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INTEGRATION OF GIS AND UNIVERSAL SOIL LOSS EQUATION (USLE) FOR SOIL LOSS ESTIMATION IN A HIMALAYAN WATERSHED

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Abstract

In order to assess soil erosion at watershed scale Universal Soil Loss Equation (USLE) erosion model has been used on IEL7 watershed of Lidder Catchment in Himalayan Region. Erosion calculation requires huge amount of information and data, usually coming from different sources and available in different formats and scales. Therefore GIS was used, which helped considerably in organizing the spatial data representing the effects of each factor affecting soil erosion. The factors that most influence soil erosion are linked to topography, vegetation type, soil properties and land use/cover. Average annual soil losses were calculated by multiplying five factors: R; the erosivity factor, K; the soil erodibility factor; LS, the topographic factor; C, the crop management factor and P; the conservation support practice. The annual soil loss predictions range between 0 and 61tons ha^{-1}. Average soil loss was highest (26 tons ha^{-1} year^{-1}) in agriculture area and lowest soil loss rate was found in forest area (0.99 tons ha^{-1} year^{-1}). For horticulture and plantation the soil loss rates were 1.47 and 5.39 tons ha^{-1} year^{-1} respectively. For pasture, fallow and scrub the soil loss rates were 25.47, 28.39 and 35.76 tons ha^{-1} year^{-1} respectively.

Keywords: Estimation, GIS, Loss, Soil, USLE, Watershed

Introduction

Universal Soil Loss Equation (USLE) is the most popular empirically based model used globally for erosion prediction and control (Laflen, 2002; Kesley, 2002). Scientifically, the main attributor to land degradation is soil erosion by runoff water (Angima et al., 2003). Of the world's land degradation problems, soil erosion is the first order category (Hitzhusen, 1993). Soil erosion by water is a major problem in mountainous areas with steep slopes. Inappropriate land use in these areas is likely to accelerate water erosion entailing soil loss and land fertility decline (Hurni et al., 1996; Liniger and Thomas, 1998). Suspension from the eroded material damages the water quality in downstream areas and its subsequent sedimentation decreases the carrying capacity of water bodies. Therefore, controlling erosion is crucial to sustain agricultural yields and to reduce environmental damage. Spatial and quantitative information on soil erosion on a regional scale contributes to conservation planning, erosion control and management of the environment. Identification of erosion prone areas and quantitative estimation of soil loss rates with sufficient accuracy are of extreme importance for designing and implementing appropriate erosion control or soil and water conservation practices (Shi et al., 2004). Equally, erosion and sedimentation research and a proper understanding of the physical processes are important in order to enhance understanding of landform development across temporal and spatial scales (Slattery et al., 2002; Wainwright et al., 2003). Remote sensing and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage. For this reason use of these techniques have been widely adopted and currently there are several studies that show the potential of remote sensing techniques integrated with GIS in soil erosion mapping (Pilesjo, 1992; Metternicht and Fermont, 1998).

Study area location

IEL 7 watershed, located in lower Himalayas, India, is a mountainous watershed with steep slopes and complex relief (Figure 1). The selected watershed (IEL 7) occupies an area of 113 km^{-2}, and about half of the study area consists of high mountains with elevations more than 3500 m. The elevation ranges from 1663 m to 4,226 m above mean sea level.

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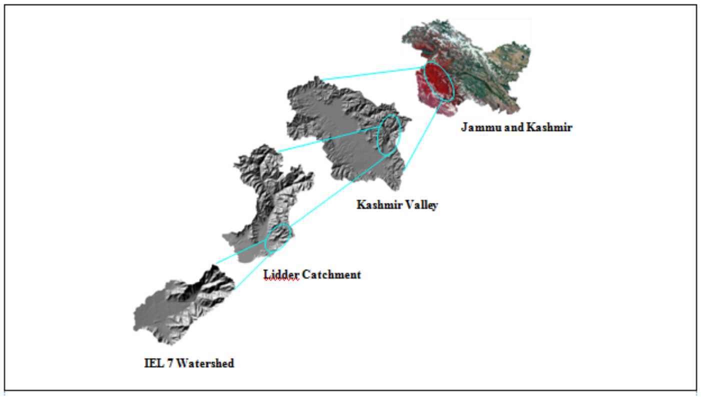
Fig. 1: Study area location



