JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS DEC. 2004, pp.3-12

JOURNAL OF THE KOREAN SOCIETY
OF AGRICULTURAL ENGINEERS,
Vol. 46, No. 7

Soil Erosion Assessment Using RS/GIS for Watershed Management in Dukchun River Basin, a Tributary of Namgang and Jinyang Lake

Cho, Byung-Jin* · Yu, Chan*

Abstract

The need to predict the rate of soil erosion, both under existing conditions and those expected to occur following soil conservation practice, has been led to the development of various models. In this study Morgan model especially developed for field-sized areas on hill slopes was applied to assess the rate of soil erosion using RS/GIS environment in the Dukchun river basin, one of two tributaries flowing into Jinyang lake. In order to run the model, land cover mapping was made by the supervised classification method with Landsat TM satellite image data, the digital soil map was generated from scanning and screen digitizing from the hard copy of soil maps, digital elevation map (DEM) in order to generate the slope map was made by the digital map (DM) produced by National Geographic Information Institute (NGII). Almost all model parameters were generated to the multiple raster data layers, and the map calculation was made by the raster based GIS software, ILWIS which was developed by ITC, the Netherlands. Model results show that the annual soil loss rates are 5.2, 18.4, 30.3, 58.2 and 60.2 ton/ha/year in forest, paddy fields, built-up area, bare soil, and upland fields respectively. The estimated rates seemed to be high under the normal climatic conditions because of exaggerated land slopes due to DEM generation using 100 m contour interval. However, the results were worthwhile to estimate soil loss in hilly areas and the more precise result could be expected when the more accurate slope data is available.

Keywords : Soil loss prediction, Erosion model, Land use, DEM, RS/GIS

I. Introduction

Information on water erosion hazard is often required in the planning of alternative types of land use. Soil loss is used as a measure of the rain erosion hazard under a certain land use. Models and approaches exist to indicate the amount of soil loss that is expected to occur. In recent years, a greatly increased emphasis has

---

* Dept. of Agricultural Eng., Gyeongsang Natl. Univ. (Institute of Agri. & Life Seience., GSNU)
* Corresponding author. Tel.: +82-55-751-5430
Fax: +82-55-752-0884
E-mail address: chanyu@gsnu.ac.kr

been placed on improving and maintaining the quality of national water resources.

Study of sediments that have been accumulated in long-established large reservoirs can provide useful records of net soil loss from the catchments. Such reservoirs retain most, if not all, of the sediment that reaches them. However, soil eroded at a point may be deposited nearby. Consequently soil loss from a catchment over time is only a partial guide to the time rate of soil erosion, nevertheless it is a useful indicator.

Several empirical and physical models are available to assess soil erosion. Some models are not applicable to a particular area and may not be directly applicable to other areas as they are designed for specific application (Shresta, 1997). The Universal Soil Loss Equation (USLE) (Wischmeir & Smith, 1965) allows to assess soil loss from agricultural fields in specific conditions. It has been adapted to other conditions through modified versions such as MUSLE (Williams & Brendt, 1977) for sedimentation yield estimation, and RUSLE (SWCS, 1993) for soil loss prediction. The Water Erosion Prediction Project (WEPP) (Nearing et al., 1989) is a process-based erosion model, designed to replace the USLE model.

To compute the soil erosion within a watershed, models such as Areal Non-point Source Watershed Environment Response Simulation (ANSWERS) (Beasley et al., 1980), and Agricultural Non-point Source Pollution (AGNPS) (Young et al., 1987) are available. These models are based on grid cells and were developed to estimate runoff quality, with primary emphasis on sediment and nutrient transports. Since they can be linked to a GIS, their application in a watershed environment may be more interesting for data integration.

Although USLE has been widely used through various modified versions, its application in mountainous terrain with steep slopes is still questionable. Some models such as AGNPS or ANSWERS, may not be suitable in the mountainous context mainly because of very high level data demand, difficulty in interpretation and validation of results due to model complexity (Shrestha, 1997).

In this study, Morgan model (Morgan and Finney, 1984; Morgan, 1986) is applied to predict the rate of soil erosion in the Dukchun watershed, which is one of two watersheds flowing into the Jinyang lake in the upstream of the Nam river.

Ⅱ. Study Area and Model used

1. Study Area

The study area, Dukchun river basin is located in upstream of the Nam river. The Nam river is one of tributaries of Nakdong river which is the longest river in Korea and flowing out to the Southern sea near Busan. Dukchun river is one of two tributaries, which originates from the summit of Jiri National Park mountain and flows into the Namgang dam and reservoir called Jinyang lake with the storage capacity of approximately 300 million tones, located in about 5 km upstream of Jinju as shown in Fig. 1 and Fig. 2.

