GLOBAL SOIL LOST ESTIMATE USING RUSLE MODEL: THE USE OF GLOBAL SPATIAL DATASETS ON ESTIMATING EROSIVE PARAMETERS

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ABSTRACT

Soil erosion is one of the most serious environmental problems commonly in over the world, which is caused by both natural and human factors. GIS and remote sensing technique has recently become a powerful tool for investigations of natural resources and environmental situation. As an inheritance of the development of GIS technique, it is possible to investigate the global issue on soil erosion. This research focused on estimation of global soil erosion by the RUSLE model with the use of a comprehensive global dataset. 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. Global datasets of land cover, digital elevation, soil property and precipitation act as indispensable database in getting erosive parameters used in the RUSLE model. Data sources and data processing methods were carefully discussed in this paper. 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: *global data sets, soil erosion by water, the RUSLE, global estimate*

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)]

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

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

This research addresses on estimating global soil erosion with 0.5-degree spatial resolution 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 grid, not the sediment moving out of the grid. The soil erosion estimated in this study is the potential soil loss.

2.1 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**.

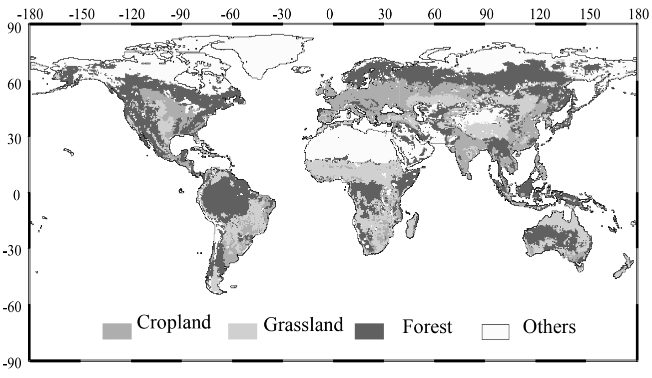

Figure 1. Present Global Land cover

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	0.01	1.0
Agriculture area	0.65	0.5
Paddy field	0.10	0.5
Grassland / Shrub	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 land use types in the same grid. The cultivation and deforestation mostly affect the soil erosion comparing with other land practices (**Figure 1**).

Table 2. Landuse types used in the RUSLE compared 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	Deciduous Broadleaf Forest, Deciduous Needle leaf Forest, Evergreen Broadleaf Forest, Evergreen Needle leaf Forest, Mixed Forest
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/Shrub	Grassland, Shrub land, Mixed Grassland and Shrub, Savanna
Wetland	Herbaceous Wetland, Wooded Wetland
Mixture	Herbaceous Tundra, Wooded Tundra, Mixed Tundra, Bare Ground Tundra

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

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

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

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

Globally, mean slope angle is approximately five degrees, and minimum slope length value is about 1-km estimating from the available global elevation data. The most applicable area of the RUSLE is the field where the slope less than 30% and the 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 few areas come with slope angle excess 30%. Thus, the global soil erosion rate that estimated by the RUSLE using the GTOPO-30 data set has different accuracy in the plain and steep areas.

2.3 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 the rate of soil loss per rainfall erosion index unit (ton/km^2 per erosion index) as measured on a unit plot, given by

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

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 **Figure 2**. 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 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.

