Soil Erosion Prediction Using RUSLE with GIS

A case study in upper Chaobai River basin of China

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Abstract—**This research integrated the Rivised Universal Soil Loss Equation (RUSLE) model with RS and GIS techniques to quantify soil erosion risk, took upper Chaobai River basin, China as an example to map soil erosion within ArcGIS environment by using the RUSLE model. The RUSLE factors were developed from local rainfall, topographic, soil classification and land use data. This study proved that the integration of soil erosion models with GIS and RS was a simple and effective tool for soil conservation. Statistical analysis determined that 14537.5 km^2 (75.1%) had minimal to low soil degradation in the upper Chaobai River basin, 2381.0 km^2 (12%) had medium soil degration, 1726.0 km^2 (8.9%) had high to very high soil degradation, only 709.5 km^2 (3.7%) had extreme soil erosion. The study area, in general, was exposed to a low risk of soil water erosion.**

Keywords-RUSLE; Chaobai Rriver ; soil loss; GIS

I. INTRODUCTION

Soil degradation, defined as the decline in soil quality caused by human's misuse, is one of the most important challenges facing mankind. Soil erosion, especially caused by water is the most important factor in soil degradation all over the world. According to Agenda 21, referring to a remote sensing survery in 1990, soil erosion affects 3,670,000 square kilometers in China, covering about 38% of the total land area. Accelerated soil erosion is a worldwide problem because of its economic and environmental impacts. To effectively estimate soil erosion and to establish soil erosion management plans, many computer models have been developed and used. One of the most widely used models to study water soil erosion is the Revised Universal Soil Loss Equation (RUSLE) [1,2], an empirically based model founded on the Universal Soil Loss Equation(USLE)[3]. It is designed to predict long-term average annual soil loss from field slopes under a specific land use and management system, based on the product of slope length and steepness factor (LS), rainfall erosivity factor (R), soil erodibility factor (K), surface cover and management factor (C) and support conservation practices factor (P). The EUSLE is written as

$$A = LS \times R \times K \times C \times P \tag{1}$$

Where A is the soil loss in t/ha over a period selected for R, usually a yearly basis; R is the rainfall–runoff erosivity factor in $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}$; K is the soil erodibility factor ($t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$); L is the slope length factor; S is the slope steepness factor; C is the cover and management factor; and P is the conservation support practices factor. The L, S, C, and P values are dimensionless.

The application of RUSLE in the upstream of the Chaobai River basin offered the following advanges: (1)the required data were readily available and the method was fairly simple to apply; (2) the widespread use of RUSLE had substantiated the RUSLE's usefulness and validity in many countries and regions including some places of China; (3)it was compatible with GIS.

The objectives of this study were: (1) to develop a method based on RUSLE and GIS technology to aid in soil conservation planning at the basin level, and (2) to predict the spatial patterns of soil erosion potential for Chaobai River basin, by adapting each of the RUSLE factors to local conditions.

II. DESCRIPTION OF STUDY AREA

Chaobai River belongs to Hai River water system, is the main river of Miyun reservoir, which is one and only surface water source for drinking water in Beijing, China. Upstream of Chaobai River including two branchs: Chao River and Bai River. In order to study the development of soil degradation, upstream of Chaobai River basin had been selected as a study area. The upper Chaobai River basin locates in Northern of North China Plain（$39^o10' \sim 41^o40'$ N, $115^o25' \sim 117^o45'$ E (Fig.1). which has a total area of 19,354 square kilometers. Annual precipitation is 610mm, of which 80% occurs in wet season between June to September.

III. DATA AND METHODS

A. Data

The climate information required for the R factor were available from 29 hydrological stations within the upper Chaobai River basin (Fig.2-a), operated by the Hydrography Department, Chinese Academy of Sciences (CAS). The topographical parameters such as slope, slope length, and so on, were derived from a digital elevation model (DEM) at the scale of 1:100, 000 with each cell (30m×30m) from Chinese State Bureau of Surveying and Mapping (Fig.2-b). The land

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use and land cover data were derived from Landsat TM image which covering the study area (TM image of 2000) (Fig.2-c). Crop operation and field mangement data were prepared based on field investigation and statistics information. The soil classification map (1:1,000,000) was obtained from Data Center for Resources & Environment Sciences (RESDC), CAS (Fig.2-d).

