The Journal of GIS Association of Korea, Vol. 14, No. 4, pp. 363-377, December 2006

Non-point Source Critical Area Analysis and Embedded RUSLE Model Development for Soil Loss Management in the Congaree River Basin in South Carolina, USA

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ABSTRACT

Mean annual soil loss was calculated and critical soil erosion areas were identified for the Congaree River Basin in South Carolina, USA using the Revised Universal Soil Loss Equation (RUSLE) model. In the RUSLE model, the mean annual soil loss (A) can be calculated by multiplying rainfall-runoff erosivity (R), soil erodibility (K), slope length and steepness (LS), crop-management (C), and support practice (P) factors. The critical soil erosion areas can be identified as the areas with soil loss amounts (A) greater than the soil loss tolerance (T) factor. More than 10% of the total area was identified as a critical soil erosion area. Among seven subwatersheds within the Congaree River Basin, the urban areas of the Congaree Creek and the Gills Creek subwatersheds as well as the agricultural area of the Cedar Creek subwatershed appeared to be exposed to the risk of severe soil loss. As a prototype model for examining future effect of human and/or nature-induced changes on soil erosion, the RUSLE model customized for the area was embedded into ESRI ArcGIS ArcMap 9.0 using Visual Basic for Applications. Using the embedded model, users can modify C, LS, and P-factor values for each subwatershed by changing conditions such as land cover, canopy type, ground cover type, slope, type of agriculture, and agricultural practice types. The result mean annual soil loss and critical soil erosion areas can be compared to the ones with existing conditions and used for further soil loss management for the area.

Keywords : soil loss, RUSLE, GIS-based model

요 약

본 연구에서는 개정범용토양유실공식(RUSLE: Revised Universal Soil Loss Equation)을

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이용하여 미국 South Carolina 주 Congaree 유역에 대한 평균 연간 토양 유실량을 산출하였으며 비점오염원 토양 유실 민감지역을 추출하였다. 평균 연간 토양 유실량은 강우-유출 침식성 인자, 토양침식성 인자, 지면특성 인자, 식생피복 인자, 그리고 토양보존 인자의 곱으로 계산할 수 있으며, 토양 유실 민감지역은 토양 유실량이 토양침식 허용량을 초과하는 지역으로 추출할 수 있다. 연구 결과, 전체 면적의 10% 이상의 면적이 비점오염원 토양 유실 민감 지역으로 확인되었으며, Congaree 유역의 7개 소유역 중 Congaree Creek, Gills Creek 소유역의 도심지역과 Cedar Creek 소유역의 농업지역에서 가장 심각한 토양 유실의 위험이 나타났다. 관심 지역의 인위적, 자연적 변화가 토양 유실에 가져오는 영향을 살펴보기 위한 시범 모형으로서, 개정범용토양유실공식에 기초한 내장형 모형이 Visual Basic for Applications (VBA)를 이용하여 ESRI사의 ArcGIS ArcMap 9.0에서 사용할 수 있도록 개발되었다. 이 내장형 모형에서 사용자는 각 소유역의 토지 피복, 식생 유형, 지표 식생 유형, 경사, 작물 유형, 경작 방식 등을 변경시킴으로써 C, LS, P 인자를 변화시킬 수 있으며, 계산된 평균 연간 토양 유실량과 민감지역을 현재 상태의 값들과 비교하여 앞으로의 토양유실 관리를 위한 주요 정보로 사용할 수 있다.

주요어 : 토양유실, 개정범용토양유실공식, GIS 기반 모형

1. Introduction

Soil erosion directly contributes to non-point source pollution, since non-point source pollution is caused by diffuse sources from agriculture, urban runoff, forestry, households, etc. While point source water pollution is the contamination of water due to the effluent of toxic materials mainly from industrial facility wastewater, the non-point source pollutants reach surface water by rainfall runoff and also infiltrate to groundwater. Non-point source pollutants contain not only excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas but also sediment from improperly managed construction sites, crop and forest lands (USEPA, 2003). According to the National Water Quality Inventory report, agricultural non-point source pollution is the main factor that affects the water quality of rivers, lakes, estuaries, ground water, and wetlands (USEPA, 2003).

There has been much effort to control the non-point source pollution. U.S. Congress passed a revision to the Federal Water Pollution Control Act in 1972 and established the Federal Water Pollution Control Act Amendments of 1972 (FWPCA72), which is known as the Clean Water Act. The Clean Water Act deals with the tools for controlling non-point source pollution, calls for the development and implementation of water quality control plans and authorizes federal grants through Section 208 (Portney and Stavins, 2000). The U.S. Environmental Protection Agency (USEPA) currently manages Section 319 of the Clean Water Act, the Non-point Source Management Program, and gives grants to the entities that are implementing non-point source pollution control programs. The National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture (USDA), the Federal Highway Administration under the U.S. Department of Transportation, and the U.S. Department of the Interior also provide several programs related to the non-point source pollution controls (USEPA, 2003). However, the non-point source pollution has still been hard to control, since the runoff can be detected and measured only after it already has entered the ecosystem. Thus, the non-point source pollution has been generally difficult to monitor and identify its source.