The area is chosen because of micro-climatic diversity due to elevation differences from mountain summit (about 1,900 m) to valley bottom (below 100 m from the mean sea level) and the related land-use change having in-

Fig. 1 Location map of the study area

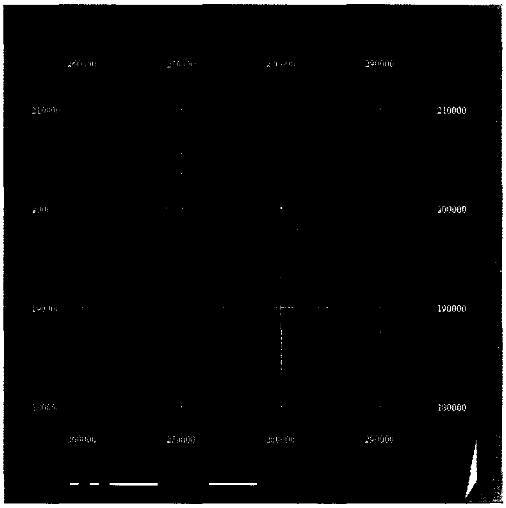


Fig. 2 Dukchun River Basin

fluences on soil erosion which is considered as typical features in the mountainous areas in Korea. The watershed area occupies about 393 km^2 and lies between 35° 03' and 35° 25' North latitude and between 127° 40' and 128° 00' East longitude. Average annual rainfall varies to the elevation; that of Joongsanri sub-station just below the mountain summit is 2,700 mm and Shinan sub-station down below the foot slope records to be 1,800 mm.

2. Morgan Model

Morgan model was developed for predicting annual soil loss from field-sized areas on hill slopes (Morgan et al., 1984). The model separates the soil erosion process into a water phase and a sediment phase.

The structure of the sediment phase is a simplification of the soil loss model described by Meyer & Wischmeir (1969). It considers soil erosion to result from the detachment of soil particles from the soil mass by raindrop impact and the transport of those particles by overland flow. The energy of rainfall for splash detachment and the volume of overland flow are estimated in the water phase.

In the water phase, the annual precipitation is used to determine the rainfall energy available for splash detachment and the volume of runoff. The rainfall energy is computed from the total annual rainfall and the hourly rainfall intensity for erosive rain, based on the Wischmeir and Smith (1978). The annual volume of overland flow is predicted using the model by Kirkby (1976). In this model, the runoff is assumed to occur whenever the daily rainfall exceeds a critical value corresponding to the storage capacity of the surface soil layer. The equations used are as follows:

For calculating the rainfall energy:

$$E = R\,(11.87 + 8.73\log_{10} I) \cdots\cdots\cdots (1)$$

Where,

E : kinematic energy of rainfall (j m^{-2})

R : annual rainfall (mm)

I : rainfall intensity (mm/h)

For computing the overland flow:

$$Q = R \exp(-R_c / R_o) \cdots\cdots (2)$$

Where,

Q : volume of overland flow (mm)
R : annual rainfall (mm)
R_c: soil moisture storage capacity under actual vegetation (mm)
R_o: mean rain per rainy day (mm)

Soil moisture storage capacity is computed considering soil moisture content at field capacity (MS), bulk density (BD), rooting depth (RD) and the ratio of actual to potential evapotranspiration (E_t/E_o).

$$Rc = 1000 \cdot MS \cdot BD \cdot RD \cdot (E_t / E_o)^{0.5} \cdots\cdots (3)$$

Mean rain per rainy day (R_o) is calculated by dividing the average annual rain per the number of rainy days in a year.

In the sediment phase, splash detachment is modelled as a function of rainfall energy, soil detachability and rainfall interception effect by crops. The transport capacity of the overland flow is determined using the volume of overland flow, slope steepness and the effect of vegetation or crop cover management (Kirby, 1976). The equations used are as follows:

For computation of splash detachment:

$$F = K \cdot [E \cdot \exp(-aP)]^b \cdot 10^{-3} \cdots\cdots (4)$$

Where,

F : rate of splash detachment (kg/m^2)
K : soil detachability index (gj^{-1}), defined as the weight of soil detached from the soil mass per unit of rainfall energy
P : percentage rainfall intercepted by crops, value of exponents : a = 0.05, b = 1.0

For computing the transport capacity of overland flow:

$$G = C \cdot Q^2 \cdot \sin S \cdot 10^{-3} \cdots\cdots (5)$$

Where,

G : transport capacity of overland flow (kg/m^2)
C : crop cover management factor
Q : overland flow volume (mm)
sin S : sine of slope gradient (degree)

For estimation of the soil loss:

Soil loss = minimum value of the two: transport capacity of overland flow (G) and the estimated rate of soil detachment (F).