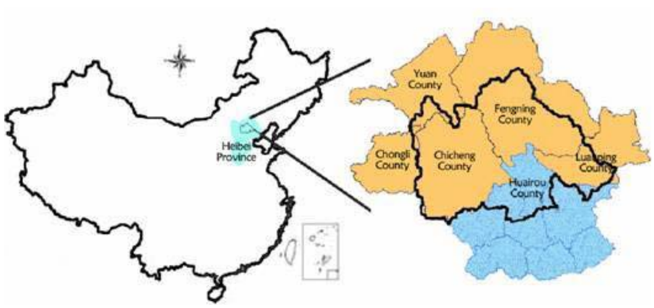

Figure 1. Location of the study basin in China

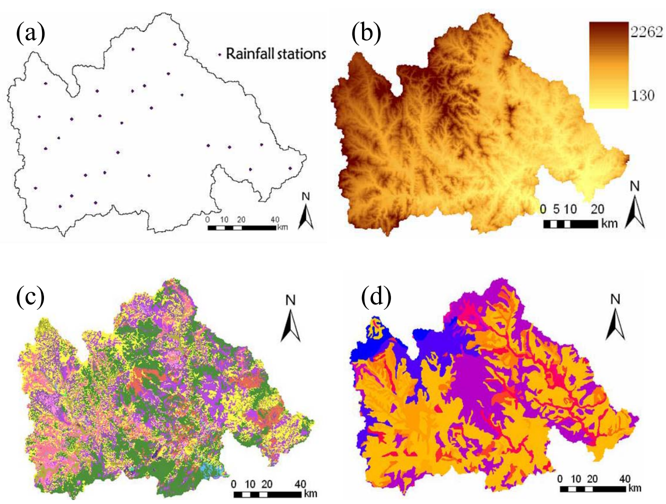

Figure 2. The original GIS layers for RUSLE model of the upper Chaobai River basin. (a) Location of the rainfall stations in the study area; (b) The original DEM with 30m spacing; (c) The land use map of the study area(2000); (d) Soil classification map of the study area.

B. Determining RUSLE factors values

Derivation of the factors required by the RUSLE was well documented in the literatures[4]. The overall method of this study involved use of RUSLE in a GIS environment, with factors obtained from hydrological stations, RESDC and the results of other relevant studies. Individual GIS files were built for each factor in the RUSLE to predict soil loss in a spatial domain. Fig.3 summarizes the methods used to derive each of the factors required by RUSLE.

1) Slope length and steepness factor(lS)

The LS factor is limited to slopes ≤18% because data used to develop RUSLE involved slopes up to 18% only[5]. However, the Chaobai River basin had 48% of its area having slope gradient in excess of 18%. Most of this steeply sloping land was under forest cover or other non-agricultural use. To study the impacts of steep slopes on soil erosion in China, Liu, B.Y. et al. [6] used soil loss data from natural runoff plots ranging from 9% to 55% slopes and reported that soil loss was linearly related to the sine of the slope angle according to the following relationship:

$$S = 21.9\sin\theta - 0.96 \quad (2)$$

Where θ is the slope angle in degrees and S is the slope steepness factor normalized to 9% slope.

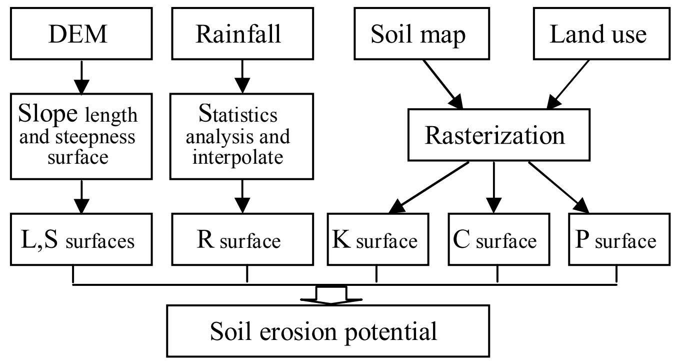

Figure 3. Summary of data and methods used to derive the RUSLE factors

Colligated (2) and equations proposed by McCool et al.[5] for computing S in RUSLE, this research adopted (3) to compute S factors.

