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Analysis of erosion in a catchment affected by a landslide

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Abstract The analysis of soil erosion in small sub-basins and on slopes with and without anti-erosional protection was based on genetic methods and experimental measurements undertaken in the 29 km^2 of Valea Larga basin. The experimental sub-basin has a surface of 20 ha; the landslide occurs at a mean depth of 2.3 m and the maximum depth reaches 4.0 m. This basin was levelled, cultivated and provided with anti-erosional structures over an area of 9 ha, using drainage techniques. Two plots of 20 m × 5 m have been used for carrying out experiments, each one located in areas with and without anti-erosional structures. The physical parameters obtained from the experiments were used in an erosion model; the data base for the entire study area was structured using the Integral Terrain Mapping (ITM) system.

INTRODUCTION

Prediction of overland flow and sediment transport from hillslope has important implications in solving water quality and land use issues. The production and transport of sediment at the basin scale is influenced by many factors acting both on the hillslope and within the drainage network. On the hillslopes, soil characteristics such as texture, permeability, bulk density and infiltration capacity are of primary importance. Vegetation (density, area extension, height) and topography (slope, slope length, slope configuration, etc.) as well as climatic factors (rainfall intensity, duration, space-time distribution, total rainfall, temperature, freeze-thaw cycles) are also important. In addition, human activities (land use, irrigation and drainage etc.) also influence sediment yield at the basin scale.

The number and complexity of the factors affecting the production and transport of sediment outlined above emphasize the considerable difficulty involved in describing the various process interactions that need to be taken into account to develop a deterministic physical model describing the entire system. Such a model, generally requires a considerable body of information concerning catchment and terrain characteristics (Bennet, 1974).

GEOGRAPHICAL INPUT DATA

The ARC-INFO GIS computer software has been employed to process and analyse the necessary geographical information. These data, coupled with experimental data and records from monitoring stations in the Valea Larga Basin, provide the necessary input data for the model. The data base for the entire study area was structured using

the Integral Terrain Unit Mapping system. Data layers consist of:
(a) the NOA image of the basin (Fig. 1),
(b) the 1:25 000 topographic maps of the Ministry of Internal Affairs (Fig. 2),
(c) the 1:50 000 geological maps,
(d) the 1:25 000 soil maps of the ICPA (Institute of Pedological Research)

The model subdivides the drainage basin into uniform grid squares called "cells". The erosion-transport model — an adaptation of the GLEAMS Model (Leonard *et al.*, 1987) — routes water and sediment through these cells in a stepwise manner, proceeding from the headwaters of the basin to the outlet. This allows the flow as well as the load parameters to be examined at any point.

The procedure used for obtaining the geographical input data file is shown in a diagrammatic form in Fig. 3. Using the actual NOA images, it is possible to continuously monitor man-made changes associated with anti-erosional structures built in the basin.

EXPERIMENTAL DATA

Experimental data concerning rainfall-runoff and suspended sediment transport under various conditions have been assembled at different scales, by means of a mobile rainfall simulator, experimental runoff plots and monitoring a drainage basin affected by a slide, having a surface of 20 ha. The basin was levelled, cultivated and provided with anti-erosional structures over an area of 9 ha. In 1980, the anti-erosional

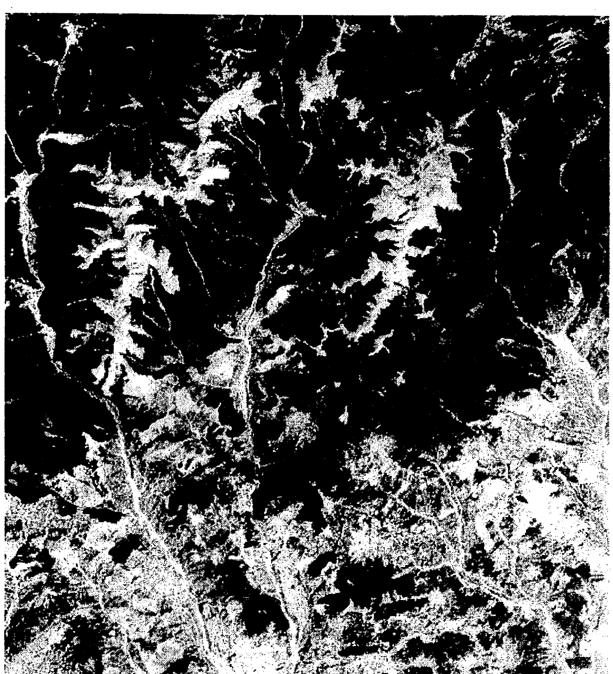


Fig. 1 NOA image of the Valea Larga basin.