Ⅲ. Data Collection and Generation of Input Data

For running the model, land cover data such as types of land use and their management practices and soil data such as detachability, moisture contents at field capacity of the surface soil layer, bulk density, rooting depth, rainfall data such as annual rainfall, rain intensity and the number of rainy days, and topographic data as slope gradient are required.

1. Land Use and Cover Information

Land use map is not available in the study area.

Land use and cover classification is generated from the supervised classification using Landsat TM, path 115 - row 035 (May 2, 1992) and path 115 - row 036 (August 28, 1991 & April 01, 1996). Land cover classes are water, paddy field, forest, residential areas, bare soil and upland, but the last three classes are sometimes overlapping in the feature spaces in the training set. The percentage of rainfall contributing to permanent interception (P), the ratio of actual to potential evapotranspiration (E_t/E_o) and the crop cover management factor (C) were used as plant parameters (Table 1).

Table 1 Plant parameters used in the model

Land use	P (%)	Et/ Eo	C
Bare soil	0.0	0.05	1.000
Forest	35.0	1.00	0.001
Paddy	43.0	1.35	0.010
Residential area	0.0	0.05	0.010
Upland	25.0	0.67	0.070

Note: The parameter values are based on Morgan et al. (1984), and C values for upland crops and paddy are adjusted by multiplying 0.15 because of conservation measures through terracing (Morgan et al., 1982).

The land cover/use maps in the Dukchun watershed is shown in Fig. 3.

2. Soil data

Soil map for Shichun subwatershed was prepared through direct screen digitizing of the soil map published in 1979 by Office of Rural Development (ORD) under the Ministry of Agri-culture and Forestry (MAF), Korean Government. The soils are classified into soil series based on FAO soil survey and classification manual. Each soil unit provides various soil information such as soil series name, texture, depth, drainage condition, topology, erosion, present land use and so on.

Soil parameters for running the model are shown in Table 2 and soil map in sub-watershed area is shown in Fig. 4.