$$S = \begin{cases} 10.8\sin\theta + 0.3 & \theta < 5^{o} \\ 16.8\sin\theta - 0.5 & 5^{o} \le \theta < 10^{o} \\ 21.9\sin\theta - 0.96 & \theta \ge 10^{o} \end{cases} \quad (3)$$

To study slope length effects on soil loss under steep slope conditions, Liu B.Y. et al.[7] used data from three sites in China with slope steepness up to 57.7% and reported that for steep slopes, the relationship between slope length and soil loss was closely approximated by the USLE equation. So, the USLE equation (4) for computing L factors was adopted in this study. The LS factors values are shown in Fig.4-a.

$$L = (\lambda / 22.13)^{m} \quad (4)$$

- L: slope length factor;
- λ: slope length (m);
- m: the slope length exponent.

$$m = \begin{cases} 0.2 & \theta < 1\% \\ 0.3 & 1\% \le \theta < 3\% \\ 0.4 & 3\% \le \theta < 5\% \\ 0.5 & \theta \ge 3\% \end{cases} \quad (5)$$

2) Rainfall-runoff erosivity factor(R)

The rainfall factor (R) is a measure of soil loss potential due to climate, such as shower distribution, intensity and the rainfall amount, at a particular location. In this study, the rainfall data were collected from 29 hydrological stations within the study basin from 1991 to 2002, the 29 stations were randomly distributed within the upper Chaobai River basin (Fig.2-a). A data file for each of the 29 stations was generated by averaging recorded amounts of rainfall over consecutive 12 years to calculate the average monthly and annual amount for each point. After experimentation with several interpolation methods, including kriging, the inverse distance weighted(IDW) interpolation method was selected as the means to interpret precipitation in this research. The R factor was interpolated from these 29 point observations in ArcGIS based on a weighted average of the precipitation values from the nearest known points, controlled by specifying a search radius. According to the data requirement, we chose (6)[3] to estimate the R vaules in the study area (Fig.4-b).

$$R=\sum_{i=1}^{12}1.375\times 10^{(1.5\times \lg pi^2/p-0.8188)} \tag{6}$$

- R: the rainfall factor ($MJ\cdot mm\cdot ha^{-1}\cdot h^{-1}\cdot y^{-1}$);
- Pi: the monthly average of rainfall (rnrn);
- P: the annual average of rainfall (mm).

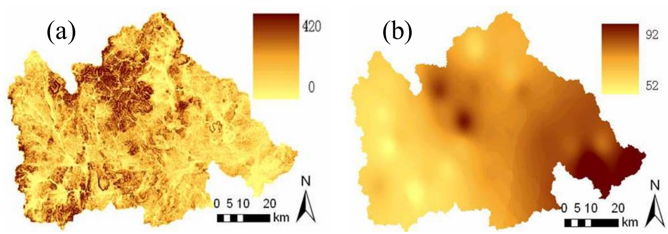

Figure 4. Slope length and steepness factor(LS) and Rainfall-runoff erosivity factor(R) for RUSLE. (a) LS factor; (b) R factor.

3) Soil erodibility factor(K)

The soil erodibility factor (K) represents the average long-term soil and soil-profile response to the erosive power associated with rainfall and runoff. In this research, the K values were estimated using the soil-nomograph method[3]. This method involves collapsing many measurable soil properties to five most closely correlated with soil erodibility. These soil-profile parameters are: percent silt (0.002~0.1mm), percent sand (0.1~2mm), percent organic matter(OM), soil structure(S) and permeability(P). After assigning appropriate permeability and structure degree to each kind of soil, K factors were calculated for each soil mapping unit (Fig.5). A useful algebraic approximation of the nomograph for those cases where the silt fraction does not exceed 70% is:

$$100K = 2.1\times 10^{-4}(12-OM)M^{1.14}+3.25(S-2)+2.5(P-3) \tag{7}$$

- K: the soil erodibility factor ($t\cdot h\cdot MJ^{-1}\cdot mm^{-1}$);
- M: the product of the primary partice size fractions: (%modified silt or the 0.002-0.1 mm size fraction)× (%silt + %sand);
- OM: the percentage of organ of matter in soil (%);
- S : soil structure degree;
- P : permeability class (m/min).

