CHAPTER 12

Erosion modelling

By:
A.M. van Lieshout
Department of Earth Resources Surveys,
International Institute for Aerospace Survey and Earth Sciences (ITC),
P.O. Box 6, 7500 AA Enschede, The Netherlands.
Tel: +31 53 4874306, Fax: +31 53 4874336, e-mail: LIESHOUT@ITC.NL

Summary

For a small catchment of 908 hectares in the North-western part of Iran the *Silsoe* model (Morgan *et al*., 1982) is used to calculate the sediment yield (g/m^2. year) from slopes. In the model the erosion process is separated in a detachment and transport component. Erosion from the fields can be either *transport* or *detachment* limited. A detachment map of the area, depending on e.g. rainfall, soil and vegetation cover has to be compared to the transport map which is a function of cover, overland flow and slope. In the case study data layers have to be prepared for several input parameters in the model. The TMU approach has been used to map various physiographic units. The units have to be linked to an attribute table with soil and vegetation parameters.

Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory d:\appguide\chap12. If you have already installed the data on your hard-disk, you should start up ILWIS and change to the subdirectory where the data files for this chapter are stored, c:\ilwis21\data\appguide\chap12. If you did not install the data for this case study yet, please run the ILWIS installation program (see ILWIS Installation Guide).

☞

- Double-click the ILWIS program icon in the ILWIS program group.
- Change the working drive and the working directory until you are in the directory c:\ilwis21\data\appguide\chap12.

Now you are ready to start the exercises of this case study.

12.1 The catchment

Description

The catchment is located south of Zanjan city in the north-western part of Iran. Despite the relatively small size of the catchment of 908 hectares, there are nine different lithologies. The altitude ranges from 1800 to 2300 m a.s.l. The average annual rainfall of 211 mm precipitates mainly in the months of April to May and during October to November.

In winter there is a snow cover. The geomorphology consists essentially of denudational and structural hills, with glacis which is now under dissection in the upper part of the catchment valley. In the downstream part of the catchment the glacis are small or absent because of the new cycle of erosion, which has led to the formation of active gullies. The incision causes a high sediment delivery ratio in most of the subcatchments. Fresh deposition was observed only at few places along the contact of the steep slopes and the glacis, south and southwest of the village.

The soils are related to the lithology. Generally their texture vary from sandy loam to sandy clay or clay. Depth and topsoil conditions are highly variable, while on some of the steeper slopes little erosion takes place because of either high infiltration or stony pavement. The land cover consists mainly of strongly grazed range land vegetation consisting of herbs, low shrub and grassland, with different canopy densities. On the moderately to fairly steeply sloping lands the old agricultural fields have been abandoned. Wheat is grown chiefly on the glacis.

Remote sensing

Stereo aerial photographs have been used to interpret physiographic units and map the gullies. Thematic mapper imagery has been used for supervised classification of the land use in conjunction with the aerial photographs. A Normalized Difference Vegetation Index (NDVI) image has been used for estimating the vegetation density.

The attributes of soil and vegetation have been stored in a data base in order to obtain the parameters required for the modelling, by means of table operations.

12.2 The SILSOE model

In this study, the detachment erosion is compared with the transport capacity of the overland flow (Morgan *et al*., 1982). The attractiveness of the method is, besides its simplicity, the recognition that erosion can be either transport- or detachment-limited.

Detachment

The rainfall detachment (D) is a function of the annual kinetic energy (KE), the soil detachability index (Kd) and the percentage rainfall interception (INT). The annual kinetic energy can be calculated from autographic rain gauge charts using equations or alternatively estimated from the rainfall data using locally derived empirical equations. The soil detachability index needs local adjustments, but values based on texture suggested in the description may be adopted. For the interception by the low vegetation, estimates may be made using values in the literature as a reference.

The algorithm in equation 12.1 is derived.

$$D = (Kd) * \{KE * e^{(-a*INT)}\}^{b} \quad (\text{g/m}^2) \qquad [12.1]$$

where,

$$KE = R * (11.9 + 8.7 * \log_{10} I) \quad (\text{J/m}^2) \qquad [12.2]$$

Kd = Soil detachability index.

INT = Interception (%).

I = Rainfall intensity (mm/h).

a,b are constants.

Transport

The transport capacity (T) in the model is a function of the cover factor, the volume of overland flow and the slope (S). The volume of overland flow (Q) is determined from the annual rainfall (R), the ratio between the soil moisture storage and the annual rainfall divided by the number of rainy days per year (n). The soil moisture storage (Rc) is given by the moisture content at field capacity (Ms), the bulk density (Bd) of the top soil, the top soil rooting depth (Rd), and the ratio of the actual (Ea) to potential evapotranspiration (Ep). The crop factor (C) has been determined from the subfactors canopy cover, basal cover and stoniness and by considering the cropping calendar and the dynamics of the vegetation of the pasture lands. Stoniness and sealing of the soil can be included in the parametrization.

The algorithm in equation 12.3 is derived.

$$T := C * Q^2 * \sin(S) \quad (\text{g/m2}) \qquad [12.3]$$

where,

S = Slope (radians).