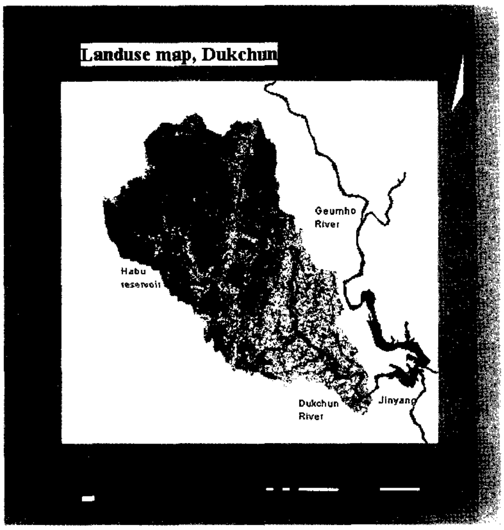


Fig. 3 Land use/cover map in Dukchun watershed area

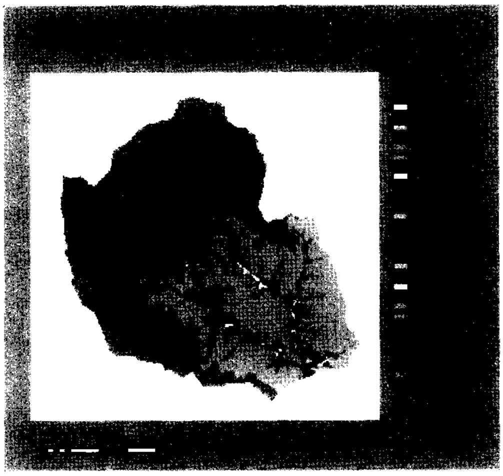
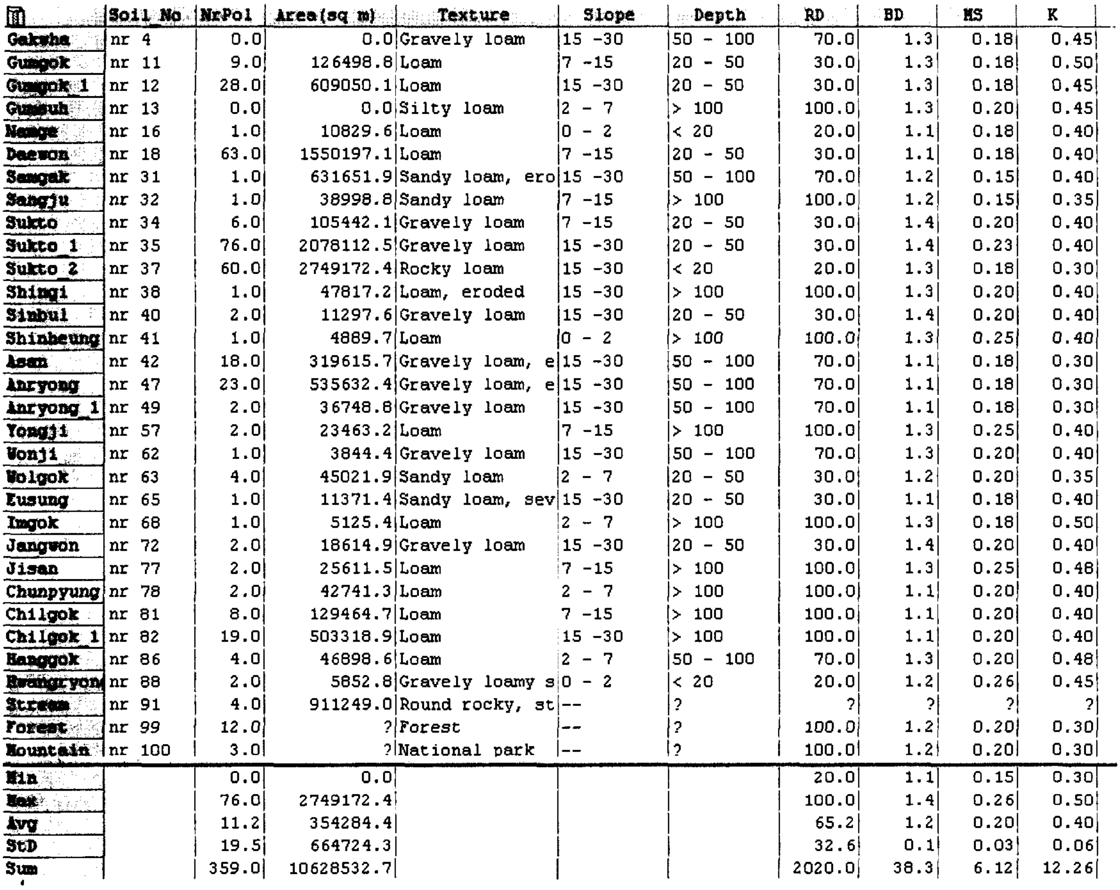