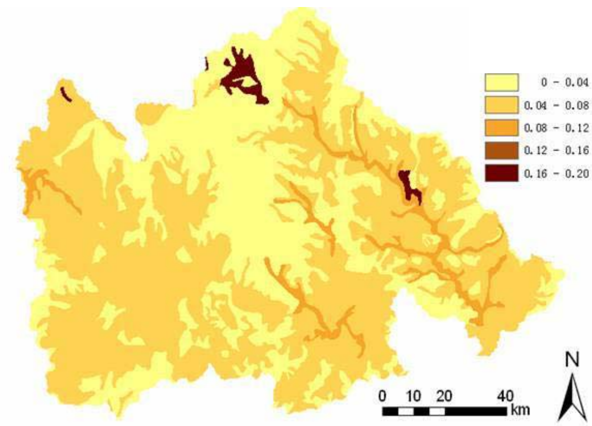

Figure 5. Spatial prediction image of soil erodibility K values based on soil classification map

We can determine the soil structure and permeability degree based on the percentage of organ of matter and the percentage of clay, as Table I and Table II.

TABLE I. SOIL STRUCTURE DEGREE CRITERIA DEPENDING ON THE CONTENT OF ORGANISM

OM(%)	≤0.5	0.51~1.5	1.51~4.0	≥4.0
Soil structure degree (S)	1	2	3	4

TABLE II. SOIL PERMEABILITY DEGREE CRITERIA DEPENDING ON THE CONTENT OF CLAY

Percentage of clay (%)	≤10	10~ 15.9	16~ 21.6	21.7~ 27.4	27.5 ~ 39	≥39.1
Soil permeability (P)	1	2	3	4	5	6

4) Cover and management factor(C)

The cover management factor reflects the effect of cropping and management practices on soil erosion rate[4]. Based on different land use classifications map from Landsat TM/ETM images taken on 2000, C values for this study were determined by empirical numbers from relevant literatures. The resultant C factor map was simply reclassed by using the C values assigned to each land use type(Fig.6-a).

5) Conservation support practice factor(P)

The effect of contouring and tillage practices on soil erosion is described by the support practice factor (P) within the RUSLE model. A value of 1 means no soil conservation support practices as used, the lower the P-value, the more effective the conservation practice is deemed to be reducing soil erosion. According to the technologic manual of soil and water conservation in the upper Chaobai River basin, the major conservation techniques used in the study area were contour tillage and level terraces. In this research, P factors values were evaluated based on the results of other relevant studies[8,9] and the land use and land cover map(Fig.6-b)

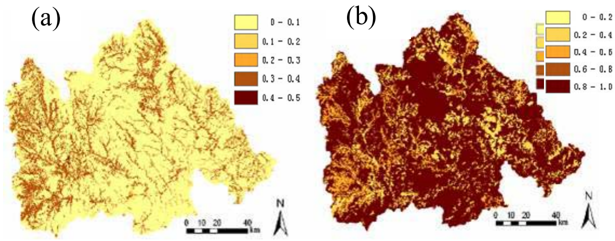

Figure 6. Spatial prediction image of land cover and management factor(C) and Conservation support-practice factor(P). (a)C factor; (b) P factor

IV. RESULT

The RUSLE equation (1) was run within the ArcGIS environment. Then, the quantitative output of predicted soil loss rates for the upper Chaobai River basin resulting from current farming practices were computed, based on the soil erosion intensity classification published by Ministry of Water Resources, P.R.China[10], soil erosion potential values of study area were grouped into six ordinal classes (Table.Ⅲ) and displayed on the map as Fig.7.