Materials and Methods

In this study, the data and methods for determining the each input parameters for the USLE is discussed as follows:

The USLE (Equation 1) is the product of several factors: rainfall and runoff (R), soil erodibility (K), slope (LS), Vegetation cover (C) and finally the management practices (P). The output is the annual soil loss per unit area (A)

$$A = R * K * LS * C * P \qquad \text{Eq. (I)}$$

where

A = The mean annual soil loss (in ton.ha^{-1}.yr^{-1})

R = Rainfall and Runoff Erosivity Index (in MJ/ha/mm/yr)

K = Soil Erodibility Factor (in ton/MJ/mm)

LS = Slope and Length of Slope Factor

C = Cropping – Management Factor

P = Erosion Control Factor Practice

Rainfall and runoff erosivity factor (R)

R is the long term annual average of the product of event rainfall kinetic energy in MJ ha^1 and the maximum rainfall intensity in 30 minutes in mm per hour (Wischmeier and Smith 1978; Renard and Freidmund 1994).

The rainfall distribution is not homogeneous all over the study area, for this reason an interpolation of annual precipitation data was applied to have a more representative rainfall distribution. Once the interpolation is performed a map representing annual rainfall in the region is obtained. This map was the input source (P_a) for the R factor calculation using the Reinard and Freimud (1994) equations for Pa > 850 mm:

$$R = 587.8 – 1.249P_a + 0.004105P_a^2 \qquad \text{Eq. (II)}$$

Soil erodibility factor (K)

Soil erodibility (K) represents the susceptibility of soil or surface material to erosion, transportability of the sediment, and the amount and rate of runoff given a particular rainfall input, as measured under a standard condition. The standard condition is the unit plot, 72.6ft long with a 9 percent gradient, maintained in continuous fallow, tilled up and down the hillslope (Weesies, 1998). K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. Soil erodibility factors (K) are best obtained from direct measurements on natural runoff plots. Rainfall simulation studies are less accurate, and predictive relationships are the least accurate (Romkens 1985). For satisfactory direct measurement of soil erodibility, erosion from field plots needs to be studied for periods generally well in excess of 5 years (Loch et al., 1998). Therefore, considerable attention has been paid to estimating soil erodibility from soil attributes such as particle size distribution, organic matter content and density of eroded soil (Wischmeier et al., 1971).

Soil classification of the study area is divided into 7 types of soil with varying soil characteristics. In this study, Soil erodibility (K) of the study area can be defined using the relationship between soil texture class and organic matter content proposed by Schwab et al. (1981). The organic matter content is assumed to be 0.5% because there is no organic matter content survey data in the study area. Table 1 presents the soil erodibility factor (K) based on the soil texture class by Schwab et al. (1981).

Table 1: Soil erodibilty factor (K) (Schwab et al., 1981)

Textural Class	Organic Matter Content (%)	
	0.5	2
Fine sand	0.16	0.14
Very fine sand	0.42	0.36
Loamy sand	0.12	0.10
Loamy very fine sand	0.44	0.38
Sandy loam	0.27	0.24
Very fine sandy loam	0.47	0.41
Silt loam	0.48	0.42
Clay Loam	0.28	0.25
Silt clay loam	0.37	0.32
Silt Clay	0.25	0.23

Topographic factor (LS)

The topographic (LS) factor grid for USLE was created according to the RUSLE model since the equations used in the calculation of the RUSLE's, LS factor, takes rill erosion into account. The topographic factor consists of two sub-factors: a slope gradient factor and a slope length factor; both of which are determined from the Digital Elevation Model (DEM). According to the SEAGIS User Guide (1999) two methods exist for deriving the slope length factor from the DEM. It can be either calculated as the horizontal length of each cell or it can be measured from each high point in eight flow directions. The boundaries of slopes are determined according to a user specified cut-off value. The cut off value in this study was specified at 50% to give an accurate representation of the possible deposition occurring after initial downslope erosion in the watershed.

The input requirement for the creation of the topographic grid is a filled DEM. Filling a DEM can be described as identifying any sinks or cells that have a lower elevation value than the surrounding cells and giving them a higher elevation value (Jennings, 2001). When the sinks are filled the area is given an average value, which is calculated using the value of the neighbouring cells (Jennings, 2001). Using the equations shown below, the slope gradient and slope length factors were calculated from the DEM and combined to result in the topographical factor grid.