A large number of models have been suggested to solve this problem. Especially, the Universal Soil Loss Equation (USLE), which is a well known soil erosion model developed by Wischmeier and Smith (1965, 1978), has been generally used to compute the longtime average soil losses from sheet and rill erosion under several conditions and to decide adequate crop system and support practice (Wischmeier and Smith, 1978). Renard et al. (1997) presented the Revised Universal Soil Loss Equation (RUSLE) model and the USDA developed several versions of RUSLE software. Although the software developed by USDA contains an enormous database for the conterminous United States, it does not show spatially distributed output and only produces a resultant annual soil loss amount for the selected location.

In this study, the spatially distributed mean annual soil loss was obtained for the Congaree River Basin in South Carolina, USA and the critical soil erosion areas were identified. Also, an embedded RUSLE model within a decision support context was developed using Visual Basic for Applications (VBA) in the ESRI ArcMap environment as a prototype model for examining future effect of human and/or nature-induced changes on soil erosion. Since users can obtain mean annual soil loss map or critical soil loss area map by modifying conditions such as canopy type and canopy cover percentage, the embedded model can be used as a spatial decision support system for soil loss management for the areas of soil loss concerns.

2. Study Area

The Congaree river basin encompasses 1,782 km^2 and seven watersheds, including two Congaree River watersheds, Congaree Creek watershed, Gills Creek watershed, Sandy Run watershed, Cedar Creek watershed, and the Toms Creek watershed (Figure 1). The land cover includes 17.2% of urban land, 9.1% of agricultural land, 7.9% of scrub/shrub land,

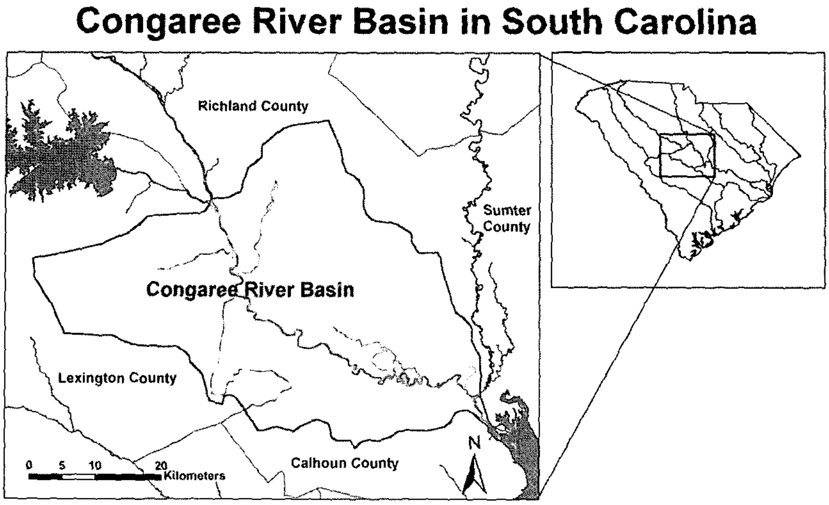

Figure 1. Study area: Congaree River Basin in South Carolina.

0.3% of barren land, 52.6% of forested land, 11.0% of forested wetland, and 1.9% of water according to the classification of the SPOT multispectral image data obtained in 1989. The classification was performed by the personnel in the South Carolina Department of Natural Resources. The large urban land cover percentage is attributed to the Columbia Metropolitan Area (SCDHEC, 1998).

The surface water quality of the Congaree River Basin on average is pretty good, according to the report of the South Carolina Department of Health and Environmental Control (SCDHEC, 1998). Observed individually, however, very high concentrations of copper, zinc, cadmium, and chromium were measured over the basin historically; toxic materials such as isophorone, P,P'DDE, O, P'DDt, methylene chloride, Benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, pyrene, and Benzo (a)anthraceen were also detected from sediment samples (SCDHEC, 1998).

The South Carolina Department of Health and Environmental Control (SCDHEC) developed a priority list of impaired waterbodies that do not meet the state water quality standard according to Section 303(d) of the Clean Water Act, and states should develop Total Maximum Daily Load (TMDL) for the listed waterbodies. SCDHEC has implemented many non-point source management programs recognizing the impairment results are mostly from non-point sources. Several water quality assessment projects relating to non-point source pollution were implemented by the University of South Carolina during 1990s: the Mill Creek Watershed Assessment Project to develop a non-point source runoff model; the Gills Creek Watershed Project to assess urban impact on water quality; and the Cedar Creek Watershed Project to evaluate groundwater and surface water agricultural chemical loadings and transport to support Best Management Practice (BMP) selection. The percentage of urban area in the Gills Creek is 56.51% and the agricultural land area in the Cedar Creek is 16.36% (SCDHEC, 1998).

