Example of automatic integrated cartography for geomorphological purpose.

P. Ballerini, F. Catani, S. Moretti

Earth Sciences Department - Università degli Studi di Firenze

Abstract

This paper addresses a methodological application of a Geographical Information System that takes into consideration physical ground information, mainly related to soil geotechnical properties, in addition to common geographical data. The integrated information will provide a support as input data to be introduced into a hydrological and erosive model. The application of such a method has been tested on the Montespertoli experimental site where many information from previous research works on geology, geomorphology, land use, hydrology and soil analysis, carried out at Earth Sciences Department, are available.

Introduction

Soil exploitation is one of the most difficult and important aspects of land and natural resource management. As the degradational processes are not well known everywhere, the quantitative evaluation of the active processes is of primary relevance. For this reason it is necessary to find methodologies which are able to provide quantitative figures and forecast on soil loss and degradation. This paper presents an integrated approach for computing soil loss on agricultural land by means of a distributed hydrological model and a Geographical Information System. The work was carried out in three main steps, including survey and data elaboration. In the first step, the georeferred topographical data and the derived information (DTM, slope, exposure and other morphometrical parameters) are employed and integrated with litology, land use and pedology. In this phase a detailed data base is produced and the information to introduce in the hydrological-erosive model, are obtained. The second step mainly deals with the computational phase by means of the erosive model, which processes the data and gives the output, in a distributed level, back to the GIS.
The chosen model is the KINematic EROsion Simulation model (KINEROS). It is a distributed physically-based model describing the processes of surface runoff and soil erosion from small watershed. The physical processes are simulated by the model using equations which represent the fundamental processes of detachment, transport and deposition. KINEROS is an event oriented model which can operate over a single rainfall event (Woolhiser et al., 1990; Smith, 1977).

Test Area Description

The site of Montespertoli, 30 km south of Florence, is located in the Pesa basin (influent of the Arno River) and more precisely in the Virginio sub-watershed. The site is a representative area of the Thyrrenian-Apennine slopes where Plio-Pleistocene marine and fluvio-lacustrine soft sediments are present. This deposits are intensely affected by geomorphological processes such as erosion and mass movements. More than half of this area is hilly with an average height of about 250 m, and the remaining part is flat with alluvial wetlands of the Pesa river. Geomorphology is rather well related to geological evolution, in fact there is a clear influence of the structure (e.g. relatively recent faults) and of the vertical and horizontal variability of the deposits on landscape evolution. Cutting down of the rivers with results in the actual hydrographic framework is a direct consequence of the runoff to which mass movements have been jointed (Canuti et al., 1990). The lateral profile of the valley is clearly influenced by the different outcrops which create a different behavior in relation to the geomorphological processes. The land use involves vineyards, olive yards and some woods; these agricultural activities, especially for wine production, have also been the principal cause of hillsides remodeling. In fact in the hillsides, where the vineyards are prevalently located, have been extensively remodeled over the last twenty years to make the vineyards themselves accessible to mechanical farm equipment. Of course this transformation has brought some advantages to productivity but in many cases reduces slope stability and makes increases soil erosion.

Geographic Information System

The data analysis procedure, carried out through both cartographic and experimental field analysis, is mainly devoted to achieving an areal distribution of morphogenetic processes such as soil erosion. For that reason the use of a GIS (GRASS public domain package by USA Construction Engineering Research Laboratories) allows us to manage the geometric-graphic and descriptive data in an integrated approach to better fit the hydrological constraint of the mathematical model (Gallant et Al., 1993).

GRASS is a workbench of tools for the analysis of geographic phenomena which operate on spatial data (C.E.R.L. & O.G.I; 1993). This data were first inputted in DXF vector format, then topologically rebuilt in GRASS binary vector format. In GRASS, spatial data are objects with dimension or physical size. Furthermore, objects with dimensions in relation to the earth's surface are called geographic spatial data. These kinds of objects are characterized by geographic location relative to a coordinate system, attributes containing quantitative or qualitative information and spatial-geometric interrelations (topology). In order to analyze data needed by the hydrological-erosive model, a further step was taken by transforming binary GRASS vector map layers into GRASS raster map layer format. Raster format uses the CELL as its fundamental unit of information. Each cell within the grid representing the study area can be assigned a data value or attribute, describing geomorphological information such as land use, pedology, litology etc. In this way each GRASS raster map data file represents a specific thematic map, allowing the application of discrete analysis methods based on statistic calculus. In fact, raster format is best when used for continuously varying surfaces such as elevation, slope, areal terrain properties and most environmental variables used in numerical modeling. This procedure envisions that each of these cells has memorized their own fundamental-geometrical characteristics and attributes values, such as slope, aspect, land use, pedology, litology and discrete overlandflow direction.