Fig. 2 Topographic map superimposed on the NOA image.

structures were constructed using drainage techniques. After three years, two plots were located in areas with and without anti-erosional structures, but with the same degree of land cover, type of crops and slope.

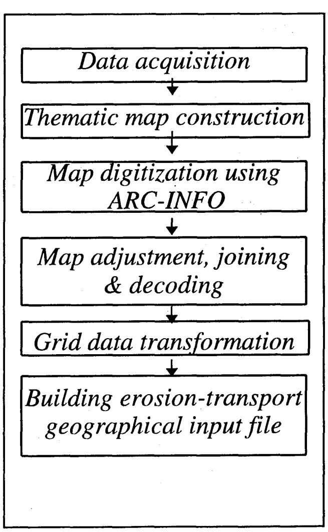


Fig. 3 The scheme for obtaining the geographical data input file.

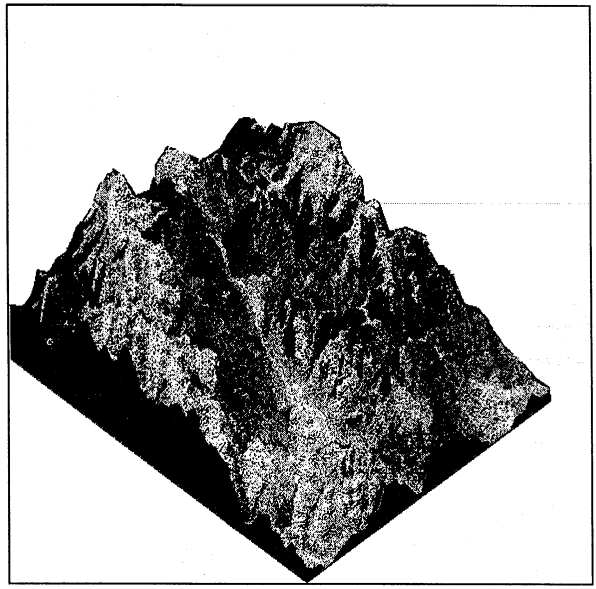


Fig. 4 The numerical terrain model.

The rainfall simulator can produce uniform rainfall onto a circular area of 0.5 m^2 on slopes of different inclinations and provides protection against the influence of wind and evaporation losses. The intensity of the simulated rain can be adjusted and kept constant during the experiment. The intensities currently used for the experiments are: 0.5 mm min^{-1}, 1.0 mm min^{-1}, 1.5 mm min^{-1}, 2.0 mm min^{-1}, and 2.5 mm min^{-1}, making up the usual experimental run. The intensity of the experimental rainfall and of the resulting runoff and sediment yield are rigorously controlled/monitored. The simulation for a given set of conditions is continued until the runoff process becomes steady over a time interval of several tens of minutes. The variation of sediment transport (soil erodibility) during the experiment is determined by analysis of the sediment concentration of samples taken at given time intervals. Knowing accurately both the variation through time of the rainfall depth and the runoff hydrograph, the hydrograph of sediment transport and the total volume of eroded soil can be obtained.

The results of two sets of experiments involving (a) different slopes, but the same soil moisture (20-22%) and land cover conditions and (b) the same slopes but

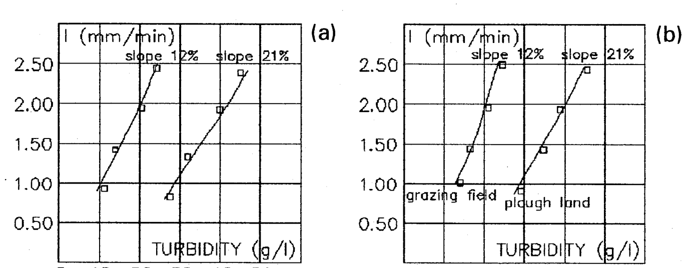


Fig. 5 Relationships between rainfall and turbidity for areas with different slopes (a) and land use (b).

different land cover are presented in Fig. 5 in terms of the suspended sediment concentration (turbidity) associated with a range of rainfall intensities. By comparing the maximum turbidity values obtained in the set of experiments for a grazing field and ploughed land, increases in the maximum turbidity for the ploughed land in the range 78-180 % can be seen.

