an analysis of this type, land use restrictions and recommendations for soil management can be obtained with reference to "land units" which will be defined in the continuation.

Furthermore, the output of our models is used to assist land planners in developing intervention strategies for water management and erosion control on slopes.

In the first model, our analysis is based on the temporal comparison of the geometric characteristics of different landslide forms with reference to land units which are uniform in their geology, soil, slope and their land use.

In the second model, the analysis is based on the temporal comparison of the erosion hazard caused by surface water on land units which are again uniform in their soil, slope, land use & management structures (i.e. they contain no breaks in surface runoff). The time lapse which can be considered as useful for this comparison must be sufficient to ensure the existence of a substantial change in land use and management in the studied area (at least 20 years). The land units are considered to be uniform at the map scale used.

LAPSE TIME ANALYSIS OF EROSION HAZARD (LAEH) MODEL

The model allows for an analytic comparison of an erosion hazard index, which in our case is that proposed by USLE (Wischmeier and Smith, 1965, 1978), in a disaggregated form by soil, slope, land use & management classes for the various periods considered. An analysis of this type clearly shows how the index is affected by particular types of farming on various soils, slopes, etc. and suggests appropriate restrictions and recommendations.

The analytic evaluation of the index for all of the land units is summarized by several tables that help such deductions and which will be described in the last part of the work.

The erosion hazard index considered is the potential soil loss which is evaluated by the equation:

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

where R is the rainfall erosivity factor, K is the soil erodibility factor, SL is the slope-length factor, C is the crops and management factor, P is the support practice factor. The soil erodibility is evaluated by a standard soil survey of the area studied relative to texture, organic matter, structure and permeability as reported in (Wischmeier, Johnson and Cross, 1971).

The C and P factors do not involve particular data processing and will not be further described.

The input data to this model for the area studied are:

a) map of contour lines

b) hydrography map

c) soil map

d) two or more land use & structures maps for distinct, well spaced periods

e) a pluviometric data series with a temporal spacing of 15/30 min. for at least 15 years (to evaluate the rainfall erosivity factor, R)

f) soil erodibility

g) crops & management factor, C (for two or more periods)

After storage, the data for a)-d) is processed to obtain the topographic contours of the land units. These are then evaluated by automatically overlaying the various maps a)-d) and are considered as uniform areas, for the scale used, with respect to each of the thematics of a)-d).

For the rainfall erosivity factor, procedures have been implemented which allow us to obtain information at specific temporal spacings, directly from the digitized pluviographic strips (Torri and Biagi, 1978); the output of these procedures includes the rainfall erosivity factor R, as it will be described later on.

LAPSE TIME ANALYSIS OF LANDSLIDE FORMS (LALF) MODEL

The input data to this model, for the area studied are:

a) contour lines map

b) geology map

c) soil map

d) the land use for two or more periods, spaced by a congruous number of years

e) landslide map for two or more periods as above

f) inventories of agricultural management practices for the different kinds of farming in each of the periods.

Our analysis is based on the evaluation of the superficial and linear extents of the various landslide forms in relation to geology, slope, soil and land use classes in the periods considered.

This evaluation makes it possible to assess, on a quantitative basis, the particular combinations of farming, practices, soils, geologic conditions and slopes which tend to develop each specific form of landslide.

In addition to useful hints on soil conservation and intervention planning, our model gives very detailed information on the degradation conditions of the area beeing examined, especially if it is used in conjunction with LAEH model.

DATA BASE STRUCTURE AND CONTENT

In the previous paragraph some information has been given on the content of the data base. Before going on to listing and describing all of the data types and their organization, it is necessary to make some introductory statements.

A distinction must be made between raw data that have been digitized from maps and graphs and data which have already been processed (and are also included in the data base) so that this second type of data can be used by the models. Two examples of raw data are the contour lines and the pluviometric series.

As slope maps are only rarely available, the contour lines are memorized and suitable interpolation procedures have been implemented so that any given point of specified x,y coordinates within the area studied can be given a height (Montani and Salvetti, 1980).

Using these procedures the computation of the boundaries of equal slope areas (i.e. of the slope map) is avoided. These areas would have to be overlaid on the other thematic maps to obtain the boundaries of the land units. In this way a lot of work is saved.