3. Conceptual Model: RUSLE

While the USLE model was originally designed to be applied to agricultural areas, Renard et al. (1997) extended the application to the nonagricultural areas such as construction sites. Both the USLE and RUSLE consist of six factors:

$$A = R\ K\ L\ S\ C\ P \quad (1)$$

where A is the computed average soil loss per unit area (ton/acre/yr), R is the rainfall-runoff erosivity factor, and K is the soil erodibility factor. L is the slope length factor, S is the slope steepness factor, C is the cover-management factor, and P is the support practice factor.

3.1 Rainfall-runoff erosivity factor, R

The rainfall-runoff erosivity factor (R) means that soil losses are proportional to the rainfall parameters of the total storm energy and the maximum 30-minute intensity, holding other variables constant (Renard et al., 1997).

$$R = \frac{\sum (E_i I_{30i})}{100} \quad (2)$$

where E_i is the kinetic energy of a given storm interval and I_{30i} is the maximum30-minute storm intensity (in/hr).

3.2 Soil erodibility factor, K

The soil erodibility factor (K) indicates that soil losses are affected by rainfall, runoff, and infiltration. K-factor values are usually obtained from the soil-erodibility monograph or estimated from algebraic approximation of the monograph. The algebraic approximation formula uses five parameters: percent silt + fine sand, that is, 0.05 to 0.1 mm fractions; percent sand > 0.1 m; percent organic matter; textural class and permeability (Renard et al., 1997).

$$K = [2.1M^{1.14} \times 10^{-4}(12-a) + 3.25(b-2) + 2.5(c-3)]/100 \quad (3)$$

$$M = (\text{percent silt} + \text{percent fine sand}) \times (100 - \text{percent sand}) \quad (4)$$

where K is the soil erodibility factor, a is the percent organic matter, b is the textural class, and c is the permeability.

3.3 Slope length and steepness factor, LS

The slope length and steepness factor (LS) consists of slope length factor (L) and slope steepness factor (S). The L-factor is defined as the horizontal distance from the point that the overland flow starts to the point that deposition occurs or merges into the channel (Wischmeier and Smith, 1978). The S-factor is the effect of slope gradient on erosion of the location (Renard et al., 1997).

$$L = \left(\frac{\lambda}{72.6}\right)^m \quad (5)$$

$$m = \beta / (1 + \beta) \quad (6)$$

$$\beta = (\sin \theta / 0.0896) / [3.0(\sin \theta)^{0.8} + 0.56] \quad (7)$$

$$S = 10.8\sin \theta + 0.03 \quad s < 9\%$$
$$S = 16.8\sin \theta - 0.50 \quad s \geq 9\% \quad (8)$$

where L is the slope length factor, λ is the slope length (ft), and m is a variable slope-length exponent. S is the slope steepness factor, θ is the slope angle (degree), and s is the slope angle (%).

3.4 Cover-management factor, C

The cover-management factor (C) represents the effect of cropping management practice on soil losses. It is based on a standardized area under "clean-tilled continuous fallow conditions," related to the soil loss ratio (SLR), an estimate of the ratio of actual soil loss (Renard et al., 1997). The SLR is calculated as the product of five subfactors: the prior-land use subfactor (PLU); the canopy-cover subfactor (CC); the surface-cover subfactor (SC); the surface-roughness subfactor (SR); and the soil-moisture subfactor (SM). Calculated SLR values for each time interval are multiplied by their percentage of annual EI (see Equation 2), summed for each time interval, and then divided by the total percentage of annual EI.

$$C = \frac{\sum SLR_i EI_i}{EI_t} \quad (9)$$

where C is the cover-management factor, *SLR* is the soil loss ratio, and *EI* is the kinetic energy multiplied by the storm intensity.

3.5 Support practice factor, P

The support practice factor (P) explains the effect of contour tillage on soil losses. It is based on the assumption that on relatively smooth soil surfaces, natural microtopography such as the ridges and surface roughness will redirect the runoff (Renard et al., 1997).

3.6 Soil loss tolerance factor, T

The soil loss tolerance factor (T) is not included in the six factors of the RUSLE. However, it is generally used to be compared with the predicted soil losses (A) so that soil erosion controls to the areas of excess soil erosion can be implemented. Soil loss tolerance (T) means the maximum rate of soil erosion that allows crop productivity to be sustained economically, and usually ranges from 1 to 5 ton/acre/yr (Renard et al., 1997).

4. GIS-Based Modeling Approach

4.1 Data

The boundary layers of the Congaree River Basin and its subwatersheds were downloaded from the University of South Carolina GIS Data Server website (see http://www.cas.sc.edu/gis/dataindex.html) as ArcInfo Coverages and Shapefiles, respectively. The Congaree River Basin Coverage was converted to a Shapefile and used for masking all raster layers. Because the boundaries of subwatersheds were not consistent with the boundary of the Congaree River Basin, the subwatershed Shapefile was also recreated by masking the original map using the Congaree River Basin Shapefile.

