Application of RUSLE Model on Global Soil Erosion Estimate

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Soil erosion is one of the most serious environmental problems commonly in over the world, which is caused by both natural and human factors. It is possible to investigate the global issue on soil erosion with the development of global data sets. This research estimated global soil erosion by the RUSLE model with use of a comprehensive global data set. The accuracy of the estimate mostly depends on the available information related to the study area. Present available finest data was used in this study. As the desired objective of estimating soil erosion by water at global scale, the application of RUSLE has shown its positive applicability on large-scale estimates. The study has shown a global view of water soil erosion potential with 0.5-degree grid resolution. Regional validations and examinations have been carried out by different ways. The global mean of annual soil erosion by water was estimated as 1100 ton/ km^2, which agrees with several results obtained in different regions.

Key Words: soil erosion by water, the RUSLE, global estimation, global data sets

1.INTRODUCTION

Land degradation is one of most serious problems commonly in over the globe. Due to the soil erosion by water, fertile soils are being washed away almost everywhere in the world. Worldwide depletion of soil and water resources continues to be a major hazard, particularly, in the third world. Soil conservation is a significant socio-environmental issue that reflects the wellbeing of the people in every country in the world. Through the recognition of the severity of the erosion problem worldwide and identification that soil erodibility is controlled by combination of many different erosion factors, such as soil properties, topography, climate, and especially the human activities. Many attempts have been made on the modeling of soil erosion.

The Revised Universal Soil Loss Equation (RUSLE) is modified from the Universal Soil Loss Equation (USLE) by the USDA (United States Department of Agriculture), which computes average annual soil loss from sheet and rill erosion. The annual soil loss by water from a field is expressed by a linear relation with the major erosion factors such as rainfall, soil erodibility, slope length, slope steepness, soil and crop management, and supporting conservation, it is given by[1)]

$$A = K \times R \times LS \times C \times P \qquad (1)$$

where A is the mass of annual soil erosion (ton/km^2); R is rainfall and runoff erosivity (kJ mm km^{-2} hr^{-1} yr^{-1}); K is soil erodibility (ton km^2 hr km^{-2} kJ^{-1} mm^{-1}); LS is slope parameter, C is soil and crop management, and P is conservation practice-erosion inhibition factor.

This research addresses on estimating soil erosion at global scale by the RUSLE. The land surface parameterization of this application incorporates the most recent available global data sets of highest resolutions using GIS technique. The regional analysis and evaluation of the results have been discussed in the paper.

2. DATA AND PROCESSING

This study has used four global data sets of land cover, digital elevation, soil property, and precipitation in the possible finest resolutions from different sources. The 0.5-degree grid size is used to uniform the parameter estimations from different resolutions, which has the length size varying from near 10-km to about 50-km. Sub-grid heterogeneity was considered in the data processing. Soil erosion estimated in a 0.5-degree grid is the mean value of soil erosion from different fields within the same