Fig. 4 Soil map of Shichun sub-watershed

Table 2 Soil parameters for running the model



	Soil No	NrPol	Area(sq m)	Texture	Slope	Depth	RD	BD	MS	K
Gakwha	nr 4	0.0	0.0	Gravely loam	15 -30	50 - 100	70.0	1.3	0.18	0.45
Gumgok	nr 11	9.0	126498.8	Loam	7 -15	20 - 50	30.0	1.3	0.18	0.50
Gumgok_1	nr 12	28.0	609050.1	Loam	15 -30	20 - 50	30.0	1.3	0.18	0.45
Gumsuh	nr 13	0.0	0.0	Silty loam	2 - 7	> 100	100.0	1.3	0.20	0.45
Namge	nr 16	1.0	10829.6	Loam	0 - 2	< 20	20.0	1.1	0.18	0.40
Daewon	nr 18	63.0	1550197.1	Loam	7 -15	20 - 50	30.0	1.1	0.18	0.40
Samgak	nr 31	1.0	631651.9	Sandy loam, ero	15 -30	50 - 100	70.0	1.2	0.15	0.40
Sangju	nr 32	1.0	38998.8	Sandy loam	7 -15	> 100	100.0	1.2	0.15	0.35
Sukto	nr 34	6.0	105442.1	Gravely loam	7 -15	20 - 50	30.0	1.4	0.20	0.40
Sukto_1	nr 35	76.0	2078112.5	Gravely loam	15 -30	20 - 50	30.0	1.4	0.23	0.40
Sukto_2	nr 37	60.0	2749172.4	Rocky loam	15 -30	< 20	20.0	1.3	0.18	0.30
Shingi	nr 38	1.0	47817.2	Loam, eroded	15 -30	> 100	100.0	1.3	0.20	0.40
Sinbul	nr 40	2.0	11297.6	Gravely loam	15 -30	20 - 50	30.0	1.4	0.20	0.40
Shinheung	nr 41	1.0	4889.7	Loam	0 - 2	> 100	100.0	1.3	0.25	0.40
Asan	nr 42	18.0	319615.7	Gravely loam, e	15 -30	50 - 100	70.0	1.1	0.18	0.30
Anryong	nr 47	23.0	535632.4	Gravely loam, e	15 -30	50 - 100	70.0	1.1	0.18	0.30
Anryong_1	nr 49	2.0	36748.8	Gravely loam	15 -30	50 - 100	70.0	1.1	0.18	0.30
Yongji	nr 57	2.0	23463.2	Loam	7 -15	> 100	100.0	1.3	0.25	0.40
Wonji	nr 62	1.0	3844.4	Gravely loam	15 -30	50 - 100	70.0	1.3	0.20	0.40
Wolgok	nr 63	4.0	45021.9	Sandy loam	2 - 7	20 - 50	30.0	1.2	0.20	0.35
Eusung	nr 65	1.0	11371.4	Sandy loam, sev	15 -30	20 - 50	30.0	1.1	0.18	0.40
Imgok	nr 68	1.0	5125.4	Loam	2 - 7	> 100	100.0	1.3	0.18	0.50
Jangwon	nr 72	2.0	18614.9	Gravely loam	15 -30	20 - 50	30.0	1.4	0.20	0.40
Jisan	nr 77	2.0	25611.5	Loam	7 -15	> 100	100.0	1.3	0.25	0.48
Chunpyung	nr 78	2.0	42741.3	Loam	2 - 7	> 100	100.0	1.1	0.20	0.40
Chilgok	nr 81	8.0	129464.7	Loam	7 -15	> 100	100.0	1.1	0.20	0.40
Chilgok_1	nr 82	19.0	503318.9	Loam	15 -30	> 100	100.0	1.1	0.20	0.40
Hanggok	nr 86	4.0	46898.6	Loam	2 - 7	50 - 100	70.0	1.3	0.20	0.48
Hwangryon	nr 88	2.0	5852.8	Gravely loamy s	0 - 2	< 20	20.0	1.2	0.26	0.45
Stream	nr 91	4.0	911249.0	Round rocky, st	--	?	?	?	?	?
Forest	nr 99	12.0	?	Forest	--	?	100.0	1.2	0.20	0.30
Mountain	nr 100	3.0	?	National park	--	?	100.0	1.2	0.20	0.30
Min		0.0	0.0				20.0	1.1	0.15	0.30
Max		76.0	2749172.4				100.0	1.4	0.26	0.50
Avg		11.2	354284.4				65.2	1.2	0.20	0.40
StD		19.5	664724.3				32.6	0.1	0.03	0.06
Sum		359.0	10628532.7				2020.0	38.3	6.12	12.26

3. Digital Elevation Model and Slope Gradient Map

Since slope is an important parameter in the model, especially in calculating the transport capacity of overland flow. The digital elevation model was generated from the digital map at the scale of 1:250,000, purchased from the National Geographic Information Institute (NGII). The digital map has the vector data format with several layers such as road, river, contour, administration boundary, etc. The contour interval is 100 m, which is too rough to use for running the model, however, this will be the first trial to use the different outsourcing digital data. The contour information in digital map was very complicated to convert into used GIS software ILWIS format.

Contour layer was separated by Auto-CAD and Arc-Info and then imported by ILWIS, but each contour had their own identifier rather than values as the elevation. Segment map was produced by manipulation of ILWIS functions to get different elevation values by each contour line, and then interpolation was made possible. Differential filters (in X & Y directions) were

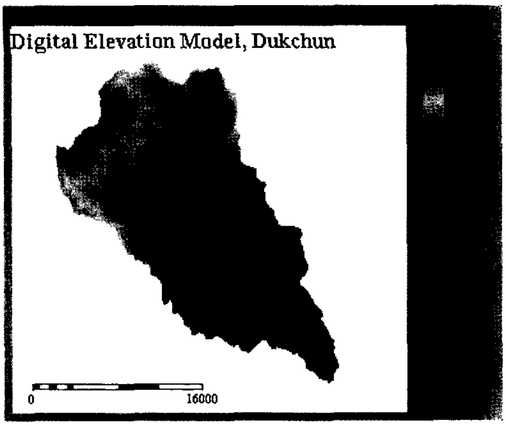


Fig. 5 DEM map in Dukchun watershed

applied to the elevation map to generate height differences in X and Y directions. Finally a slope-gradient map was computed using the height difference map (Fig. 5).