In fact, the units that are obtained by overlaying the other thematic maps, excluding the slope map, are sufficiently small in relation to the slopes of the territories so far examined, that their mean slope can be evaluated directly with a good approximation.

For the pluviometric series, raw data are obtained by digitizing the significant points of the pluviographic strips produced by the instruments that are considered relevant for the area studied. These data are then processed to evaluate the rainfall in millimeters with a temporal spacing of 15 min. and then to evaluate the maximum intensity in a half-hour period for all the rainy events during the period considered (at least 15 years).

The data base thus includes both the data obtained by processing the contour lines for the slope evaluation (a matrix of levels) and the rainfall intensity data used to evaluate the erosivity factor.

At the present moment the Query Language for the data base has not been completely implemented, and only the interface to the models has been completed. In any case, however, data in the data base can be accessed and used for other purposes using the commands which will be described later on.

The data base is implemented on a IBM 3081 and the d.b. management procedures use CMS under VM/370.

All the graphic data are stored and processed in instrumental coordinates, i.e. those output by the digitizer.

The lines in the maps, for example the contour lines, channels, ridges or boundaries of the particular land-use areas, are represented by vectors; in this way the coordinate pairs are associated to the vertices of the polygonals which approximate the lines in the maps.

For several years, methodologies of input and output have been studied so that, with a well-trained operator, when an original map is overlapped by a plotter output of the digitized map no deviations will be evident.

Obviously, before digitization, the maps must be adequately prepared and it should be remembered that this operation takes at least as long as the memorization itself.

An example for the hydrography map is shown in fig. 3.

The hydrography map must be arranged so that each left and right slope can be distinguished for every channel segment, and all the individual segments of ridges and channels must be numbered sequentially.

Before being processed, all the maps must be brought to the same scale so that they can be overlaid. This can be performed automatically using one of the data base functions.

DATA STRUCTURES AND ORGANIZATION

Figure 1 shows the contents of the data base for the application of the LALF and LAEH models. If data for more than one area is to be included, the data sets can be considered as multiple ones and their files are identified by the area name.