The R-factor raster layer was derived from the isoerodent map of the eastern United States from the Agricultural Handbook No. 703 (Renard et al., 1997). The isolines were digitized and rectified to have the same x and y coordinates with the boundary layer of the Congaree River Basin. The vector lines were converted to vector points and kriged to create 30-m grids of R factor values (Figure 2a). The Congaree River Basin has R factor values ranging between about 289 and 308.

K-factor values were created from the Soil Survey Geographic (SSURGO) Data downloaded from the South Carolina Department of Natural Resources (SCDNR) website (see http://water.dnr.state.sc.us/gisdata/) and soil data from the National Soil Information System (NASIS) Database downloaded from the Earth Science and Resources Institute website of the University of South Carolina (see http://www.esri.sc.edu/SC_soils/). The map scale of the original SSURGO Data is 1:24,000. The "Map Unit ID" (MUID) of SSURGO data was joined with the "County FIPS Code" and "Map Symbol" of NASIS data. The K-factor grid map was also created in 30-m grid size (Figure 2b). For some soil types with no K values (Quarry, Clay Pit, Borrow Pit, Sand Pit, and DAM in Lexington County), zero values were assigned. Pits and quarries were assumed to have only rocks remaining. The K-factor values over the Congaree River Basin range between 0 and 0.43.

LS factor values were obtained from the 1 : 24k Digital Elevation Model (DEM) downloaded from the SCDNR website and the AML (ARC Macro Language) program code of Hickey et al. (Hickey et al., 1994; Dunn et al., 1998; Hickey, 2000; Van Remortel et al., 2001). The input for this ARC/INFO AML program is the DEM, and outputs are the S-factor (Figure 2c), L-factor (Figure 2d), and LS-factor grid maps with a 30-m grid size. Hickey et al. (1994) used the concept of cutoff factors, in which the critical slope angle decreases from one cell to the next along the flow direction, to solve the problem of deposition. If the slope angle drops below the cutoff factor value, net deposition rather than erosion occurs. The LS-factor values over the Congaree River Basin range between 0 and 87.27.

The basic equations to calculate the LS-factor included in the AML program code are used directly when the percent slope and the slope length values are entered by users in the embedded model. Local mean percent slope and slope length values for subwatersheds were given as default values.

Due to the lack of data, C factor values were estimated from the land cover Shapefiles downloaded from the GIS Data Server of the University of South Carolina website. The spatial resolution of downloaded files was 60-m, which had been aggregated from the land cover classification using 20-m cells

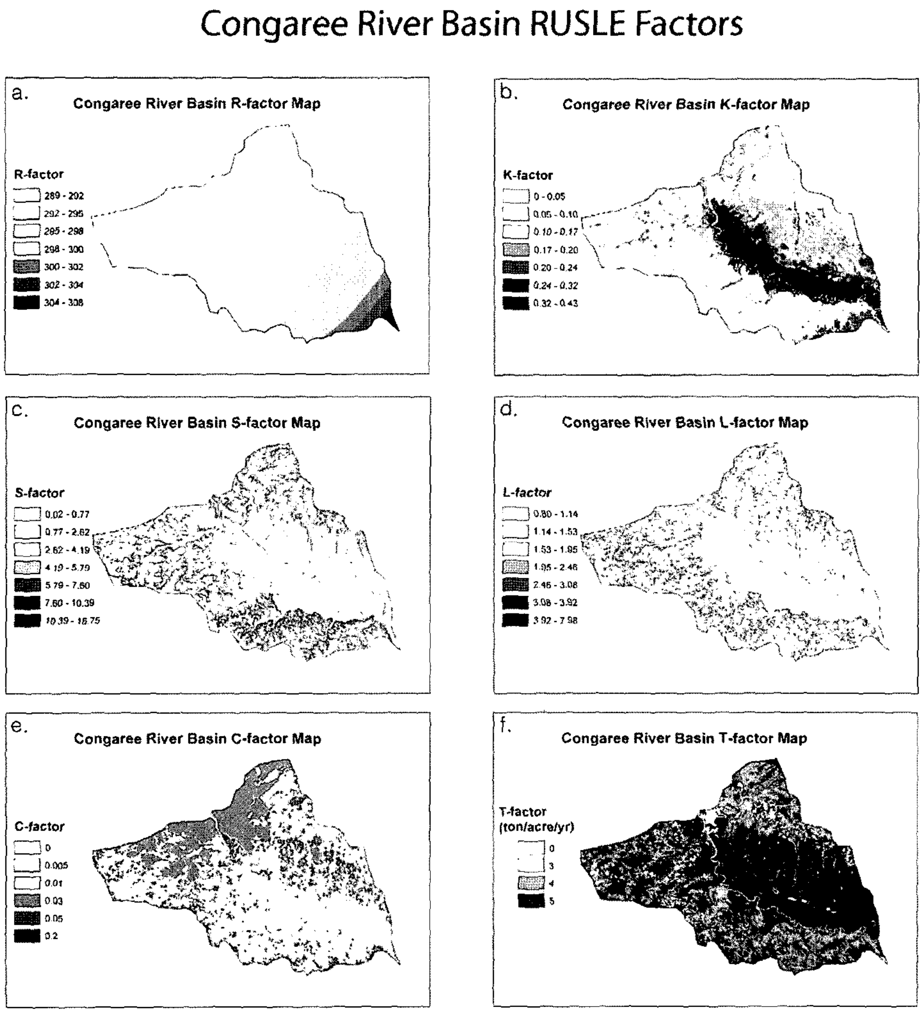

Figure 2. Six factors used in the RULSE model for the Congaree River Basin.