4. Rainfall data

Rain data recorded during a 4-year period (1999-2003) by automated rain loggers were available through the courtesy of Jinju meteorological observation station. Daily rainfall data are available for four stations within the study watershed, Soogok, Shinan, Samiang, and Jungsanri (Table 3).

For assessing soil erosion, average annual rainfall, rainfall intensity of 30 minute and the number of rainy days per year are important parameters. Especially rainfall intensity is very important since splash detachment is a function of rainfall energy, soil detachability and rainfall interception by crops. The rainfall energy is directly related with rain intensity. However, not all rainfall events are erosive. Rain showers of less than 12.5 mm are assumed too small to have practical significance and are not considered erosive (Wischmeir & Smith, 1978). If the total rain was less than 12.5 mm in a given day, it was not considered. Without rain chart, it is not possible to compute rainfall intensity. Therefore, the 30-minute rainfall intensity is assumed to be 12 mm/h for the computation.

The weighted mean of area rainfall was computed with the point rainfall data obtained from the four sub-stations by means of Thiessen network and used to compute the rainfall energy.

Ⅳ. Results and Discussion

All raster maps and attribute tables showing the land use/cover classification, and plant parameters (percentage rainfall contributing to permanent interception, ratio of actual and potential evapotranspiration, and crop management factor), rain (annual rain, rainfall energy and

Table 3 Rainfall at four stations

Stations	Elevation (m)	Annual rainfall		Erosive rain	
		Rainy days	Amount (mm)	Rainy days	Amount (mm)
Soogok	50	90.6	2039.7	39.2	1818.0
Shinan	50	89.4	1791.6	31.0	1576.9
Samjang	280	98.0	2226.6	40.5	2009.5
Jungsanri	470	104.2	2704.8	46.4	2495.6

daily mean rain), topography (slope gradient), and soil (soil moisture at field capacity, bulk density and soil detachment index) were generated using map calculation procedures in the ILWIS software. The model was run in a GIS environment using map calculation procedures.

The prediction of detachment by rainsplash is shown in Fig. 6 and the transport capacity of the runoff is shown in Fig. 7. The prediction of detachment is compared with the transport capacity of the runoff and the lower values are assigned as the annual rate of soil loss, denoting whether the detachment or the transport is the limiting factor. The resulting annual soil loss rates in sub-watershed Shichun is shown in Fig 8. Soil losses are comparatively high under cultivated lands such as 18.4 tons/ha/year in paddy cultivation and 60.2 tons/ha/year in upland fields. Soil losses in bare soil, built-up sites and forest area are 58.2, 30.3 and 5.2 tons/ha/year respectively as shown in Table 4.

Annual soil losses in paddy cultivation seems to be over estimated because the bench terraces

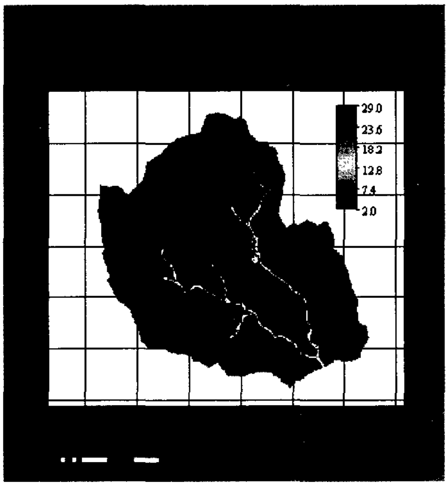


Fig. 6 Soil detachment and transport capacity (F value)

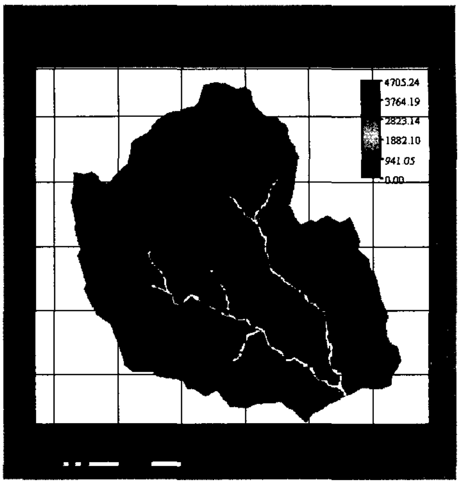


Fig. 7 Transport capacity of overland flow (G value)