Slope length factor

$$L = (x/22.13)^m, \qquad \text{Eq. (III)}$$

where

L = slope length factor

X = length of slope (in m)

$m = \beta/(1+\beta)$, where β is the ratio of rill erosion to interrill erosion.

Values for β can be computed from:

$\beta = (\sin\theta/0.0896)/[3.0(\sin\theta)^{0.8} + 0.56]$, where θ = slope angle

Slope gradient factor

For slopes shorter than 15 feet (4.5 m)

$$S = 3.0(\sin\theta)^{0.8} + 0.56 \qquad \text{Eq. (IV)}$$

where

S = slope gradient factor

otherwise:

$S = 10.8\sin\theta + 0.03$, slopes steepness < 9 %

$S = 16.88\sin\theta + 0.03$, slopes steepness > 9 %

Cropping – management factor (C)

The crop management factor was calculated mainly from literature review, since there was not local data available regarding this factor. Based on the land use/cover classified image of IEL 7 watershed, similar ecosystems were searched on different bibliographical sources and therefore assigned to the ones existing in study area. The search was orientated to those areas with similar geographical settings. C factor ranges from 1 to approximately 0, where higher values indicate no cover effect and soil loss comparable to that from a tilled bare fallow, while lower C means a very strong cover effect resulting in no erosion (Erencin, 2000).

Support practice factor (P)

Support practice factor indicates the rate of soil loss according to the various cultivated lands on the earth. There are contour, cropping and terrace as its methods and it is important factor that can control the erosion. Table 2 shows the value of support practice factor according to the cultivating methods and slope (Shin, 1999). P values range from 0 to 1, whereby the value 0 represents a very good manmade erosion resistance facility and the value 1 no manmade resistance erosion facility. In the study area there were some agricultural support practices, such as contour farmland and terraced farmland.

Table 2: Support practice factor according to the types of cultivation and slope

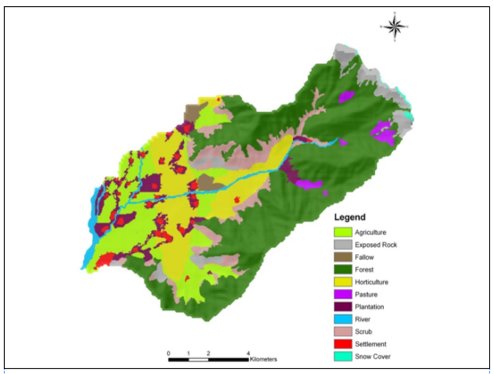
Slope (%)	Contouring	Strip Cropping	Terracing
0.0 - 7.0	0.55	0.27	0.10
7.0 - 11.3	0.60	0.30	0.12
11.3 – 17.6	0.80	0.40	0.16
17.6 – 26.8	0.90	0.45	0.18
26.8 >	1.00	0.50	0.20

However, most of the farmlands in the study area were small and consisted of self-managed lands. Since the spatial resolution of the Cartosat-1 imagery was 2.5 m, it was possible to distinguish the separate practices in the watershed from the available data.

Land use/land cover analysis

Land use/land cover classification of the Cartosat-1 dated 13th December 2005 data was done by on screen digitization in Arc GIS 9.2. The land use/land cover map was classified in eleven classes including forest, agriculture, horticulture, settlement, scrub, pasture, fallow, plantation, river, snow cover and exposed rock with total areas 113 km^{-2} (Figure 2).

Figure 2: Land use/land cover map of IEL 7 watershed



The distribution of the land use types is presented in Table 3. According to the classification results, forests have the largest area coverage 46.05%. Agriculture and horticulture having area coverage 14.79% and 12.71% respectively

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Table 3: Distribution of the land use/land cover classes of IEL 7 watershed

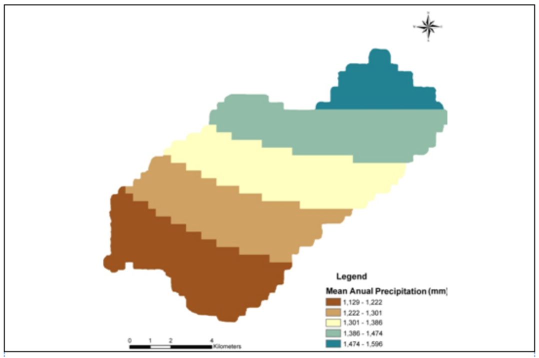
Land use/land cover class	Area (km^{-2})	Area (%)
1 Exposed Rock	5.65	5.00
2 Settlement	2.19	1.94
3 Horticulture	14.37	12.71
4 Agriculture	16.71	14.79
5 Fallow	1.46	1.29
6 Forest	52.04	46.05
7 Snow cover	0.26	0.23
8 Scrub	8.94	7.91
9 Pasture	1.71	1.52
10 River	2.84	2.51
11 Plantation	6.79	6.01
Total	113.00	100.00