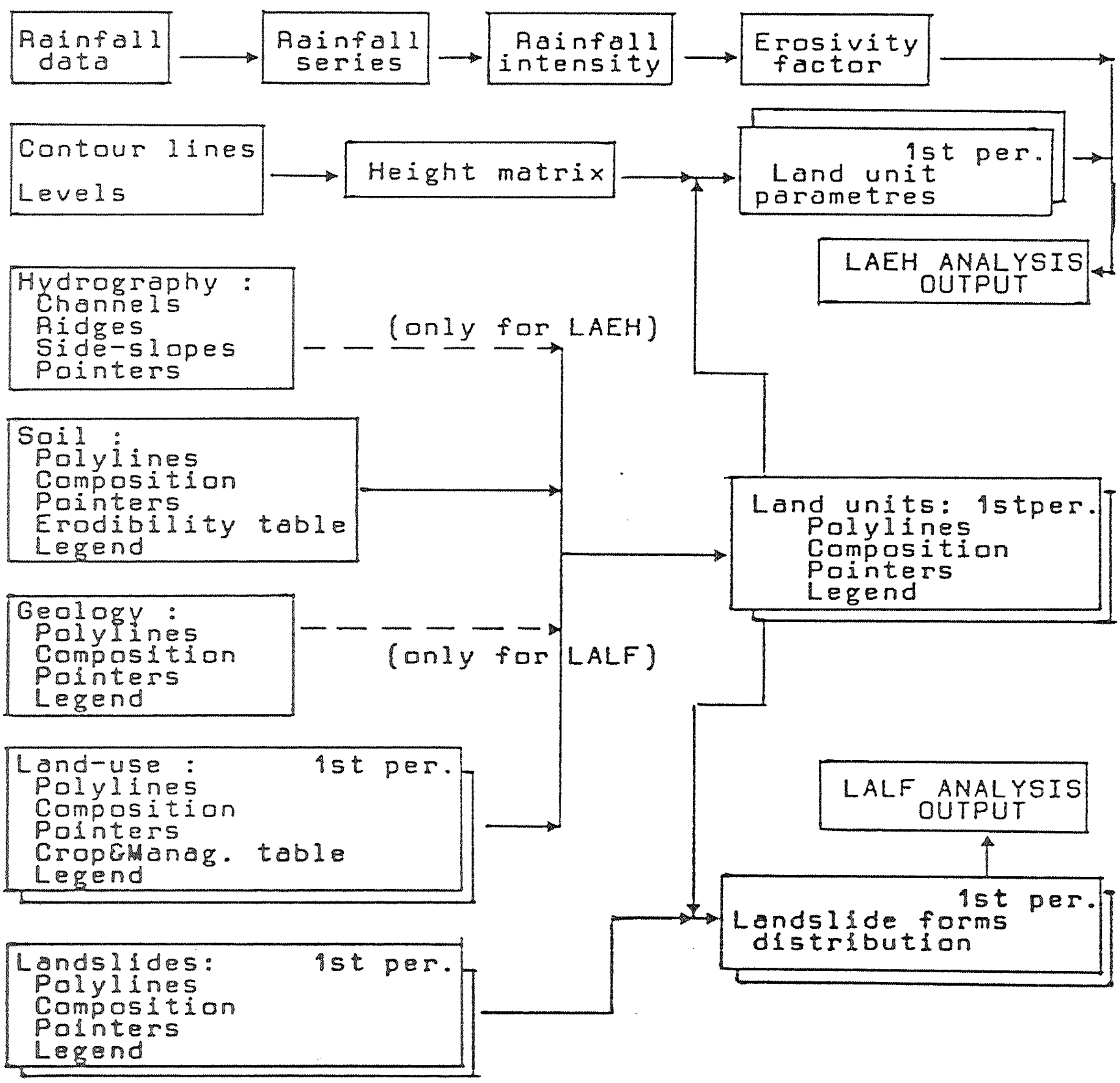


Fig. 1

Figure 2 shows the interaction between models, the data base management system, the query language and the data.

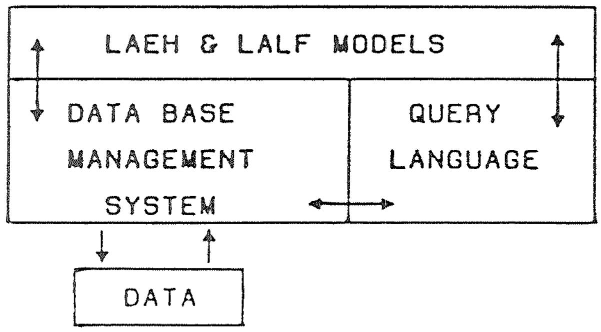


Fig. 2

The content of the various graphic data files can be represented as shown here, according to the maps related to :

```
   CONTOUR LINES map : it is  coded in two files, POLYLINES and
                                LEVELS

        POLYLINES : no.of Polyline, no.of Vertices
                           x1      ,      y1
                           x2      ,      y2
                           .       ,      .
                           .       ,      .
                           xn      ,      yn
                    no.of Polyline,  no.of Vertices
                           x1      ,      y1
                           .       ,      .
                           .       ,      .

   LEVELS : Polyline no., height, no.of polyline beginning rec.
            Polyline no., height, no.of polyline beginning rec.
                .      ,    .   ,        .
                .      ,    .   ,        .
                .      ,    .   ,        .

  HYDROGRAPHY map :  the map is coded in four  files:  CHANNELS,
                     RIDGES, SIDE_SLOPES and POINTERS

   CHANNELS and RIDGES : no.of channel/ridge tract, no.of vert.
                                      x1           ,      y1
                                      x2           ,      y2
                                      .            ,      .
                                      .            ,      .
                         no.of channel/ridge tract, no.of vert.
                                      x1           ,      y1
                                      .            ,      .
                                      .            ,      .

  SIDE_SLOPES :  no.of ridge tract;  no. of tracts composing the
                   left  ridge:   N1,N2.....Nn;   no.  of  tracts
                     composing the right ridge: N1,N2.....Nn
                     (see fig.3 )
```

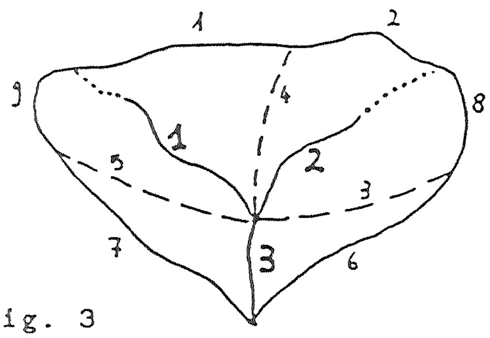


Fig. 3

1 ; 2 :1,4; 2 :5,9
2 ; 2 :8,3; 2 :2,4
3 ; 2 :7,5; 2 :3,6

POINTERS : no.of tract , no. of tract beginning record
no.of tract , no. of tract beginning record
. , .
. , .
. , .