of SPOT multispectral sensor images obtained in 1989. The classification was performed by the personnel of South Carolina Department of Natural Resources. The land cover Shape-files were converted to a raster layer with 30-m cell size and reclassified based on the USGS land cover classification system. Then, the C-factor values were assigned according to the classification of Sivertun and Prange (2003) (Table 1 and Figure 2e). The C-factor values over the Congaree River Basin range between 0 and 0.2.

In the embedded RUSLE model, the C-factor value for the selected subwatershed

Table 1. C-factor values for land cover classification (Sivertun and Prange, 2003)

Code	Land cover classification	C-factor
1	Evergreen forest	0.005
2	Mixed forest	0.005
3	Deciduous forest	0.005
4	Scrub/shrub	0.01
5	Bottomland forest	0.005
6	Non-forested wetland	0.01
7	Agricultural grassland	0.05
8	Barren land	0.2
9	Urban/built-up land	0.03
10	Water	0
16	Mixed urban/built-up land	0.03

Table 2. C-factor values in rangeland (Wischmeier and Smith, 1978; USSCS, 1975)

Type of Canopy and Average Fall Height of Water Drops	Canopy Cover (% area)	Ground Cover Condition	C-factor value for given Ground Cover (% area)					
			0-20	20-40	40-60	60-80	80-95	95-100
No appreciable canopy	NA	G	0.45	0.2	0.1	0.042	0.013	0.003
		W	0.45	0.24	0.15	0.09	0.043	0.011
Canopy of tall weeds or short brush (0.5 m fall height)	0-25	G	0.36	0.17	0.09	0.038	0.012	0.003
		W	0.36	0.2	0.13	0.082	0.041	0.011
	25-75	G	0.26	0.13	0.07	0.035	0.012	0.003
		W	0.26	0.16	0.11	0.075	0.039	0.011
	75-100	G	0.17	0.1	0.06	0.031	0.011	0.003
		W	0.17	0.12	0.09	0.068	0.038	0.011
Appreciable brush or brushes (2 m fall height)	0-25	G	0.4	0.18	0.09	0.04	0.013	0.003
		W	0.4	0.22	0.14	0.085	0.042	0.011
	25-75	G	0.34	0.16	0.085	0.038	0.012	0.003
		W	0.34	0.19	0.13	0.081	0.041	0.011
	75-100	G	0.28	0.14	0.08	0.036	0.012	0.003
		W	0.28	0.17	0.12	0.077	0.04	0.011
Trees but no appreciable low brush (4 m fall height)	0-25	G	0.42	0.19	0.1	0.041	0.013	0.003
		W	0.42	0.23	0.14	0.087	0.042	0.011
	25-75	G	0.39	0.18	0.09	0.04	0.013	0.003
		W	0.39	0.21	0.14	0.085	0.042	0.011
	75-100	G	0.36	0.17	0.09	0.039	0.012	0.003
		W	0.36	0.2	0.13	0.083	0.041	0.011

G: Grass, grass-like plants, decaying compacted duff, or litter at least 2 inch deep
W: Mostly broadleaf herbaceous plants

Table 3. C-factor values in woodland (Wischmeier and Smith, 1978; USSCS, 1975)

Tree Canopy (% area)	Litter >2" thick (% area)	Undergrowth	C-factor value
0-35	0-70	G	0.009
		H	0.09
	70-90	G	0.004
		H	0.04
	90-100	G	0.001
		H	0.011
35-70	0-70	G	0.006
		H	0.055
	70-90	G	0.003
		H	0.025
	90-100	G	0.001
		H	0.007
70-100	0-70	G	0.003
		H	0.02
	70-90	G	0.002
		H	0.01
	90-100	G	0.001
		H	0.003

G: Grazing and burning controlled
H: Heavily grazed and burned

was designed to be determined by several user inputs of land cover type, type of canopy, canopy cover percentage area, ground cover condition, ground cover percentage area, tree canopy percentage area, thick litter percentage area, and undergrowth condition according to the classification of Wischmeier and Smith (1978) and U.S. Soil Conservation Service (1975) (Table 2 to 4).

For the spatially distributed critical soil erosion analysis, no support practices utilized, assumed due to the lack of data. P-factor values of unity were assigned for all grids. In the embedded RUSLE model, the P-factor value for the selected subwatershed was designed to be calculated from the user input parameters of percent slope and practice type (Wischmeier and Smith, 1978; USSCS, 1975) (Table 5).

