GRID-BASED SOIL LOSS MODELLING USING A GEOGRAPHIC INFORMATION SYSTEM

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Introduction

Soil erosion is one of the major environmental impacts of sugarcane agriculture. Loss of topsoil and associated reduction in crop production potential, together with the decrease in storage capacity of reservoirs and sediment deposits in reservoirs, wetlands and estuaries, remain major problems facing agricultural and water resource authorities (Schulze and Lorentz, 1995).

There is no simple procedure for estimating soil erosion potential in a catchment, but simple empirical methods do, however, meet most of the requirements for initial planning and design, and in the absence of gauged data form a suitable basis for water resources and soil conservation decisions (Schulze and Lorentz, 1995). The Universal Soil Loss Equation (USLE) is a widely used estimator of long term average annual soil loss. Much local research has been carried out on components of the equation, making its application relevant to local conditions (Mander *et al.*, 1993), and for this reason it was deemed a suitable model for use in this exercise. The Geographic Information System (GIS) approach entails dividing the catchment into thousands of cells, making the application of field scale models, such as the USLE, a practical option. The cells in each theme (e.g. slope or soil erodibility) can then be treated as variables in algebraic calculation.

Using the USLE in a GIS environment also enables the production of a catchment map classified according to predicted erosion potential. Other GIS maps such as roads and farm boundaries can then be overlaid on the catchment classification and supplied to field workers to carry out further investigation where necessary.

Keywords: soil loss model, GIS, grid-based model

Aims and Objectives

The primary objectives of this exercise were to:

- develop techniques using GIS technology to assess potential soil erosion within a specific river catchment
- demonstrate the capabilities and usefulness of the GIS in such an exercise
- evaluate potential data sources and the available data for such projects
- classify and map potential soil erosion in the catchment using the USLE
- discuss the wider role of the technology in catchment management, conservation planning and environment auditing.

Environmental setting of the Mgwahumbe catchment study area

Location

The catchment area under study covers approximately 20 000 hectares, lying between latitudes 29°52′S and 30°03′S and longitudes 30°25′E and 30°38′E. The altitudes in the catchment range from 1 037 m near its source to 240 m at the point where it flows into the Illovo river.

Climate

The mean annual rainfall of the catchment is 861 mm, with most rain falling between November and March.

Soils

Soils data for the catchment were based on land type maps from the Institute for Soil Climate and Water (ISCW). These indicate mapped soil associations, with the percentages of each soil form within that unit in an associated memoir. Dominant soil types within this catchment were Cartref, Glenrosa and Hutton.

Vegetation

The catchment is predominantly under sugarcane and timber plantations, with some indigenous bush and veld along the lower reaches of the river.

Slope

The catchment is in general steep, with most slopes falling between 10 and 30%.

Method

The equation used to compute soil loss was the USLE, as below:

$$A = R\ K\ LS\ C\ P$$

where

A = the computed long term average soil loss per unit area (t/ha/annum)
R = an index of rainfall erosivity (MJ.mm/ha/h/annum)
K = soil erodibilty factor (t.ha/MJ/mm)
LS = slope length and gradient factor (dimensionless)
C = cover and management factor (dimensionless)
P = support practice factor (dimensionless).

Rainfall erosivity factor (R)

The rainfall erosivity factor is a measure of the erosivity of rainfall events due to the kinetic energy created by the intensity of the rainfall at the surface and the duration of this intensity. The values for this factor were obtained using a simple relationship between altitude and rainfall erosivity for the study area, determined by a local researcher ([1]personal communication).

Soil erodibilty factor (K)

The soil erodibility factor is a quantitative description of the inherent erodibility of a particular soil. The only readily available soils data for the catchment were the Land Type data prepared by the ISCW in 1993. Areas with a high degree of uniformity with respect to terrain, soil pattern and climate are grouped in mapping units, with an accompanying memoir which gives a breakdown of the estimated relative proportions of soil series within each mapping unit.

The ISCW map was digitised and processed into the GIS and converted to a grid. Estimates of soil erodibility were obtained from the Agricultural Catchments Research Unit (ACRU) user manual (Schulze, 1995), allowing a weighted average K-factor to be predicted for each mapping unit (see Table 1) and applied to the GIS grids. A map of soil erodibility classes was then produced by classifying the erodibility ratings of the mapping units from very low to very high, based on tables in the ACRU manual (Schulze, 1995).

Slope length and gradient factor (LS)

The effects of slope length and gradient are represented in the USLE as L and S respectively, but are often evaluated as a single topographic factor, LS. Slope length is defined as the distance from point of origin of overland flow to the point where slope decreases sufficiently for deposition to occur (McCloy, 1995). The data source for slope were the 1:10 000 series orthophotos of the region. The contours were digitised and slope gradients were calculated for the catchment using digital terrain modelling routines in the GIS. The modelled surface was then converted to a grid, such that each cell in the grid had a specific gradient.