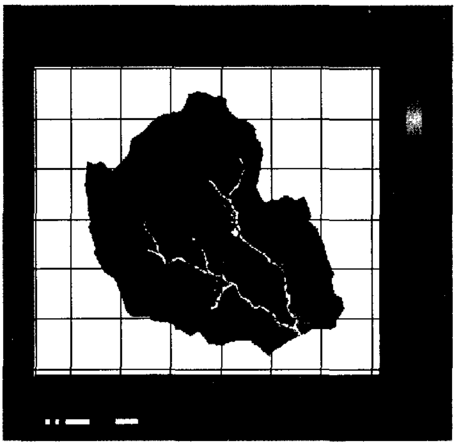
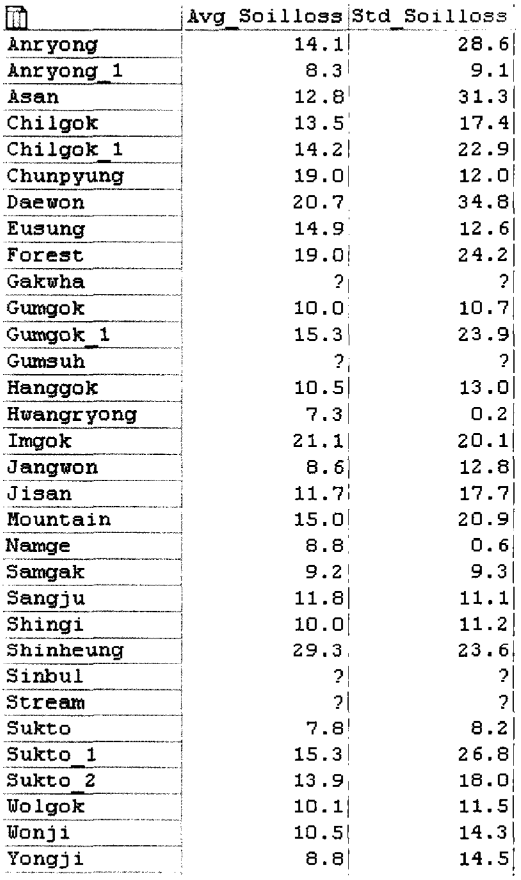


Fig. 8 Soil loss estimation in Shichun sub-watershed

Table 4 Soil losses by different land use/cover classes (tons/ha/year)

	Avg Soilloss	Std Soilloss
bare soil	58.2	76.9
forest	5.2	3.1
paddy	18.4	11.4
residential are	30.3	7.2
upland	60.2	64.5
water	?	?
Min	5.2	3.1
Max	60.2	76.9
Avg	34.5	32.6
StD	24.3	35.2
Sum	172.3	163.1

Table 5 Average soil losses by soils (tons/ha/year)



	Avg_Soilloss	Std_Soilloss
Anryong	14.1	28.6
Anryong_1	8.3	9.1
Asan	12.8	31.3
Chilgok	13.5	17.4
Chilgok_1	14.2	22.9
Chunpyung	19.0	12.0
Daewon	20.7	34.8
Eusung	14.9	12.6
Forest	19.0	24.2
Gakwha	?	?
Gumgok	10.0	10.7
Gumgok_1	15.3	23.9
Gumsuh	?	?
Hanggok	10.5	13.0
Hwangryong	7.3	0.2
Imgok	21.1	20.1
Jangwon	8.6	12.8
Jisan	11.7	17.7
Mountain	15.0	20.9
Namge	8.8	0.6
Samgak	9.2	9.3
Sangju	11.8	11.1
Shingi	10.0	11.2
Shinheung	29.3	23.6
Sinbul	?	?
Stream	?	?
Sukto	7.8	8.2
Sukto_1	15.3	26.8
Sukto_2	13.9	18.0
Wolgok	10.1	11.5
Wonji	10.5	14.3
Yongji	8.8	14.5

Note) ? : undefined due to no value or descripancy in soil map

are not taken into account. If a soil loss of up to 25 tones/ha/year is considered tolerable in mountainous areas where the natural rate of soil loss is high (Morgan, 1986), this study watershed has moderate or slightly severe soil losses.

It is also interesting to know what kind of soil is more erosive under the given conditions as Table 5. As shown in the Table Shinheung is the most susceptible to erosion and Sukto series soil is less erosive whatever the land use is.

V. Conclusions

To predict the annual soil erosion rate, Morgan's model is applied in the Dukchun watershed area, one of two tributaries flowing into the Jinyang lake. The model is known to be able to predict annual soil loss especially from hill slopes (Morgan et al., 1994).