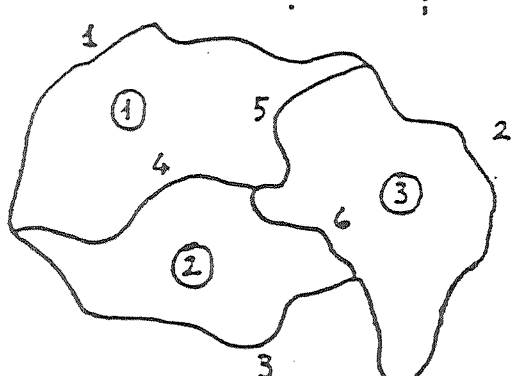
If the first tract (polyline) has 5 vertices, the second tract has 8 and the third 4 vertices, then the pointer file is

1 , 1
2 , 7
3 , 16
4 , 21
. , .
. , .
. , .

SOIL map, GEOLOGY map, LAND-USE & STRUCTURES map, LANDSLIDES map : are coded in three files: POLYLINES, POINTERS and COMPOSITION.

The POLYLINES and POINTERS files are analogous to those shown before. (see fig. 4)

COMPOSITION :no. of area; no. of polylines: P1,P2,..,Pn; class
no. of area; no. of polylines: P1,P2,..,Pn; class
. ; . : . , .,..., . ; .
. ; . : . , .,..., . ; .



1 ; 3 : 1,4,5 ; F (Forest)
2 ; 3 : 3,4,6 ; P (Pasture)
3 ; 3 : 5,2,6 ; V (Vineyard)

Fig. 4

DATA BASE COMMANDS AND FUNCTIONS

The data base commands can be subdivided into three groups: output commands, editing commands and procedure calling commands.

The output commands

The output commands allow the content of the data base to be printed or plotted depending on the type of data.

For the print facilities, an index of the file names is provided together with some tables resuming the content of the various files. The output of the graphic files is in table form and contains the map type, the number of areas or linear entities in the map, the number and type of classes in the map. The user is only able to edit the graphic files that contain numeric information related to polylines; these files have to be printed by the system manager because of their extent.

The graphic output of files is arranged on a four pen Calcomp 1051 plotter and facilities for scaling or partial plotting operations are available.

The maps' legends can be ouput both in tabular and in graphic mode, as an option of the plotting command.

The editing commands

The data base management system provides the user with full editing facilities for both graphic and tabular files, using graphic or alphanumeric terminals.

The standard tasks of insertion, deletion and update are provided for polylines and attributes of the graphic entities, with automatic update of the POINTERS files. Syntactic error handling is completely controlled by the system with sending of messages to the user; semantic errors are recovered by the restoring of the data base state previous to the session during which error has occurred.

At the present, the data base can be used by one user at a time, therefore, clearly, no problems of concurrent access during the editing phases can arise.

The procedure calling commands

Some general procedures not included in the LALF and LAEH models can be directly invoked by these commands.

MATRIX : this command creates the matrix of levels for an area for which the contour level map has been digitized.

The boundaries of the matrix and the resolution of the grid must be entered in input, so that the user can create submatrices with the desired degree of precision; the maximum precision possible is obviously reached when the grid sides are equal to the resolution of the digitizing tablet.

As the invoking of this procedure implies long CPU times and the use of large amounts of magnetic disk memory, the user must carefully control the correctness of the contour lines.

OVERLAY : this command allows the user to overlay two maps; given, for example, the geology map and the land use map which have been already described, the overlay will produce a new map, which contains all the areas obtained by the intersection of the two maps. The resulting map can be further overlaid on another map, as occurs in the LALF and LAEH models.

LENGTH : this command evaluates the length of an open polyline (contour line, channel tract, etc.) or closed polyline (boundary of a land unit, soil unit, etc.). The evaluation is performed simply by adding the distances going from one vertex of the polyline to the next, starting from the first one. The evaluation is performed both on planar polylines and three dimensional polylines (the boundary of a soil unit, for example, can be quoted after digitizing so that every vertex has three components x,y and z).