Slope length was estimated from the gradient (Schulze, 1979) by applying various equations and relationships to each cell in the grid. These equations were applied step-wise to the GIS grids, using cartographic algebra.

Cover and management factor (C)

The cropping cover and management factor represents the ratio of soil loss from specific cover conditions to the soil loss from a tilled, bare fallow condition for the same soil, slope and rainfall (McCloy, 1995). This is difficult to estimate and, because it may vary during a year, the factor chosen needs to account for 'average' conditions. Land use data were obtained from satellite data which were imported and analysed in the GIS. C-factors were estimated from curve numbers as given in the ACRU manual and applied to the various predefined land cover classes.

Support practice factor (P)

The support practice factor is defined as the ratio of soil loss with a specific support practice, to the corresponding loss with up- and downslope culture (McCloy, 1995). For uncultivated lands the P-factor was assumed equal to unity. For the cultivated lands, namely those areas demarcated as sugarcane, general agriculture and plantations, the P-factor was taken from tables by Wischmeier and Smith, 1978. The assumption was made that the cane areas have contour banks with grassed waterways.

Results and Discussion

Through manipulation of the above five factors using map algebraic functions, a map was produced showing the potential average annual soil loss spatially distributed over the catchment. The GIS calculated the average expected soil loss to be 6,6 t/ha/annum with a range of zero to over 65 t/ha/annum. This does not equate to the amount of sediment transported out of the catchment, but is an indication of soil erosion potential at a chosen point. The USLE was designed to estimate soil loss from rill and inter-rill erosion (McCloy, 1995) and does not take into account factors such as stream bank and gully erosion.

Apart from allowing visualisation of the data, the particular strengths of GIS in this type of work are:

- the ability to integrate and analyse data from disparate sources
- the allocation of data to small grids, rather than averaging catchment conditions, which gives the ability to classify and display the distribution of the sensitive areas geographically and then overlay relevant data such as farm boundaries
- further analysis can be carried out easily, e.g. average expected soil loss for a particular farm or soil type, or a particular land cover class, can readily be determined.

One of the objectives of the project was to determine the availability of the various data sets needed. With the exception of the soils and land cover data, the base data were readily available - usually in an analogue format, thus requiring some digitising. The satellite derived land cover data (from the Russian satellite, Sojuzkarta) was sourced from a GIS data company which is no longer in operation. This data, however, is in the public domain, and may possibly be obtained elsewhere in future projects. Similar data is being processed by the CSIR from Landsat TM.

Soils data were obtained from the ISCW Land Type data in the form of paper maps and an accompanying memoir. The data were derived from 1:250 000 mapping and could thus be considered too coarse for this type of project. The erodibility factors derived from the data seemed to reflect what could be expected on slopes such as those in the study area, and for the

[1]Lorentz, Dept of Agricultural Engineering, University of Natal, Pietermaritzburg (1996)

purposes of this exercise appeared to be adequate. Future data from the ISCW for certain areas could be obtained in digital form and, short of undertaking a field survey, would appear to be the best available option - particularly for areas not fully covered by the SASEX parent material maps.

GIS is being used more routinely in integrated catchment management, and the USLE model used in this exercise could be included in others to demarcate areas of high soil erosion potential.

Conclusion

GIS has proved a natural tool for soil loss modelling exercises of this nature and is being used in similar work by a number of organisations here and abroad. The USLE was not devised for use with grid-based modelling applications and, although it intuitively appears suited to the task, a number of researchers are working on revising the equation to perform more accurately in the GIS environment. Should the revisions prove more suitable, they will be evaluated and applied to future SASEX GIS projects of this nature.

REFERENCES

Mander, JJ, Quinn, NW and Mander, M (1993). *Umhlali River Catchment: Rehabilitation Pilot Project.* Institute of Natural Resources, University of Natal, Pietermaritzburg.

McCloy, KR (1995). *Resource Management Information Systems: Process and Practice.* Taylor and Francis Ltd, London. 415 pp.

Schulze, RE (1979). *Hydrology and Water Resources of the Drakensburg.* Natal Town and Regional Planning Commission, Pietermaritzburg. 179 pp.

Schulze, RE (1995). *Hydrology and Agrohydrology: a text to accompany the ACRU 3.00 agrohydrological modelling system.* Department of Agricultural Engineering, University of Natal, Pietermaritzburg.

Schulze, RE and Lorentz, SA (1995). Chapter 16 of *Hydrology and Agrohydrology*, Department of Agricultural Engineering, University of Natal, Pietermaritzburg.

Wischmeier, WH and Smith, DD (1978). *Predicting Rainfall Erosion Losses - a guide to conservation planning.* USDA Agricultural Handbook, Washington DC. 537 pp.