As the results it is shown that erosion is more pronounced in sloping rainfed agriculture and seems to be over estimated at 18.4 ton/ha/year in paddy fields nevertheless it has level terraces. Soil losses in bare soil, built-up sites and forest area are 58.2, 30.3 and 5.2 tons/ha/year respectively as shown in Table 4, and those of different soil series are shown in Table 5.

Better accuracy can be obtained with the use of more precise input data such as contour map at 1:25,000. Also, land use/cover map was prepared using supervised classification without validation of the accuracy using the ground truth information. Thus, use of auxiliary dataset for validation of classification will be helpful to generate more accurate land use/cover map.

The availability of data is restricted the validation of the model to single years. While it can be used to predict annual runoff and erosion, the design strategies for soil conservation also demands information on trends in rate of erosion in longer term. An attempt would be therefore made to see how well the model could simulate erosion problems over time with a view to provide of understanding and indication of trends rather than details of absolute quantities.

Acknowledgements

This work was supported by the Korean Research Foundation (KRF-2003-013-D00160), and Gyeong Sang National University (GSNU) for overseas study during the author's sabbatical leave.

The author would like to express his sincere gratitude to Dr. D. Rossiter, Dr. D. P. Shrestha, and Dr. C. J. Westen from the International Institute for Aerospace and Earth Sciences (ITC), the Netherlands and Dr. K. Honda from the Asian Institute of Technology (AIT), Thailand for allowing his stay at their institutes and free use of facilities, fruitful discussions and encouragements.

References

1. Beasley, D. B., Hugins, L. F. and Monke, E. J. 1980. ANSWERS: a model for watershed planning. *Transaction of the American Society of Agricultural Engineers*, 23, 938-944.
2. Knisel, W. G. Jr. (ed.). 1980. CREAMS: A field scale model for chemicals, runoff and runoff from agricultural management systems, *USDA Conservation Res. Rep. No. 26.*
3. Kirby, M. J. 1976. Hydrological slope models; the influence of climate. *Geomorphology and climate, Derbysire, E.(ed)*, wiley, pp. 247~267.
4. Morgan, R. P. C. 1986. *Soil Erosion and Conservation, D.A.Davidson(ed.)*, Longman Scientific and Technical, UK copublished with John Wiley Co. 111-139.
5. Morgan, R. P. C., D.D.V. Morgan and H. J. Finney. 1984. A Predictive model for the assesment of soil erosion risk, *J. of Agricultural Eng. Research* 30:245-253.
6. Morgan, R. P. C., J. N. Quinton and R. J. Rickson. 1994. Modelling methodology for soil erosion assessment and soil conservation design: *The EUROSEM Approach, Outlook on Agriculture*, Silsoe college, Cranfield Univ. UK, Vol. 23, No. 1, 5-9.
7. Morgan, R. P. C. 1982. Splash detachment under plant cover: result and implication of a field study, *Trans. of the ASAE*, Vol. 25 987-991.
8. Nearing, M. A. G. R. Foster, L. J. Lane and S. E. Finkner. 1989. A process-based soil erosion model for USDA-Water erosion prediction project technology, *Trans. of the ASAE*, Vol. 32, 1587-1593.
9. Pantone D. J. and R. A. Young. 1996. *AGNPS*: A software program for assessing nonpoint source pesticide pollution, Hort-Technology, 6(4), 344-350.
10. Shrestha, D. P. 1997. Assessment of soil erosion in the nepapese Himalaya: A case study in Lkhu Khola valley, middle mountain region, *Land husbandry*, Vol.2, Oxford & IBH Publishing Co. 59-80.
11. Shrestha, D. P. 2000. Soil erosion modeling, Chapter 24, *ILWIS Application Guide*, ITC, The Netherlands, 323-341.
12. SWCS. 1993. User's guide, *Revised Universal Soil Loss Equation*, version 1.03, Soil and Water Conservation Society, Iowa, USA.
13. Young, R. A. et al. 1987. AGNPS, Agricultural non-point source pollution model, Agricultural research service, Conservation research report 35 USDA, USA.
14. Wishmeir, D. H. and D. D. Smith. 1978. Prediction rainfall erosion from cropland, A guide for selection of practices for soil and water conservation. *USDA Agri handbook, No. 282*, Washington D.C., USA.
15. Wishmeir, D. H. and D. D. Smith. 1978. Predicting rainfall erosion losses. *USDA Agricultural Handbook No.537.*
16. Williams, J. R. and H. D. Brendt. 1977. Sediment yield prediction based on watershed hydrology, *Trans. of the ASAE*, 20: 1100-1104.