Results and Discussion

R-factor

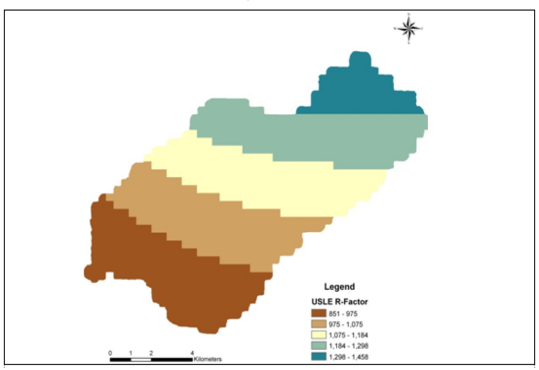
The precipitation data from 2 surrounding meteorological stations were used for estimating the average annual precipitation (AAP) Figure 3, over the entire watershed.

Figure 3: Mean annual precipitation



The estimated AAP was used for calculation of the rainfall and the runoff erosivity R-factor in ArcGIS. The R-factor (Figure 4) varied from 851 to 1458 MJ mm $ha^{-1}h^{-1}$ yr^{-1}.

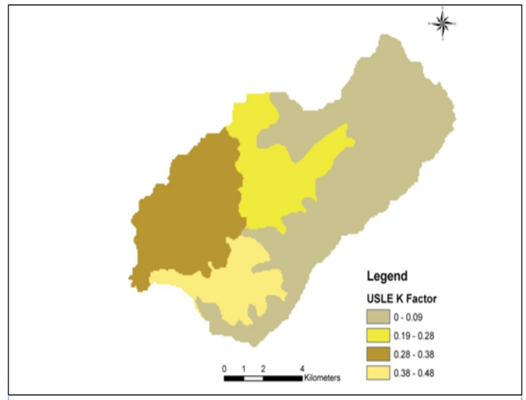
Figure 4: R-factor map following Reinard and Freimud (1994) equation



K-factor

The soil erodibility factor (K factor) is a quantitative description of the inherent erodibility of a particular soil type. The K factor reflects the fact that different soils erode at different rates when the other factors that affect erosion remain the same. Soil texture is the principal cause affecting the K-factor, but the soil structure, organic matter content, and permeability also contribute. A map for the K-factor was produced based on the soil map and soil erodibility texture. The K-factor (Figure 5) in the present study area varied between 0.09 and 0.48 Mg h $MJ^{-1}mm^{-1}$.

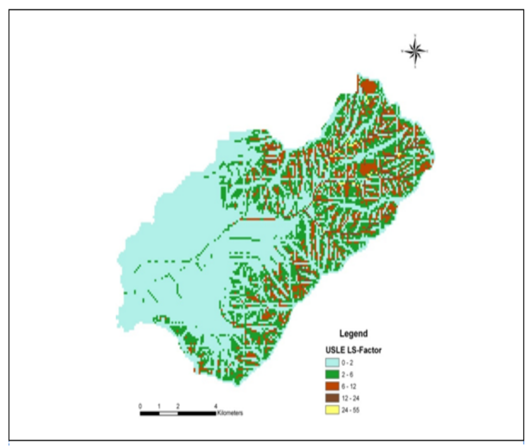
Figure 5: K-factor map indicating the degree of erosion risk according to the susceptibility of soil to erosion (based on the soil texture class by Schwab et al. 1981)



LS-factor

The factors of slope length (L) and slope steepness (S) are combined in a single topographic index termed LS factor. Many researchers have used these two L and S factor as combined LS factor. The LS-factor (Figure 6) in the present study area varied between 0 and 55.