In the measurements undertaken on two 100 m² (20 m × 5 m) plots an increase in the erodibility of the slide areas without anti-erosional structures ranging from 44% to 132% (81 g l^{-1} and 132 g l^{-1} registered at a maximum rainfall intensity of 2.21 mm min^{-1}) was found. Figure 6 presents the relationship between the maximum rainfall intensity and surface erosion (turbidity). Drainage increases infiltration and there is therefore a reduction in runoff intensity at the soil surface and, implicitly, in the amount of sediment transported. This behaviour is also reflected in the runoff coefficients (Fig. 7).

Outputs from the entire basin were measured by a gauging station during the period 1962-1996.

The experiments provided a hydrological classification of the runoff and erosion parameters of the slopes in the study basin (Valea Larga basin). This information was used as input parameters in the rainfall-runoff and sediment transport models for the basin. The results were compared with the measured data.

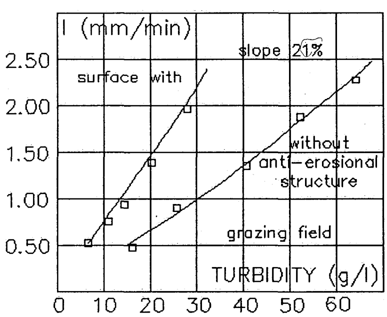


Fig. 6 Relationships between rainfall and turbidity for areas with and without anti-erosional structures.

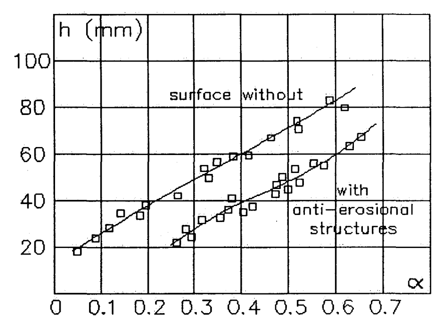


Fig. 7 Relationships between rainfall and runoff coefficients for areas with and without anti-erosional structures.

SIMULATION OF EROSION-TRANSPORT-DEPOSITION

The hydrology component contains sub-models for computing runoff, soil moisture, percolation through the root zone, and evapotranspiration within the selected watershed. The hydrology component requires a precipitation data file for the period to be simulated and a hydrology parameter file. There are two modelling options for the precipitation file in the hydrology component. Option 1, the daily rainfall model, uses the SCS curve number procedure (Fig. 8). Option 2, the hourly or breakpoint rainfall model, uses an infiltration procedure (Fig. 9).

The erosion/sediment component of the model, which operates on the same watershed as the hydrology component, computes the erosion, sediment yield and grain size composition of the sediment on a storm-by-storm basis. This component