C = Crop factor (0-1).

$$Q = R * e^{-Rc/Ro} \quad \text{(mm)} \qquad [12.4]$$

where,

R = Mean annual rainfall (mm).

$$Rc = 1000 * Rd * Ms * Bd * \left(Ea/Ep\right)^{0.5} \quad \text{(mm)} \qquad [12.5]$$

where,

Rd = Rooting depth (m).

Ms = Moisture content at field capacity (w/w).

Bd = Bulkdensity of topsoil layer (g/cm^3).

Ea/Ep = ratio of actual to potential evapotranspiration.

$$Ro = R/n \quad \text{(mm)} \qquad [12.6]$$

where,

n = Number of rain days.

Use of GIS

Most data needed in the *Silsoe* model is related to physiographic units and land use. For each location in the catchment represented by a pixel, the detachment and transport capacity can be calculated using a raster-based GIS. Data layers such as terrain mapping units have to be digitized; units are then linked to an attribute table containing specific physiographic data for each unit. From the digitized contourlines the DEM and the slope (needed in the transport component) are calculated. All map layers are made available in a GIS; detachment and transport capacities for each pixel are calculated using MapCalculation. The smallest value of the two is taken as the modelled erosion rate.

12.3 GIS procedures

The detachment and the transport map have to be calculated separately. After that their values have to be compared to come to the final erosion rate map. All data required for the exercise are available in the form of maps or tables.

Data available

The following maps are available:

`Tmu` Raster map with table `TMU`.

`Mask` Raster map with delineation of catchment.

`Contour` Vector map with contourlines.

`Stream` Drainage system.

For the study area the following values have been derived from field survey, hydrological data records or values taken from literature:

a = 0.05 and b = 1.

Number of raindays = 45 days.

Rainfall = 367 mm.

Kinetic energy of rainfall = 4623 J/sq. meter.

Interception assume 10%.

Ea/Ep assume 0.25.

Rooting depth = 0.15 m.

The following soil data was obtained from field/laboratory measurements:

Soil	Code	Soil moisture	Bulk density	Detachment factor
Clay	C	0.45	1.1	0.02
Clay loam	CL	0.40	1.3	0.4
Silty clay	SiC	0.30	1.2	0.3
Sandy clay	SC	0.25	1.2	0.35
Sandy clay loam	SCL	0.28	1.2	0.3
Silty clay loam	SiCL	0.25	1.3	0.3
Loam	L	0.20	1.3	0.35
Fine sand	FS	0.15	1.4	0.2
Sand	S	0.08	1.5	0.7

Detachment map

☞

- Calculate the detachment map. Use the parameters which are given above.
- Display the detachment map, check the result using the pixel information option.

Transport map

☞

- Calculate the transport map. Use the parameters which are given above. Most of the calculation can be done on the table `Tmu`.
- Display the transport map, check the result using the pixel information option.

! To obtain the soil parameters of each terrain mapping unit the table `Tmu` has to be linked to the table `Soil`!

Final result

If both maps are correct the final map can be calculated. The erosion is either detachment limited or transport limited. The minimum value of both maps has to be selected.

☞

- Compare the transport with the detachment map and select for each pixel in the catchment the smallest one to obtain the final erosion map.
- Use the histogram equalization method to reclassify the final map in 5 equal classes.

12.4 Discussion of results and conclusions

Actual erosion rates have been measured at seven places in the form of accumulation behind some water retention structures. They vary from 8 to 400 tons/km^2/y. On the whole, the results of the approach by Morgan work reasonably well, with the exception of one observation. The attributes of the terrain mapping units have also been used for the determination of the spatial model parameters, and this is reflected in the patterns of the resulting maps. Hence they are not independent.

The results of the approach by Morgan *et al.* (1982) has a good similarity with the field survey' map, except in the units north-west of the village (in the center of the catchment). The advantage of the former approach is that the erosion assessment uses functions to arrive at quantitative estimates, but the functions for erosion by overland flow on fields should be tested for their use in small catchments.

The flow component in the model is not very realistic since there is no transfer of flow downslope (to other pixels). The incorporation of the flow accumulation downslope will result in a more realistic approach in terms of the effects of the depth and velocity of flow on the erosion. A geoinformatic system is a good platform for incorporating the flow accumulation component in the *Silsoe* model.

References

Meijerink, A.M.J., de Brouwer, H.A.M., Mannaerts, C.M and Valenzuela, C. (1994). *Introduction to the use of geographic information systems for practical hydrology*. UNESCO, Div. of Water Sciences. ITC Publ. no.23, 243 pp.

Meijerink, A.M.J. (1988a). Data acquisition and data capture through terrain mapping units. *ITC Journal* 1988-1, 23-43

Meijerink, A.M.J. (1988b). Modelling in the land and water domain with a versatile GIS, ILWIS; experiences from a large tropical catchment. In: J. Bouma and A.K. Bregt (eds.), *Land qualities in space and time*. Proc. Symp. Int. Soc. of Soil Science, Wangeningen. The Netherlands, pp. 73-87.

Morgan, R.P.C., Hatch, T and Wan Suleiman, Wan Harun. (1982). A simple procedure for assessing soil erosion risk; a case study for Malaysia. *Zeitschrift fur Geomorph.* N.F. Suppl-Bd. 44: 69-89.