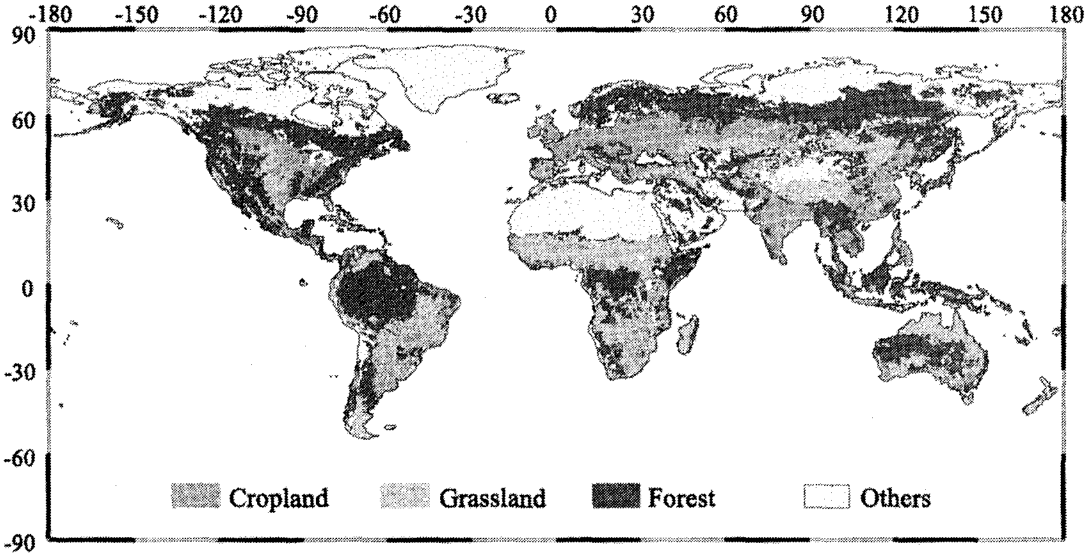

Fig. 1 Present global land cover

grid, not the sediment moving out of the grid. The soil erosion estimated in this study is the potential soil loss.

(1) The *C* and *P* factors

The *C* and *P* factors were estimated from the USGS global land cover map of 1-km resolution. The *C*-factor represents resistance of the ground surface to the transport of water-soil mixture. The *P*-factor stands for erosion inhibition effect, and reflects partly people's effort (resistance) not to allow soil erosion. The *C* and *P* are grouped into 9 land cover categories, which are given in **Table 1**.

Table 1 *C* and *P* factors and the classification of land use

Land cover	*C*-factor	*P*-factor
Drainage / Water	0.01	1.0
Built up Area	1.00	1.0
Barren Area	0.28	1.0
Forest / Shrub	0.01	1.0
Agriculture area	0.65	0.5
Paddy field	0.10	0.5
Grassland	0.15	0.5
Wetland	0.56	1.0
Mixture	0.40	0.5

To estimate the *C* and *P* factor, firstly, the original landuse map of 24 categories is reclassified into a new 9-types land cover map (**Table 2**) by their similarity. Then the coverage ratio of each land cover type in a 0.5-degree grid is calculated. The value of *C* and *P* in a 0.5-degree grid is the area average of all landuse types in the same grid. The cultivation and deforestation mostly affect the soil erosion comparing with other land practices. **Fig. 1** shows the present situation of global land uses.

Table 2 Landuse types used in the RUSLE comparing with USGS classification

RUSLE Category	USGS Classification
Water bodies	Water Bodies Snow or Ice
Built up area	Urban and Built-up Land
Barren area	Barren or Sparsely Vegetated
Forest / Shrub	Deciduous Broadleaf Forest Deciduous Needle leaf Forest Evergreen Broadleaf Forest Evergreen Needle leaf Forest Mixed Forest Shrub land
Agriculture	Dry and Crop land and Pasture Cropland/Grassland Mosaic Cropland/Woodland Mosaic
Paddy field	Irrigated Cropland and Pasture Mixed Dry land/Irrigated Cropland and Pasture
Grassland	Grassland Mixed Grassland and Shrub Savanna
Wetland	Herbaceous Wetland Wooded Wetland
Mixture	Herbaceous Tundra Wooded Tundra Mixed Tundra Bare Ground Tundra

(2) Slope parameter, *LS*-factor

Slope length and slope steepness parameters are calculated from GTOPO-30 data set. Elevations in GTOPO-30 are regularly spaced at 30-seconds (about 1-km). These parameters are calculated based on river-hillslope assumption, which is averaged over 0.5-degree grid size[2]. *LS* -factor is determined