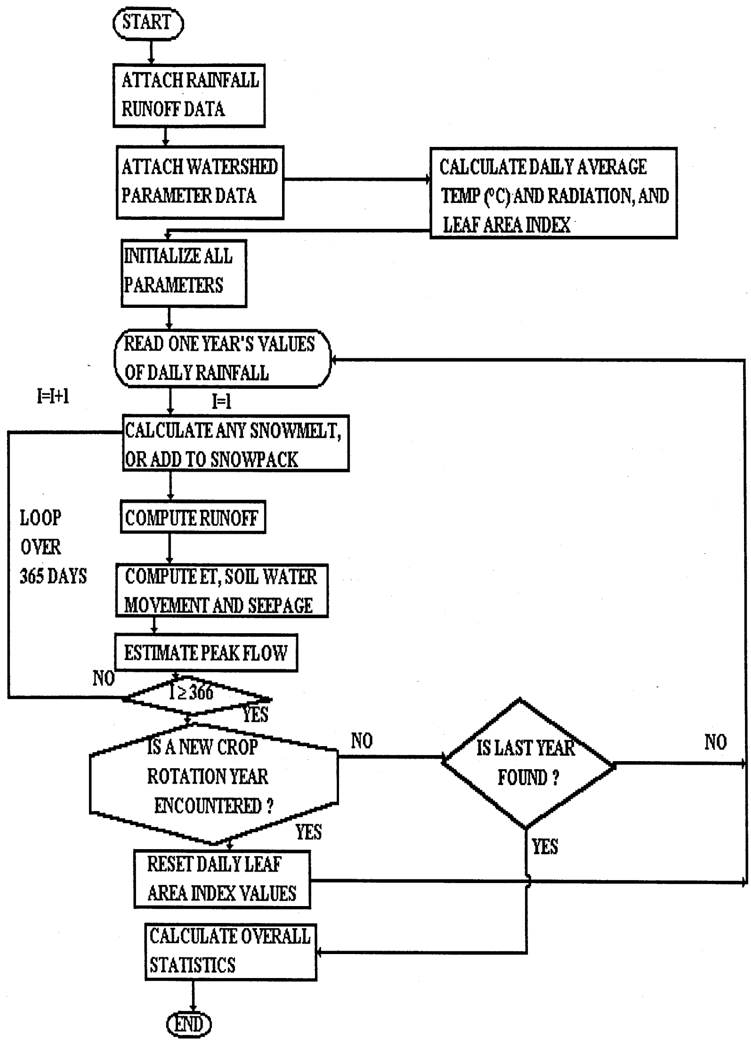


Fig. 8 Flow chart for HYDONE.

combines new modelling concepts with such commonly accepted relationships as the Universal Soil Loss Equation (USLE). The model incorporates three types of surface runoff including: overland flow, concentrated (channel) flow and flow from an impoundment. One, two or all three elements may be present. Figure 10 presents the flow chart for the detachment-transport-deposition computations within an overland flow segment or concentrated flow element.

The major assumptions of the model are linked to the slope profile, and the discharge, erosion and sediment transport both across the surface and in the channel. The curved portion of a slope profile are assumed to be described by a quadratic equation where the end slopes are the same as the adjoining uniform slopes. The actual field slope may not be precisely duplicated, but the essential effects of concavity, convexity and complexity are included.

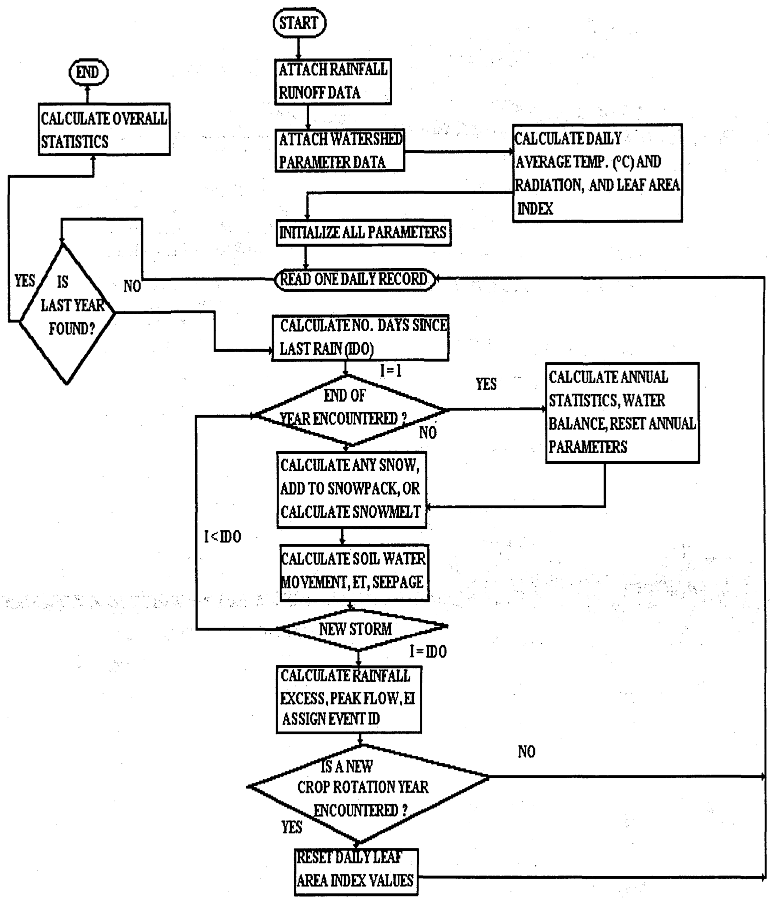


Fig. 9 Flow chart for HYDTWO.