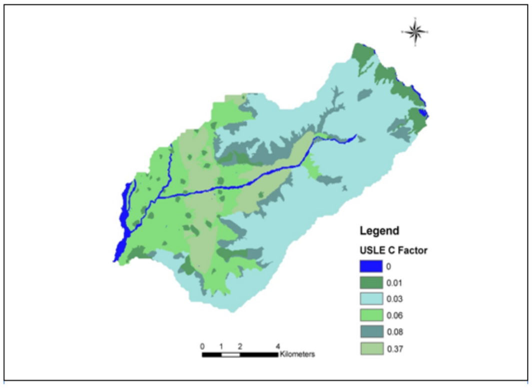
Figure 6: LS-factor map indicating the degree of erosion risk according to the cumulative slope length derived from DEM



C-factor

The ratio of soil loss under given crop to that from bare soil is represented as crop management factor (C). In order to determine C factor, IEL 7 watershed was classified into 11 land uses/land cover classes generated from Cartosat-1 13th December 2005 data. The C-factor (Figure 7) in the present study area varied between 0 and 0.37.

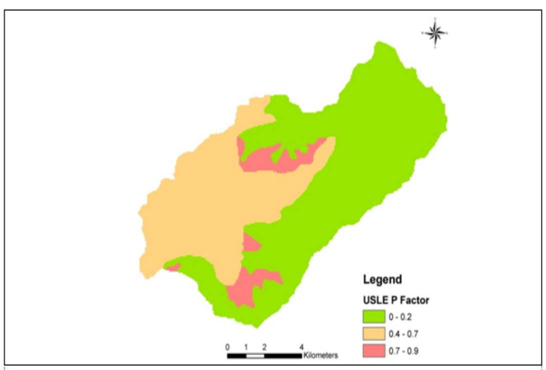
Figure 7: C-factor map indicating the degree of erosion risk according to the level of protection of a soil type under a certain land use/cover category



P-factor

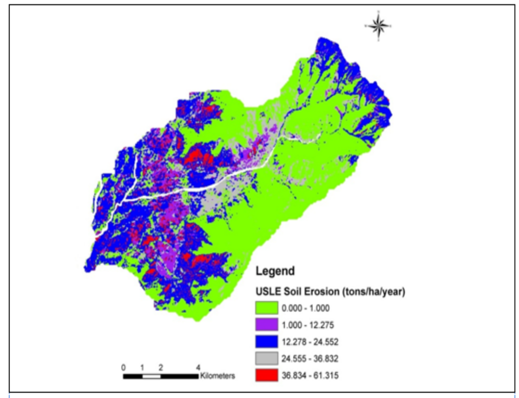
The P-factor is a ratio between erosion occurring in a field treated with conservation measures and another reference plot without treatment. Therefore, erosion control practice factor is based on the soil conservation practices operated in a particular area. The P-factor (Figure 8) in the present study area varied between 0 and 0.9.

Figure 8: P-factor map indicating the level of erosion risk according to the conservation practices referring to land use maps (based on the values given by Shin, 1999)



The R-factor, K-factor, LS- factor, C-factor and P-factor of the watershed varied from 851 to 1458 MJ mm $ha^{-1}h^{-1}$ yr^{-1}, 0.09 and 0.48 Mg h $MJ^{-1}mm^{-1}$, 0 and 55, 0 and 0.37 and 0 and 0.9 respectively. These factors are combined in a number of formulas in USLE, which returns a single number, the computed soil loss per unit area, equivalent to predicted erosion in ton ha^{-1} $year^{-1}$ (Wischmeier and Smith, 1978). Once all erosive factors were calculated, they were introduced into the USLE using "ArcMap / Spatial Analyst / Raster Calculator", therefore erosion risk map was obtained (Figure 9).

Figure 9: Actual erosion risk map of IEL 7 watershed



Conclusion

The annual soil loss predictions range between 0 and 61 tons ha^{-1}. Average soil loss was highest (26 tons ha^{-1} $year^{-1}$) in agriculture area and lowest soil loss rate was found in forest area (0.99 tons ha^{-1} $year^{-1}$). For horticulture and plantation the soil loss rates were 1.47 and 5.39 tons ha^{-1} $year^{-1}$ respectively. For pasture, fallow and scrub the soil loss rates were 25.47, 28.39 and 35.76 tons ha^{-1} $year^{-1}$ respectively. Researchers (Mitra et al., 1998; Ahamed et al., 2000; Metternicht and Gonzales, 2005) concluded that traditional USLE overestimates the areas prone to high level erosion risks. It was also found in present study that USLE over estimates the areas prone to moderate and severe soil erosion.