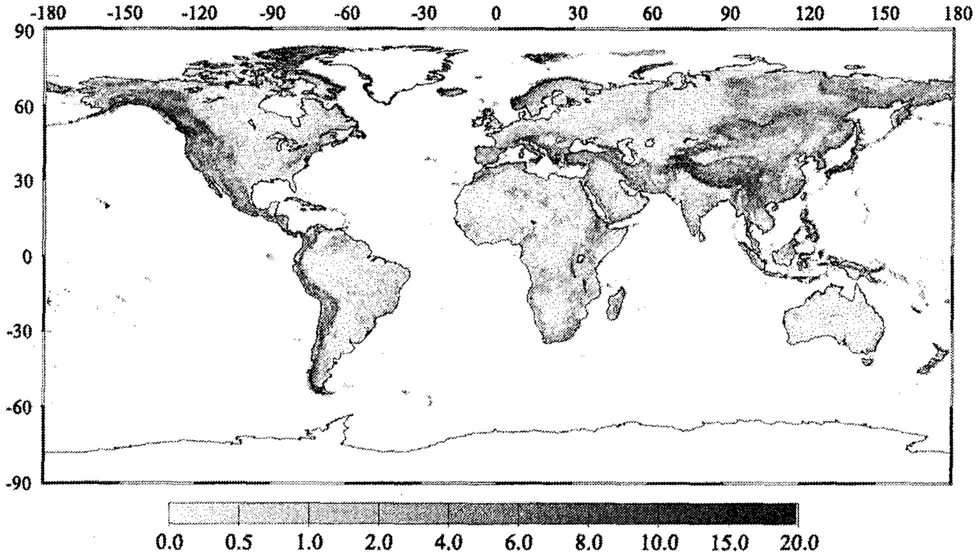

Fig. 2 Distribution of *LS*-factor (slope parameter)

by the length and the angle of the slope of the ground, given by[1)]

$$LS = \left(\frac{\lambda}{22.1}\right)^{\xi}\left(65.41\,S^2 + 4.56\,S + .065\right) \quad (2)$$

where S is the land surface slope (m/m), λ is the slope length (m), and ξ is a parameter dependence upon slope. The value of ξ varies with slope and it is estimated by

$$\xi = \frac{0.3\,S}{S + \exp(-1.47 - 61.09S)} + 0.2 \quad (3)$$

Globally, mean slope angle is approximately five degrees, and minimum slope length value is approximately 1-km estimating from the available global elevation data. **Fig. 2** shows the global distribution of *LS*-factor, from which it can be found that the high values correspond to the mountainous areas.

The most applicable area of the RUSLE is the fields where the slope less than 30% and length does not excess 100-m. An examination determining the relationships between slope length, slope angle and *LS*-factor has been carried out. The *LS*-factor varies with the slope and length in the same trend. But the slope and length change in an opposite way when the DEM (digital elevation model) grid size increases. The result showed that the *LS*-factor could be compensated by the opposite changes of slope and length when the coarse elevation information is used. Because the RUSLE was validated mostly in the areas where the slope is less than 30%, soil erosion estimated in the steep mountainous areas is less reliable. According to the global map of slope angle, most of areas, which have the slope less than 30%. There are some areas with slope angle excess 30%. The global soil erosion that estimated by the RUSLE using the GTOPO-30 data set has different accuracy in the plain and steep areas.

(3) Soil erodibility, *K*-factor

This study uses global soil map from the FAO to estimate the soil erodibility (*K*-factor). The origin data exists with 5-min grid size. This 5-min global grid size data set is first converted into 30-min by taking the majority. *K*-factor is expressed as function of sand, silt, clay and organic carbon concentration. The global estimate of *K*-factor is obtained following the formulation with the use of four global maps of such involved parameters. The *K*-factor is expressed as rate of soil loss per rainfall erosion index unit (ton km^2 hr km^{-2} kJ^{-1} mm^{-1}) as measured on a unit plot, given by

$$K = \left[0.2 + 0.3\exp\left\{-0.0256SAN\left(1 - \frac{SIL}{100}\right)\right\}\right]$$
$$\left(\frac{SIL}{CLA + SIL}\right)^{0.3}\left(1.0 - \frac{0.25\,OrgC}{OrgC + \exp(3.72 - 2.95OrgC)}\right) \quad (4)$$
$$\left(1.0 - \frac{0.7\,SN1}{SN1 + \exp(-5.51 + 229\,SN1)}\right)$$

where *SAN*, *SIL*, *CLA* and *OrgC* are sand, silt, clay and organic carbon contents of the soil (%), respectively. The *K* value varies from 0.1 to 0.5.