AREA : this command allows the user to evaluate the area of a closed polyline according to the following equation:

$$A = 0.5 * ABS \sum(X(i)*Y(i+1) - X(i+1)*Y(i))$$

The absolute value in the equation has the effect of making the evaluation independent of the clockwise or anticlockwise digitizing of the polyline.

QUOTE : this command gives the level of a vertex of a polyline or of any point inside the level matrix created with the MATRIX command.

SCALE : this command allows the user to scale the coordinates of the elements of a map. The name of the map and the output scale factor must be given (the input scale factor is input from the map's files).

EVALUATION OF THE PARAMETERS OF LALF AND LAEH MODELS

As previously stated in the foregoing paragraph, many computations are common to both models and thus the description will begin from these ones. In particular, the boundaries of the land units, even when obtained by overlaying different maps, are evaluated using the same procedures. For the LAEH model the evaluation of the slope length factor and of the R factor will be described.

Evaluation of the land units boundaries

As previously stated in the first paragraph, the overlay operation between land use map and soil map is common to both the models. Tha resulting map is then overlaid to hydrography map for the LAEH model and to geology and landslide maps for the LALF model.

As far as regards the boundaries of the areas resulting by such overlay, two files RECT1 and RECT2 are associated to the files that contain the areas of the maps to be overlaid, MAP1 and MAP2, respectively. The files RECT1 and RECT2 contain the rectangles that are circumscribed (i.e. XMIN,XMAX,YMIN,YMAX) to each of the areas in the two maps.

For each area in MAP1 a test is performed for the possible intersection with each area in MAP2; in fact, only if the circumscribed rectangles do intersecate each other, an intersection is possible between the two areas.

In this case the procedure of evaluation of the boundary of the possible overlap area is activated (Biagi and Montani, 1982). Obviously, it is possible that the two areas do not overlap even if the circumscribed rectangles do, as shown in fig 5.

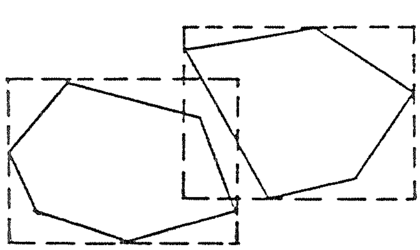


Fig. 5

The overlay operation is very heavy; in fact, a land-use map at 1:25000 scale and dimensions of 50 by 60 cm. which shows intensive farming (like the Cesena land-use map) can have a mean value of the areas of only 3 hectares; this density implies that over 6000 units are to be processed.

The overlay of such a map to a geology map with mean area values of 60 hectares (300 units, about) results in a map containing over 9000 units.

The computational effort is proportional to the number of units in a map by the number in the other (6000 * 300) for the comparison of the circumscribed rectangles; in addition, about 3000 units are to be actually overlaid, and this is the most expensive part.

Some attempts have been made to use more efficient algorithms more efficient than the combinatorial one, but at the present time this is the only one that has shown the capability of treating so large number of units; the other algorithms, in fact, also if more efficient and fast than the combinatorial one, show a too large memory occupancy even for a mainframe computer like IBM 3081.

For the classes related to the areas, it is necessary to arrange for a file that contains the legend of the resulting map; the legend must be given as a matrix (see fig. 6).

		LAND-USE CLASSES			
		1	2	3	4
Geology classes	1	1	3	5	5
	2	1	4	6	6
	3	2	2	7	7
	4	2	2	8	8

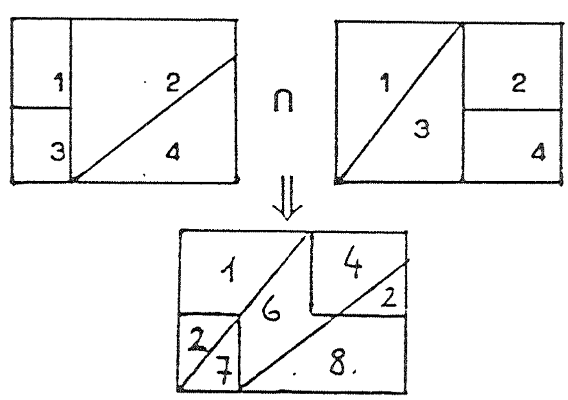


Fig.6

It is necessary to group the various classes for a good output of the map; it is possible, anyway, to maintain the attributes in a disaggregate form for the development of analysis procedures, such as those of LAEH and LALF models.