Table 4. C-factor values for other land cover types (Wischmeier and Smith, 1978; USSCS, 1975)

Land Cover		C-factor value
Type of Agriculture	Covered	0.05
	Harvested	0.1
	Perennial	0.075
Urban		0.03
Barren		0.2

T-factor values were also created from the Soil Survey Geographic (SSURGO) Data downloaded from the South Carolina Department of Natural Resources (SCDNR) website and soil data from the National Soil Information

Table 5. P-factor values for percent slope and practice types (Wischmeier and Smith, 1978; USSCS, 1975)

Practice	Slope (%)	P-factor value
Irrigated Terracing	$0 \leq S < 2$	0.1
	$2 \leq S < 8$	0.1
	$8 \leq S < 13$	0.12
	$13 \leq S < 19$	0.16
	$19 \leq S < 24$	0.18
	$24 \leq S$	1
Contour Furrows	$0 \leq S < 2$	0.25
	$2 \leq S < 8$	0.25
	$8 \leq S < 13$	0.3
	$13 \leq S < 19$	0.4
	$19 \leq S < 24$	0.45
	$24 \leq S$	1
Contour Strip Cropping	$0 \leq S < 2$	0.25
	$2 \leq S < 8$	0.25
	$8 \leq S < 13$	0.3
	$13 \leq S < 19$	0.4
	$19 \leq S < 24$	0.45
	$24 \leq S$	1
Contouring	$0 \leq S < 2$	0.5
	$2 \leq S < 8$	0.5
	$8 \leq S < 13$	0.6
	$13 \leq S < 19$	0.8
	$19 \leq S < 24$	0.9
	$24 \leq S$	1
None	-	1

System (NASIS) Database downloaded from the Earth Science and Resources Institute website of the University of South Carolina (Figure 2f). Each segment of the Congaree River Basin has a T-factor value of one of 0, 3, 4, 5 ton/acre/yr.

4.2 Critical Soil Erosion Area Analysis

As described in Equation 1 and shown in the flow diagram in Figure 3, the mean annual soil loss was obtained from the spatially distributed R, K, LS, C, and assumed P factor layers with 30 m cell size (Figure 4). The mean annual soil loss was 1.18 ton/acre/yr (291,594.9 kg/km^2/yr) and the average annual soil loss of the Congaree River Basin is 519,568.0 ton/yr (519,568,000 kg/yr). The calculated annual soil loss values were compared to the soil-loss tolerance T-factors. If the estimated soil loss amount is greater than the soil loss tolerance at a certain site, the site needs implementations of conservation practices. In this study, about 10.3% (45,439.80 acre) of

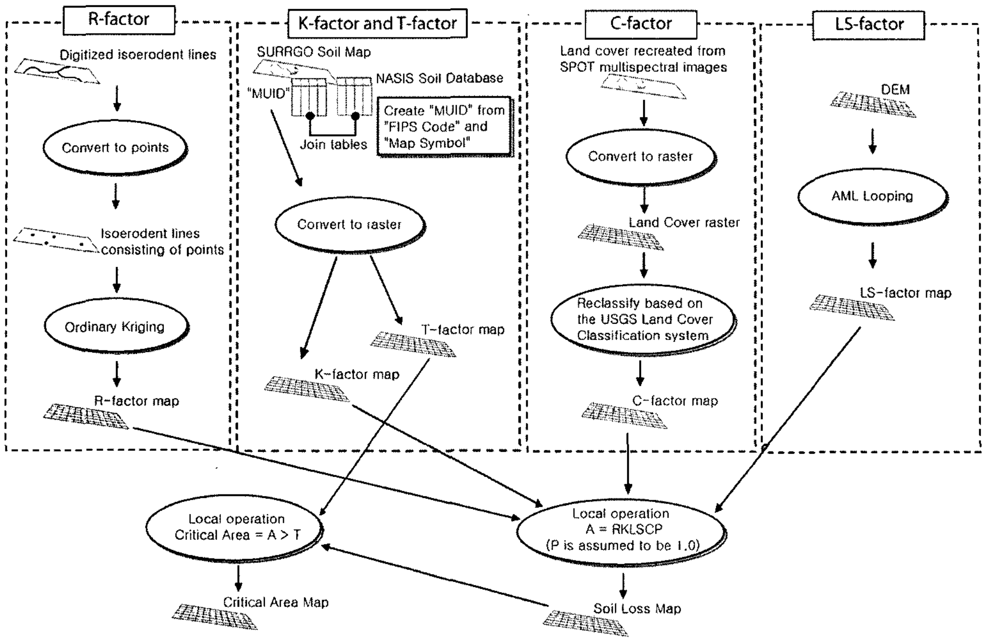

Figure 3. Data processing flow diagram for soil loss estimation and critical erosion area analysis.