Discharge at any point in the watershed is assumed to be directly proportional to the drainage area above that point. Overland flow discharge at a location is computed, therefore, as a product of the slope length to that point and the maximum excess rainfall rate which is attenuated for nonuniform rainfall rates and travel time. This attenuated peak discharge is used as a characteristic discharge for the runoff event.

The relationship used to estimate detachment operates on a storm basis, while transport is estimated on an instantaneous discharge basis. The sediment concentration in the flow is assumed to be the average concentration for the storm. The concentration for detachment is determined by dividing the amount of sediment detached during the storm for a segment by the total amount of runoff per unit area. The characteristic discharge multiplied by the concentration gives the rate of soil loss (per unit time) at the characteristic discharge. The transport is also computed using the characteristic discharge rate, so that both detachment and transport will be on the same basis. Whether the flow is detaching or depositing, the model assumes that interrill erosion always adds sediment to the flow. On a given segment, the potential sediment load is computed by adding the detachment associated with the interrill

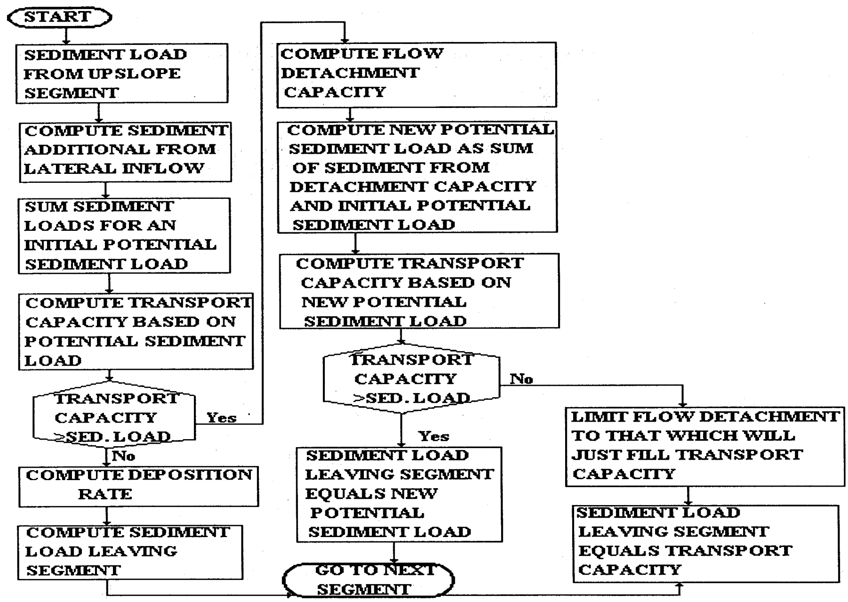
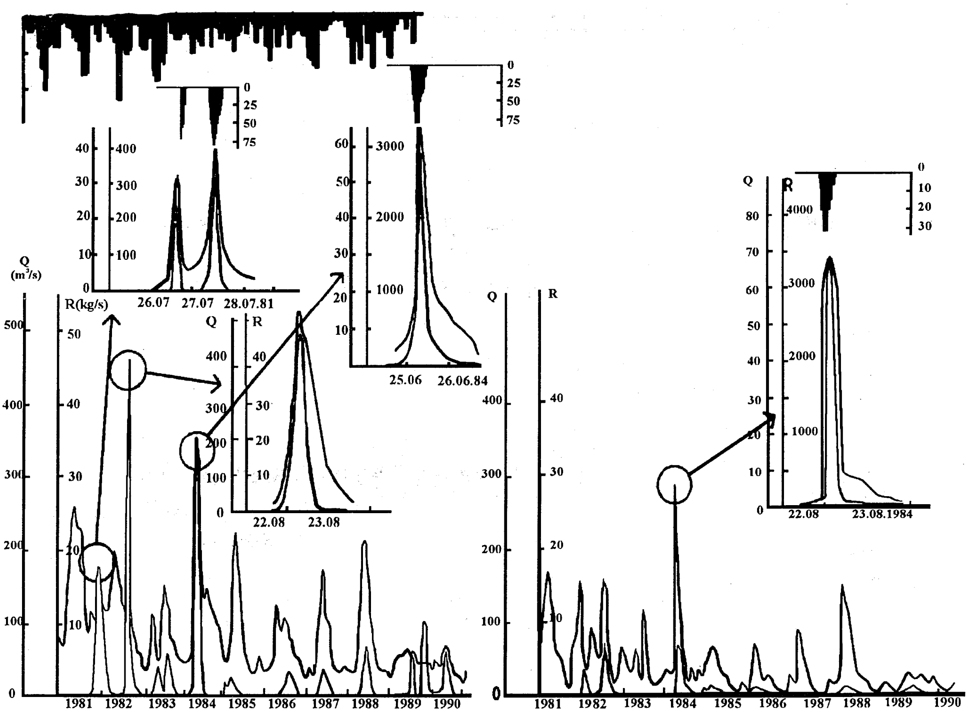