The intersection between closed (land units) and open polylines (some landslide types) is considered as a particular case and the circumscribed rectangles are still used; the polyline tracts that intersecate the land units are output in this case.

The slope-length factor, SL

For the evaluation of this parameter, it is necessary to evaluate the mean slope and the mean length along the maximum slope of each land unit.

The evaluation of the mean slope of the land units is performed by assigning a height, as described in the second paragraph, to the vertices of the polyline that represents the boundary of the area. The land unit surface is then approximated by a plane interpolating the vertices in the least square sense.

The angle between the projection onto the x,y plane of the maximum slope line of the interpolating plane and a reference axis, for example that of the abscissae, is now evaluated.

Let ideally sweep the land unit with a line parallel to the maximum slope line and memorize the lengths of their intersections; the maximum and mean lengths of the land unit along the maximum slope direction can be so evaluated.

These computations are not very expensive in terms of CPU time because they are performed by using optimized algorithms created ad hoc; it is a fact, obviously, that the total time required grows linearly with the number of land units to be considered.

Let S be the mean slope (in %) and L be the mean length of the land unit (in metres); the SL factor is then evaluated by the equation :

$$SL = (L/22.1)^m * (0.065+0.045*S+0.0065* S^2)$$

where m depends on slope (Wischmeier, Smith, 1978).

Evaluation of the rainfall erosivity factor, R

The evaluation of the R factor is performed by cumulating the erosivity indices in the various years for all of the rainy events during the period considered and by taking their mean value.

These indices are evaluated by the equation (Wischmeier and Smith,1978) :

$$R(i) = 0.129E-02*(\sum_j (12.13 + 8.9* Ln\ I(j))*(I(j)*T(j)) *I30(i)$$

where R(i) is the raifall erosivity for the event i;

I(j) is the rainfall intensity for each time lapse T(j) during which it has remained steady;

T(j) is the duration in hours of the intensity I(j) in the event;

I30(i) is the maximun 30 minutes intensity in the event.

The indices R(i) can be thus evaluated by the series of the 30 min. intensities in each event during the period considered.

As already stated, the intensities are evaluated directly by the raw data related to the pluviometric strips.

THE RESULTS OF THE MODELS

At the end of the processing described in so far for the model LAEH, the values of the parametres area, land use and SL factor are known for each land unit. The additional knowledge of the erosivity factor R, soil erodibility K and crops&management factor C (that, in turn, depends on the mean slope) allows for the evaluation of the potential soil loss for each land unit.

It is obvious that the analytic values of the parametres for some thousands of land units is not very useful; these values must be synthetized for a comparison between different zones or times.

The synthesis of the parametres' values is performed by the arrangement of tables and/or graphs; to this purpose it is necessary to subdivide the ranges of the various parametres into several classes.

For the potential soil loss the following tables have been arranged for (ordinates: abscissae, values represented by the entries of the table) :

- Area classes : land use classes , potential soil loss

- Mean slope classes : land use classes, potential soil loss (weighted on the area)
- Mean length classes : land use classes, potential soil loss (weighted on the area)

The examination of the entries in the tables for several zones shows the different erosion hazard and the factors affecting it (morphologic or crop & management); in the case of temporal comparison, the tables show whether the hazard is increased or decreased, why (whether there has been a particular crop change or shift to different areas) and in which zones (towards lesser slopes, in smaller units, etc.).

A further result of the model deals with the morphometric and land use analysis of the area considered and also if it is independent on the erosion hazard, it helps the interpretation of the former results.

The following tables have been arranged for :

- Area classes : land use classes , frequences
- Mean slope classes : land use classes , frequencies
- Mean slope classes : land use classes , total area
- Mean length classes : land use classes , frequencies
- Mean length classes : land use classes , total area

For the LALF model, the area or length and the number of landslide forms are considered for each soil and geology class versus mean slope classes.

This analysis results in a very detailed comparison between two zones or different periods, allowing for the evaluation of the areas that are more subject to degradation or that are becoming so.

The following tables have been arranged for each soil class, geology class , land use class and soil, geology and land use class:

- Mean slope classes : landslide classes, area or length and number.

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