The sensitivity of *K*-factor to the soil texture has been analyzed. The eleven basic soil types are selected according to the USDA soil texture triangle. By changing the organic carbon ratio from 0% to 50%, the variations of *K* values for each soil type are shown in **Fig. 3**. For all 11-soil types, soil erodibility decreases dramatically where organic carbon concentration increases from 0% to 5%. After this threshold, *K* increases slightly with soil

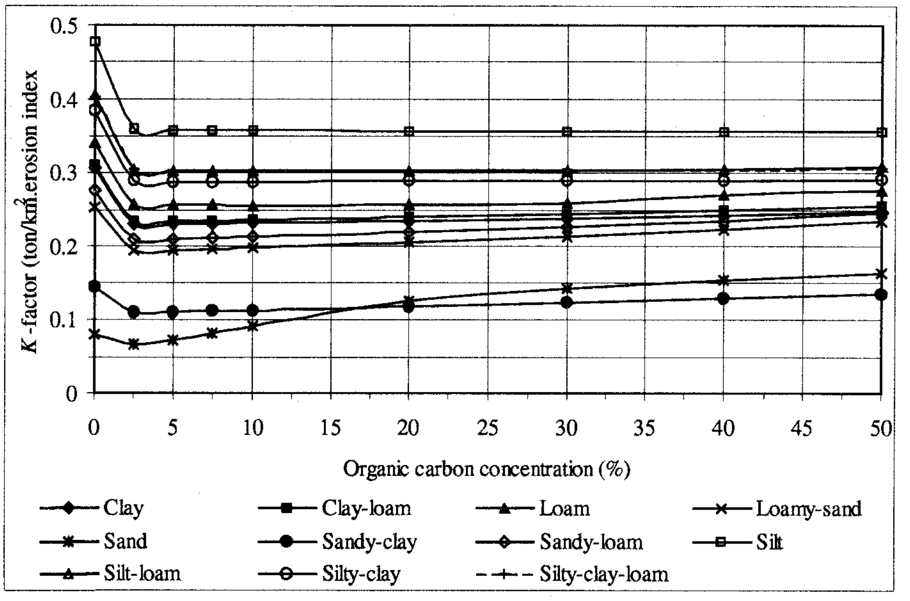

Fig. 3 Variation of *K*-factor with Changing of Organic Carbon Content

types, which have sand origin such as sand, sandy clay, sandy loam, and loamy sand. For soil types that have the origins from silt and clay, *K* values are almost stable when organic carbon concentration excesses the threshold of 5%. The variation of organic carbon within 0% to 5% is the most sensitive range for soil erodibility of all soil types. And it has been found that the organic carbon content is less than 5% in approximate 85% of the global land.

(4) Rainfall erosivity, *R*-factor

A 15-year period of global daily meteorological data by Nijssen *et al.*[3] was used to calculate rainfall erosivity (*R*-factor). This data set contains precipitation, minimum and maximum air temperatures, which is in 2-degree spatial resolution and daily temporal resolution from 1979 to 1993. The *R*-factor, the rainfall-runoff erosivity, presents the effects of precipitation on soil erosion. It is expressed with an annual integration of the multiplication of daily rainfall energy and rainfall intensity. The *R* (kJ mm km^{-2} yr^{-1} hr^{-1}) is given by

$$R = E * I$$

$$E = 43.27 * (1 - 0.72 e^{-0.5 I_{30}}) N \quad (5)$$

$$I_{30} = \frac{N}{24}\left(\frac{24}{N}\right)^{2/3}$$

where E is the rainfall energy (kJ/km^2); I is the rainfall intensity[4] (mm/hr); N is daily rainfall (mm/day); T is duration of rainfall data in hours.