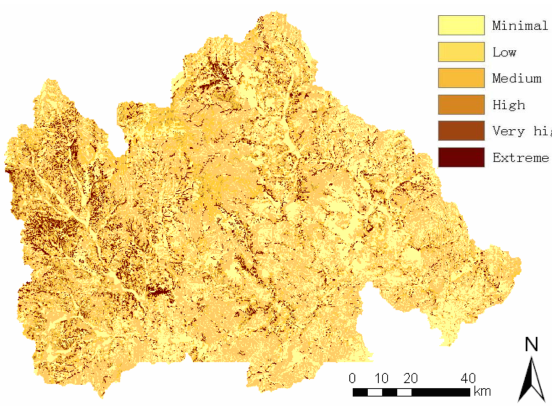

Figure 7. Soil erosion potential under average erodibility conditions in different erosion potential category

TABLE III. SOIL EROSION POTENTIAL IN 2000 IN UPSTREAM OF CHAOBAI RIVER BASIN

Erosion potential category	Average soil erosion potential ($t/hm^2\cdot a$)	Area (hm^2)	Percent (%)
Minimal	0～500	6254.08	32.31%
Low	500～2500	8283.44	42.80%
Medium	2500～5000	2381.02	12.30%
High	5000～8000	881.28	4.55%
Very high	8000～15000	844.72	4.36%
Extreme	≥15000	709.47	3.67%

Statistical analysis(Table Ⅲ) determined that in upper Chaobai River basin, 14537.5 km^2 (75.1%) had minimal to low soil degradation, 2381.0 km^2 (12%) had moderate soil degration, 1726.0 km^2 (8.9%) had high to very high soil degradation, only 709.5 km^2 (3.7%) had extreme soil erosion. The study area, in general, was exposed to a low risk of soil water erosion.

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REFERENCES

[1] Guangxing Wang, George Gertner, Xianzhong Liu, Alan Anderson, “Uncertainty assessment of soil erodibility factor for revised universal soil loss equation”, Cantena, Vol. 46, 2001, pp.1-14.

[2] Natalia Hoyos, “Spatial modeling of soil erosion potential in a tropical watershed of the colombian andes”, Catena, vol. 63, 2005, pp. 85-108.

[3] Wischmeier, W.H., Smith, D.D., “Predicting rainfall erosion losses: a guide to conservation planning, USDA, Handbook”, U.S. Department of Agriculture, Washington, DC, vol.537, 1978, pp. 58.

[4] Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., “Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)”, Agric. Handb., US Department of Agriculture, Washington, DC, vol.703, 1997, pp. 1-251.

[5] McCool, D.K., Foster, G.R., Mutchler, C.K., Meyer, L.D., “Revised slope length factor for the Universal Soil Loss Equation”, Transactions of the ASAE 32, 1989, pp.1571– 1576.

[6] Liu, B.Y., Nearing, M.A., Risse, L.M., “Slope gradient effects on soil loss for steep slopes”, Transactions of the ASAE, vol.37, 1994, pp. 1835–1840,

[7] Liu, B.Y., Nearing, M.A., Shi, P.J., Jia, Z.W., “Slope length effects on soil loss for steep slopes”, Soil Science Society of America Journal, vol.64, 2000, pp. 1759–1763.

[8] Huang, J. L., Hong, H. S., Zhang L. P., “Study on Predicting Soil Erosion in Jiulong River Watershed Based on GIS and USLE”, Journal of Soil Water Conservation, vol.184, 2004, pp.75-79.

[9] Shi, Z.H., Cai, C.F., Ding, S.W., Wang, T.W., Chow, T.L., “Soil conservation planning at the small watershed level using RUSLE with GIS: a case study in the Three Gorge Area of China”, Catena, Vol.55, 2004, pp.33-48.

[10] Zhou W. F., Wu ,B.F., “Soil erosion estimation of the upriver areas of Miyun Reservoir located on the Chaobai River using remote sensing and GIS”, Transactions of The Chinese Society of Agricultural Engineering, vol. 21, 2005, pp.46-50.