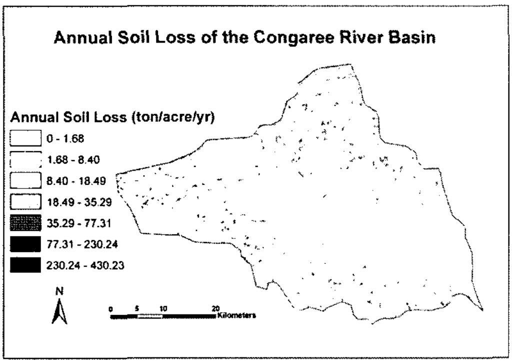

Figure 4. Annual soil loss amounts of the Congaree River Basin calculated from the RULSE model.

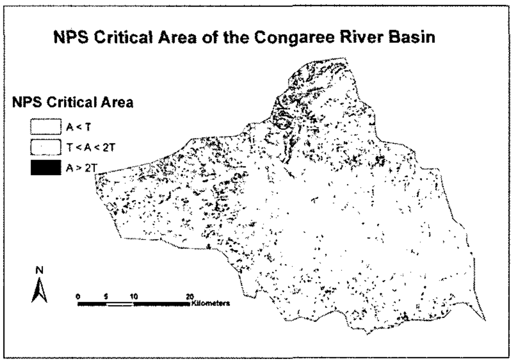

Figure 5. Critical soil erosion area of the Congaree River Basin.

the study area has soil loss amounts greater than the soil loss tolerance, and 4.56% (20,087.43 acre) of the area has soil loss amounts greater than two times of the soil loss tolerance and identified as critical soil erosion areas (Figure 5). The criteria to determine the critical areas can be changed according to the purpose of the study or available resources.

The soil loss of the urban area of the Congaree Creek subwatershed and the Gills Creek subwatershed turned out to be very significant. The land cover of these two watersheds contains 34.59% and 56.51% of urban surface, respectively. The agricultural land of the Cedar Creek subwatershed, which occupies 16.36% of the area, is also very vulnerable to soil loss.

4.3 Development of an Embedded RUSLE Model

An embedded RUSLE model was developed using Visual Basic for Applications in the ArcMap 9.0 environment for soil loss management in the study area. In the embedded model, the C-factor, LS-factor, and P-factor values for the selected subwatershed in the Congaree River Basin were designed to be calculated by several user inputs such as canopy type and canopy cover percentage so that they will be combined with the R-factor and K-factor raster layers to derive the annual soil loss amount of the subwatershed. Using this prototype model for examining future effect of human and/or nature-induced changes on soil erosion, users can compare the two resultant raster layers added to the ArcGIS map document, which are the annual soil loss amount and the critical soil erosion area raster layers, to the maps with existing conditions calculated using the spatially distributed input layers. The data-processing flow diagram for this embedded RUSLE model is presented in Figure 6 and the Graphical User Interface is shown in Figure 7.

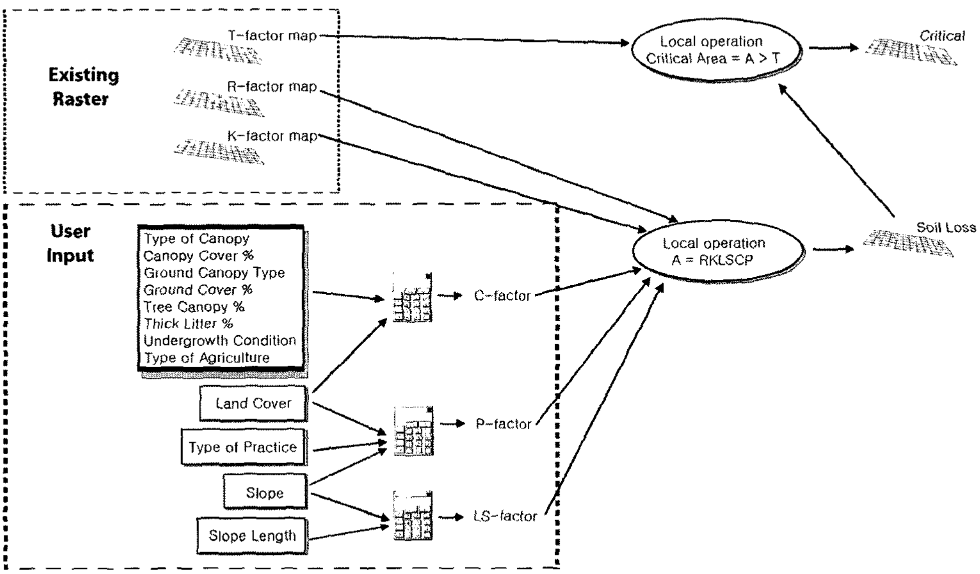

Figure 6. Data processing flow diagram for the embedded RULSE model.