The estimated global *R*-factor (**Fig. 4**) represents land areas with potential soil erosion under the

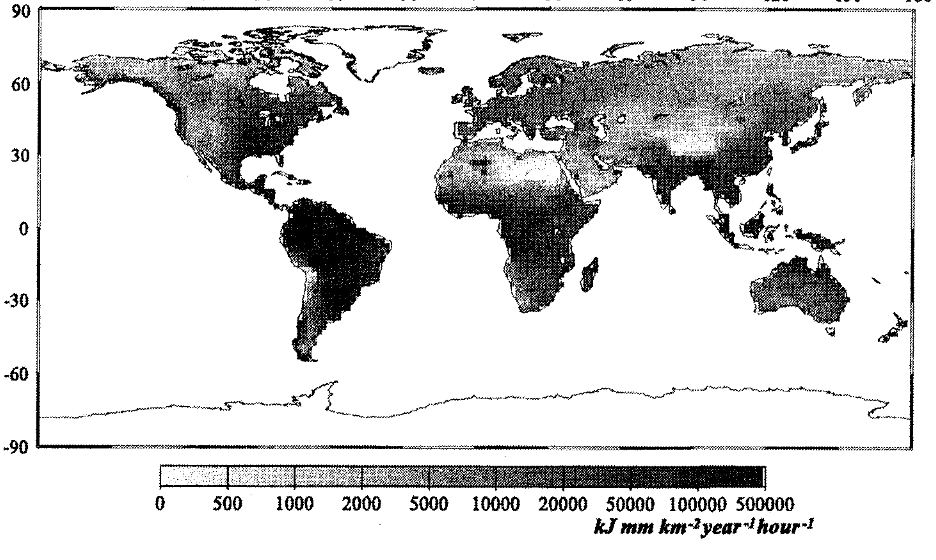

Fig. 4 Distribution of *R*-factor (rainfall erosivity)

effect of precipitation. Its value is estimated to vary from zero to 10000 kJ mm km^{-2} yr^{-1} hr^{-1}. Areas observed under big effect of precipitation are Northeast America, South America-Amazon, East and Southeast Asia, and central Africa. Especially, Southeast Asia and the Amazon basin are the areas under the greatest effect of precipitation.

3. RESULT AND DISCUSSION

The global map of soil erosion presents an overview of soil erosion rate and distribution. The global mean of annual soil erosion of 1979-1993 is shown in **Fig. 5**. The 15-years mean soil erosion rate is about 1100 ton km^{-2} yr^{-1} and varies from lowest value of nearly zero to the peak of 50000 ton km^{-2} yr^{-1}. This spatial variation of erosion rate is caused by the difference of local characteristics, such as rainfall, topography, landuse and land cover. **Table 3** provides general soil rates of regions or continents. These regions are separated on basis of common geographical delineation. The regional distribution of average annual soil erosion rate comes the highest in South America region (1674 ton km^{-2}) followed by Asia (1580 ton km^{-2}) and Europe at 1341 ton km^{-2}. It appears that Australia has lowest mean erosion rate, of 390 ton km^{-2} yr^{-1}.

The results were compared with the globally estimated results with statistical information at some selected locations where soil erosion information is available. Two locations were selected, North America and Southeast Asia. The soil loss information was introduced by different methods and was obtained from many different sources (**Table 4**). It was found in this comparison that in the North America region, the results here are quite reasonable. There are no big differences between the present result and reported estimate. In Asian region, however, the obtained results seem to be variable, especially for Thailand and Vietnam. Thus, it is rising a question that why errors seem to occur more in East Asia rather than in North America.

It was found that the areas with good results are in plain areas where the slope angle is basically less than 5-degrees. In the case of East Asia where topography is commonly formed by mountains, the estimated soil loss volume is extremely high. The slope angle in these areas is sometimes higher than 20-degrees.

Table 3 Regional Analyses (unit: ton km^{-2} yr^{-1})

Region	Range	Mean
North America	0.0 ~ 98000	690
South America	0.0 ~ 88000	1670
Australia	0.0 ~ 52000	390
Africa	0.0 ~ 52000	580
Asia	0.0 ~ 199000	1580
Europe	0.0 ~ 62100	1340
Global	0.0 ~ 199000	1150

It may be difficult to directly compare two different estimates of global soil erosion because of various models and scales. However, comparing the soil erosion pattern with other studies, it is helpful to judge the reasonability of the results. A study of global sediment yield has been introduced by Walling and Weep[10]. In which, only the suspended sediment yield in the main rivers in the world has been included. The soil erosion studied in this research is the sediment moving from small fields into local rivers. When the eroded soils from field transport through rivers, some of them deposit at somewhere. The yield at a river section is part of the erosion. However, the sediment yield gives a