Fig. 10 Flow chart for detachment-transport-deposition computation.

erosion to the incoming sediment load from the next upslope segment. If this potential sediment load exceeds the transport capacity of the segment, deposition occurs within the segment. If deposition occurs, no rill erosion is permitted. If transport capacity exceeds this sediment load, two other possibilities exist. The first is that rill erosion can occur at its capacity rate and still give a total sediment load less than the transport capacity. The second possibility is that rill erosion occurs at its capacity rate, but the total sediment load at the end of the segment exceeds the transport capacity. In this situation, the rill erosion is limited to that which would just match the transport capacity. This concept is more realistic than assuming that rill erosion occurs at its capacity rate even when deposition occurs. To allow simultaneous rill erosion and deposition is a conceptual inconsistency for erosion and transport over cohesive agricultural soils.

The capacity of the overland flow to transport sediment is estimated using the Yalin bed load sediment transport equation. A constant is added to the equation to account for both bed load and suspended load. This is best determined by calibration of the model, or derived from experiments. The Yalin equation is modified to also consider particle mixtures. If the sediment load of each particle type exceeds the transport capacity, it is distributed among the particle types based on the transportability of the particles. If the sediment load of a particular type is less than the transport capacity for that type, its excess transport capacity is shifted to particles having a transport capacity deficit. When deposition occurs, the rate of deposition is assumed to be directly proportional to the difference between the transport capacity and the sediment load. The proportionality constant is assumed to be directly proportional to the fall velocity of the particle divided by the product of the flow velocity and flow depth. This gives an exponential decay for the rate of deposition as a function of distance. Any deposited particles are assumed to become reattached



(a) The flow (Q) and load ® hydrographs during 10 years simulation of the regime without antierosional structures

(b) The flow (Q) and load hydrographs during 10 years simulation of the regime with antropogenic influence

Fig. 11 A comparison of simulated flow and load hydrographs for a 10 year period without (a) and with (b) anti-erosion measures.

immediately to the soil mass, i.e. deposited particles are unavailable for subsequent transport without being redetached.

The input to the channel is a uniform lateral inflow of runoff and sediment from an overland flow or another channel element. The characteristic discharge is used to compute detachment, sediment transport, deposition and sediment concentration in the channel elements. Outlet conditions for the channel are assumed to be controlled by a downstream uniform flow, critical depth or a structure having a known rating curve. Subcritical flow is assumed, unless the option that the slope of the energy gradeline (friction slope) equals the channel slope is specified. The concepts used for detachment and transport in the channel are exactly the same as those for overland flow, except that channel erosion does not occur throughout the duration of a storm. Detachment occurs only when the shear stress exceeds critical shear stress. This time is estimated by assuming that the shear stress is linearly distributed in time. The detachment is assumed to occur at a rate based on the characteristic discharge for the period that shear stress exceeds the critical shear stress. Using the available gauged data for three years (Drãgoi *et al.*, 1993), the model was calibrated (for overland flow - soil erodibility and Manning *n* and for the channel - soil erodibility, critical shear stress and Manning n). The simulation results for long term (10 years) natural flow (without anti-erosional structures in the basin) (a) and with anthropogenic influence (b) are presented in Fig. 11.

Great differences between peak discharges and loads during floods can be seen in Fig. 11, with a more uniform regime after the building of the anti-erosional structures.

The structures built employed the drainage techniques in the case of slopes affected by increased land sliding. The increased penetration of precipitation inputs to the soil, cause a reduction in surface runoff intensity and implicitly a reduction in transported sediment.

CONCLUSION

The proposed model together with the Integral Terrain Unit Mapping is a powerful instrument in predicting anthropogenic impacts on runoff as well as on sediment transport in a basin. This could be an advantage in deciding the best policy in water and land management.

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