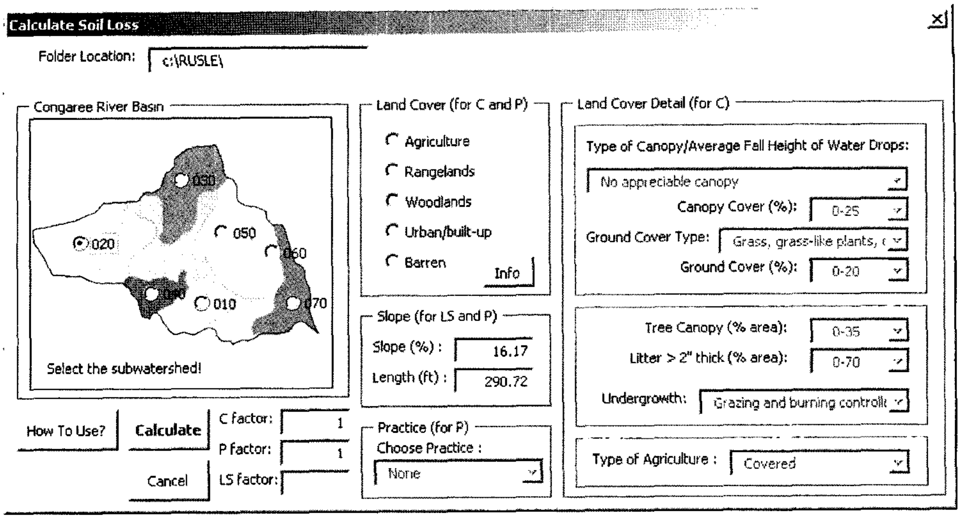

Figure 7. Graphical user interface of the RULSE model implemented in the ArcMap 9.0 environment.

5. Conclusions

Soil loss erosion by water has been studied for decades, and soil erosion models, such as USLE, RUSLE, Modified Universal Soil Loss Equation (MUSLE), and Agricultural Non-Point Source (AGNPS) model, have been developed and widely used. These models will continue to provide useful soil loss information until the new technology such as Water Erosion Prediction Project (WEPP) model becomes fully available.

In this study, the annual soil loss of the Congaree River Basin of South Carolina was estimated using the RUSLE model and GIS techniques and the critical soil erosion areas were also identified. The urban areas of the Congaree Creek subwatershed and the Gills Creek subwatershed and the agricultural area of the Cedar Creek subwatershed appeared to be exposed to the risk of severe soil loss. The embedded RUSLE model was also developed using Visual Basic scripts in ESRI ArcGIS as a useful spatial decision support system for soil loss management in the Congaree River Basin for examining the effect of changes in land cover and agricultural practices. Although there are still some limitations, such as confined number of land cover types provided, it can be a good tool to facilitate the efforts to reduce soil erosion especially in agricultural area by providing the spatially distributed soil loss information.

In the agricultural area, efforts to reduce soil loss have to be focused on the crop-management and support practice because other factors are relatively difficult to modify while the two factors can be altered quickly by the best management practices (BMPs) as Section 208 of Clean Water Act emphasizes. In urban areas, the role of runoff model is very important because of the imperviousness of the surface as well as the soil erosion model. The use of the integrated model such as AGNPS will be very useful for further study.

Similar to the embedded model developed for the Congaree River Basin in South Carolina, USA, customized models using locally specified data and information can be developed and used for soil management in Korea. More diverse and appropriate options for Korean land cover types, agriculture types, and agricultural practices must be identified for Korean soil loss applications.

References

Dunn, M. and R. Hickey, 1998. The Effect of Slope Algorithms on slope estimates within a GIS, *Cartography*, 27(1): 9-15.

Hickey, R., A. Smith, and P. Jankowski, 1994. Slope length calculations from a DEM within ARC/INFO GRID, *Computers, Environment and Urban System*, 18(5): 365-380.

Hickey, R., 2000. Slope angle and slope length solutions for GIS, *Cartography*, 29(1): 1-8.

Portney P. R. and R. N. Stavins, 2000. Public *Policies for Environmental Protection* (2nd Ed.), Resources for the Future, Washington DC, USA, pp.176-189.

Renard K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D.C. Yoder, 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE)*, U.S. Department of Agriculture, Agriculture Handbook, No. 703. 384 p.

SCDHEC (South Carolina Department of Health and Environmental Control), Bureau of Water, 1998. *Watershed Water Quality Assessment: Saluda River Basin*, Technical Report, No. 005-98.

Sivertun A. and L. Prange, 2003. Non-point source critical area analysis in the Gisselo watershed using GIS, *Environmental Modelling & Software*, 18: 887-898.

USEPA (U.S. Environmental Protection Agency), 2003. Polluted Runoff (Nonpoint Source pollution), URL: http://www.epa.gov/owow/nps/.

USSCS (U.S. Soil Conservation Service), 1975. *Procedure for Computing Sheet and Rill Erosion on Project Area*, Technical Release No. 51.

Van Remortel, R., M. Hamilton, and R. Hickey, 2001. Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data, *Cartography*, 30(1): 27-35.

Wischmeier W. H. and D. D. Smith, 1965. *Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains: Guide for Selection of Practices for Soil and Water Conservation, U.S.* department of Agriculture, Agriculture Handbook No. 282, 47 p.

Wischmeier W. H. and D. D. Smith, 1978. *Predicting Rainfall Erosion Losses – A Guide to Conservation Planning*, U.S. department of Agriculture, Agriculture Handbook, No. 537, 58 p.