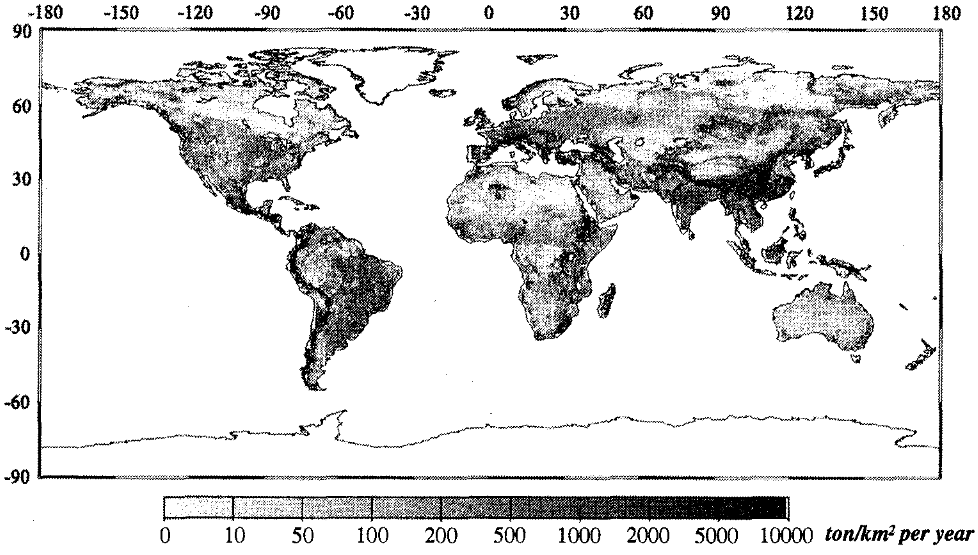

Fig. 5 Present Situation of Global Soil Erosion by Water (mean of1979-1993)

Table 4 Regional Analyses of the Results

Country	Present estimation (ton km^{-2} yr^{-1})	Other sources		
		Value (ton km^{-2} yr^{-1})	Method	Sources
China	2962	1500	Statistic	Guo T., 2000[5]
Thailand	1046	1450	USLE	Sha B. , 2000[6]
Vietnam	9300	5600	Statistic	Pham T.N., 2000[7]
U.S.A.	622	600	USLE	USDA, 1997[8]
Canada	199	150	Statistic	Shelton et al., 2000[9]

checking of the soil erosion estimated in this study at global scale. The pattern of sediment yields in most of the world agrees with the distribution of soil erosion in this study, in which the most serious soil erosions are in the Southeast Asia. In north America and Amazon basin, present estimations of soil erosion show more variability than Walling and Weep's map[10]. It can be concluded that the result issued by this study is reasonable.

4. CONCLUSION

Global soil erosion has been estimated with the use of the RUSLE model and comprehensive global data sets. The latest global data sets with the finest available resolution were used in this study. The accuracy of the estimate mostly depends on resolution available data, rather than how large the area it considers. It is possible to investigate the global issue on soil erosion with the development of global data sets. As the desired objective was to estimate the mean annual soil erosion at global scale, the use of RUSLE shows its positive applicability on large-scale estimates. Although reference sources are limited, the validations and examinations made this estimates become more confident. The study has shown a global view of annual soil erosion with approximate 0.5-degree grid resolution. The result was examined by different methods. The mean annual soil loss rate was estimated about 1100 tons km^{-2}, which is fairly agrees with several other researches.

Additional studies are needed to verify the accuracy of erosion figures and the rate of changes. It is necessary also to carry out, at the same time, getting better data resolution and revise the formulation of involved parameters. The global soil erosion estimated in this study is the rain-made soil loss. However, the soil loss by wind is also a major component of soil erosion. This issue should be studied in the future, in addition to consider full feature of global soil loss. Another topic on global soil erosion estimate is the result evaluation. The traditional observation of sediment is the river sediment yield at particular cross sections, and most of these measurements are suspended sediments only. It needs new technique to observe the surface soil erosion in large scale. One possibility is use of remote sensing technique.

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