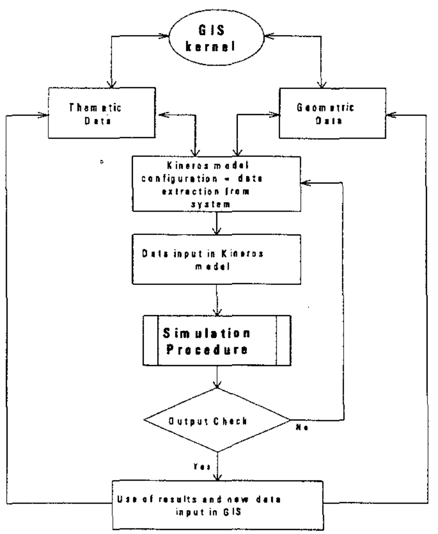

Fig. 1 - Flowchart of method calibration

As can be seen in Fig. 1, the flow chart of data development involves most GIS operations. In particular, in the first step of data acquisition, the following sub-steps were carried out: digital data acquisition (in DXF format), conversion to GRASS vector format (v.in.dxf function), building of topology (v.support), coordinate checking (g.region), conversion to GRASS raster format (v.to.rast), completing raster support files (r.support) and finally spatial analysis, generating the DTM (r.surf.idw), weighted average of thematic data fitting into KINEROS areas (r.stats), slope and aspect map (r.slope.aspect) and watershed basin analysis (r.watershed).

Following this procedure it is possible to request interactively, in the investigated area, information on each cell or cluster (group of adjacent cells) through typological-geometrical requests, such as the boundary of an areal KINEROS element inside a polygon.

The study of these descriptive areal data in discrete data and their union to those punctual geometric helps obtain a data bank of the territory under examination that, in addition to offering its graphic representation and aid the production of derived maps, also gives information about the distributed indicators useful for the emission in adulterate calculus systems, such as mathematical models of simulation and forecast.

Erosive Model Application

The KINEROS model has been used for evaluating the response of the watershed under the effect of rainfall events of notable intensity in terms of overland flow and soil loss. During the simulation, the watershed surface and the channel network are represented by a branched system of rectangular surfaces contributing to the discharge into the channels. The choice of each plane must preserve the principal spatial variations of topography, soil type and vegetation cover.
A preliminary subdivision of the basin in overland flow elements on the base of hydraulic criterion has been completed. In subdividing the basin into individual elements of outflow, a digital model of the preferential directions of outflow (flow lines) has been created. Following the first subdivision, more information has been considered and introduced into the GIS such as pedology, land use and slope geometry.
Through the overlap of the different themes considered, each being introduced in the geographic information system, it has been possible to characterize homogeneous areas in terms of pedology, slope classes and land use. The subsequent overlap of the decided elements on the hydraulic criterion allowed further subdivisions of the already defined elements.
This procedure has shown to the representation of the watershed in a cluster of 9 elements, according to the scheme in figure 2.

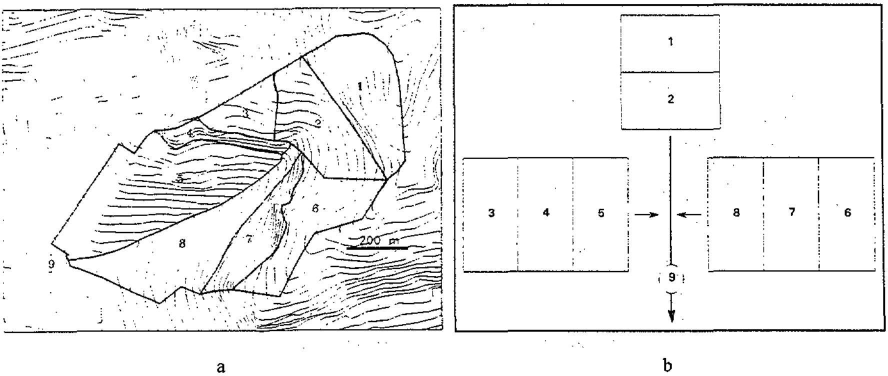

Fig. 2 - a) Map showing the watershed and relative elements; b) presentation of KINEROS planes and channels.

For the morphometric characteristics of the elements, the areas of the equivalent planes relative to the individual elements have been computed and, by using the map of the overland flow directions, the average lengths of the slopes have been abstracted. Once the area and length of each element were obtained it was then possible to compute the width of the relative equivalent rectangle. A subsequent elaboration of the slope map helped obtain the mean slope of each element which was associated to the equivalent plane. Slope and length of the channel were defined and were associated to the correspondent element (Lane et al. 1975).
The 8 planes have been represented by rectangles with area among 2 ha and 16 ha and with average slopes among 17% and 36%. The river channel (element 9) is instead represented, according to the field observations, by an nonerodible trapezoidal channel, characterized by a length of 800 m and by an average slope of 8%. At the end of the channel, corresponding to the last element it has been valued the hydrogram and the corresponding soil loss.
Each element (plain or channel) has been characterized from a set of relative indicators regarding geometric characteristics, physical characteristics of the soil and type of vegetation. The attribution of a specific parameter for each element has been done using opportune elaborations performed by means of the GRASS. To determine the hydraulic conductivity (i.e. of a plane), the percentages of areas with different soil types (characterized by