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References

Ahamed, T.R.N., Rao, G.K., Murthy, J.S.R., (2000). Fuzzy class membership approach to soil erosion modelling, Agricultural Systems, 63, pp.97-110.

Erencin Z. (2000). "C-Factor Mapping Using Remote Sensing and GIS. A case Study of Lom Sak/Lom Kao, Thailand". International Institute for Aerospace Survey and Earth Sciences (ITC).

Hurni, H., Eger, H. and Fleischhauer, E. (1996). Precious Earth: From Soil and Water Conservation to Sustainable Land Management, Berne.

Jennings, D. (2001). Surface Water Delineation for Moundsville. Spatial Analysis for Resource Management. http://www.nrac.wvu.edu /rm493591/fall2001/students/jennings/revised.htm, May, 2003.

Liniger, H.P. and Thomas, D.B. (1998). GRASS: Ground Cover for Restoration of Arid and Semi-arid Soils, in: Advances in GeoEcology 31, pp. 1167-1178.

Loch, R. J., B. K. Slater., and Devoil, C. (1998). Soil erodibility (Km) values for some Australian soils. Australian journal of Soil Research, 36: 1045-1055.

Metternicht G. I, and Fermont A. 1998. Estimating erosion surface features by linearmixture modeling. Remote Sensing of Environment 64 (3): 254-265.

Metternicht, G., and Gonzales, S., (2005). FUERO: foundation of a fuzzy exploratory model for soil erosion hazard predict, Environmental Modelling & Software 20, pp. 715-728.

Mitra, B., Scott, H.D., Dixon, J.C. and McKimmey, J.M., (1998). Applications of fuzzy logic to the prediction of soil erosion in a large watershed, Geoderma, v. 86, pp. 183-209.

Pilesjo, P. (1992). "GIS and Remote Sensing for soil erosion studies in semi-arid environments". PhD thesis: Meddelanden fran Lunds Universitets Geografiska, Sweden, pp. 203.

Renard, K. G. & Freidmund, J. R. 1994. Using monthly precipitation data to estimate the R factor in the RUSLE. Journal of Hydrology 157: 287–306.

Romkens, M. J. M. (1985). "The soil erodibility factor: A perspective. In S.a. El-Swaify, W.C. Moldenhauser, and A. Lo, eds., Soil Erosion and Conservation, pp. 445-461. Soil Water Conserv. Soc. Am., Ankeny, Iowa.

Schwab, G. O., Frevert, R.K., Edminster, T.W., and Barnes, K.K. (1981). "Soil Water Conservation Engineering (3rd ed.), Wiley, New York.

Shi, Z.H., Cai, S.F., Ding, S.W., Wang, T.W. and Chow, T.L., 2004. Soil conservation planning at the small watershed level using RUSLE with GIS: a case study in the Three Gorge area of China. Catena, 55: 33-48.

Shin, G. J. (1999). "The analysis of soil erosion analysis in watershed using GIS", Ph.D. Dissertation, Department of Civil Engineering, Gang-won National University.

Slattery, M., Gares, P.A. and Phillips, D., 2002. Slope-channel linkage and sediment delivery on North Carolina coastal plain cropland. Earth Surface Processes and Landforms, 27: 1377-1387.

Soil Erosion and Assessment using GIS (SEAGIS) 1999. Documentation and user guide. Version 1.0, February 1999.

Wainwright, J., Parsons, A. J., Michaelides, K., Powell, D. M. and Brazier, R. (Editors), 2003. Linking short and long term soil erosion modelling. In: Long Term Hillslope and Fluvial System Modelling. Concepts and Case Studies from the Rhine River Catchment. Springer-Verlag, Bonn, Germany.

Weesies, G.A. (1998). "Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)." Agriculture Handbook No. 703. Washington, District of Columbia, USA.

Wischmeier W. H., and Smith DD. 1978. Predicting rainfall-erosion losses: A guide to conservation planning. Agricultural Handbook No. 537. US Department of Agriculture.

Wischmeier, W. H., Johnson, C. B., and Cross, B. V., 1971. A Soil Erodibility Nomograph for Farmland and Conservation Sites. Journal of Soil and water Conservation, 26, pp. 189-193.