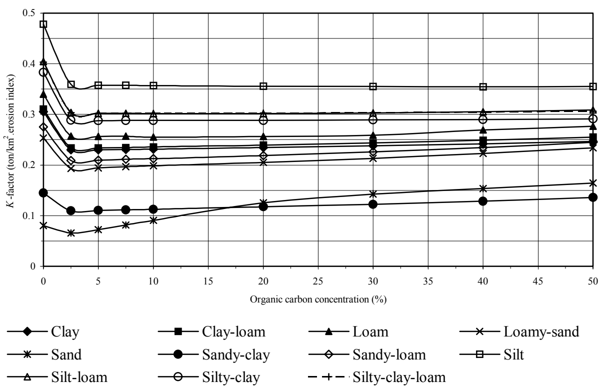

Figure 2. Variation of *K*-factor with Changing of Organic Carbon Content

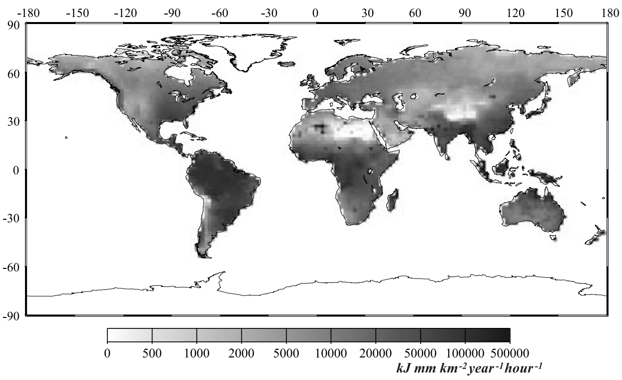

Figure 3. Distribution of R-factor (Rainfall erosivity)

2.4 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 (**Figure 3**) represents land areas with potential soil erosion under the 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 **Figure 4** presents an overview of 1979-1993 mean annual soil erosion rate and distribution. The 15-years mean annual soil erosion rate is about 1000 ton km^{-2} yr^{-1} and varies from lowest value of nearly zero to the peak of 50000 ton km^{-2} yr^{-1}. This result agrees with the global balance requirement by the geographical study. 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 erosion rate of regions or continents. These regions are separated on basis of common geographical delineation of the globe. The average annual soil erosion rate comes highest in South America region (1674 ton km^{-2} yr^{-1}) followed by Asia (1580 ton km^{-2} yr^{-1}) and Europe at 1341 ton km^{-2} yr^{-1}. It appears that Australia has lowest rate, of 390 ton km^{-2} yr^{-1}.

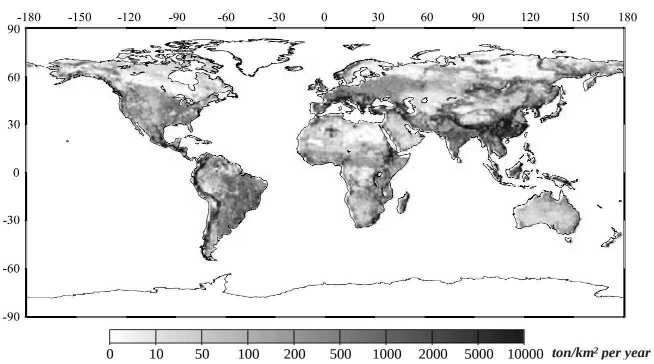

Figure 4. Present Situation of Global Soil Erosion by Water (mean of 1979-1993)

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

Region	Min.	Max.	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

These estimated results were then compared with previous statistical soil erosion information for validate and examination. Two locations, North America and Southeast Asia were selected. The soil loss information of these locations was introduced by different methods and was obtained from many different sources. Apparently, results in the North America region are quite reasonable and there are no big differences between the two results. 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 much higher than real amount. The slope angle in these areas is sometimes higher than 5-degrees. Although results from the two kinds of compared maps may be different, (this is possibly caused by the use of different soil estimate models and in different scales), similar pattern of soil loss distribution between them can give observer some reasonable ideas.

A study of global sediment yield was introduced by Walling and Weep[7)]. In which, only the suspended sediment yield in the main rivers in the world is 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 checking of the soil erosion estimated in this study at global scale. This gave a meaningful idea that the pattern of global sediment yield agrees with the distribution of soil erosion in this study, in which the most serious soil erosions are in the Southeast Asia. It can be concluded that the result issued by this study is reasonable.

4. CONCLUSION

Global soil erosion rate has been estimated with the use of the RUSLE model and comprehensive global data sets. The latest data 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. This feature makes it possible to the reality of the result using up-to-date global data sets with possible finest resolution. The use of RUSLE shows its positive applicability on large-scale estimates. Although reference sources are limited, the validations and examinations made estimated results 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 1154 tons $km^{-2}year^{-1}$ was reasonable and it fairly agrees with several results obtained from different regions.

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.

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