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Methodology of Time Series of Soil Erosion Dataset in Water Erosion Area of China in Five-year Increments (2000–2015)

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Abstract: With the change of global climate and the increase of human activities, soil erosion has become a national even a global issue, which can limit the sustainable development of economy and society. By using the Universal Soil Loss Equation (USLE), we estimated the reference values of the annual soil erosion in China in 2000, 2005, 2010 and 2015 respectively. We calibrated the rainfall erosivity factor (*R*) based on climate zones and the cover-management factor (*C*) based on land-cover types and agricultural crops. The support practice factor (*P*) was also revised based on crop types and crop land slope. The results indicate that: (1) The hotspots with major erosion rates are predicted to occur in Yunnan-Guizhou Plateau, Loess Plateau and the foothill area of Kunlun Mountains, accounting for 9.65% of the statistical area. (2) The hotspots with a rapid increase during the study period are in the arable area of Xinjiang, Sichuan Basin, southeastern Yunnan-Guizhou Plateau, Yangtze Plain and Northeast Plain, and the erosion areas with a significant decrease are distributed in the southern and eastern Loess Plateau, Qinling Mountains and Southeast Coast of China. This dataset includes soil erosion values of China in 2000, 2005, 2010 and 2015 respectively, of which unit is $t\cdot hm^{-2}\cdot a^{-1}$, cell size is 1 km, and format is .tif. These data are expected to provide a basis for making soil conservation measures in different regions in China.

Keywords: Soil erosion; USLE model; Rainfall erosivity; Soil conservation

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1 Introduction

Soil erosion can lead to soil nutrient loss, water siltation and eutrophication, carbon storage reduction, biodiversity decline, and even population poverty. It has become one of the most serious threats to the environment and economy in China and even the world[1–4]. Quantitative assessment and change analysis of long-term soil erosion can provide a certain theoretical basis and reference for researchers and decision-makers related to agriculture and geo-biochemical cycles[5].

The USLE (Universal Soil Loss Equation) model is an empirical model developed by the United States Department of Agriculture (USDA). This model predicts the long-term average annual soil loss caused by the processes of thin layer and rill erosion[6,7], describing the relationship between the soil loss rate and control factors, such as rainfall, soil properties, topography, vegetation coverage, and land management[8]. With the development of computing technology, the advancement of geographic information systems (GIS) and the availability of high-resolution images, the use of the USLE model in assessing large-scale water erosion has become a reasonable and feasible method[9,10]. At present, most of the studies estimating soil erosion on a large scale or even a global scale are based on the USLE equation and its revised versions[2,11–15]. There have been a lot of studies in China based on USLE and related models to carry out watershed-scale soil erosion assessment[16–18].

Currently, some studies have proposed optimization methods of the input factors for the USLE model[19–24]. For example, based on the climate zone and land use type on the regional scale, the rainfall erosivity (R) factor and vegetation coverage and management (C) factor in the USLE model are calibrated[19,20]. However, the calculation method of other factors is relatively less optimized, such as the soil and water conservation measure (P) factor. In addition, there are relatively few optimizations of soil erosion factors and soil erosion assessments on a national scale. In order to clarify the distribution pattern and trend of soil erosion in water erosion areas in China, this study uses the newly published quantification and optimization methods of factors in USLE model. The factors concerned are updated according to the geographic and climatic features in China, which aims to improve the accuracy of the estimation of soil erosion calculated by the USLE model.

2 Metadata of the Dataset

The metadata of the Time series of soil erosion dataset in water erosion area of China in five-year increments (2000–2015)[25] is summarized in Table 1. It includes the dataset full name, short name, authors, year of the dataset, temporal resolution, spatial resolution, data format, data size, data files, data publisher, and data sharing policy, etc.

3 Methods

3.1 Data Source and Processing

The rainfall data used in the calculation of this dataset are the daily precipitation data from 1981 to 2015, recorded at 839 national-level stations across China. They are downloaded from the China Meteorological Data Network[1] and the SPSS software is employed to obtain the annual precipitation, latitude, longitude, and altitude of each station. The climate zone is based on the Köppen-Geiger climate classificaion[27] . The original source of the Digital

[1] China Meteorological Data Network. https://data.cma.cn.

Elevation Model (DEM) data is from the US Geological Survey's ASTER GDEM data. The filling processing is performed before the calculation. China's annual vegetation index (Normalized Vegetation Index, NDVI) data is based on SPOT/VEGETATION NDVI, generated by the maximum value composite method. The resolution of the NDVI data is 1 km × 1 km and the format is .tif. The land cover data are the CCI LC (Climate Change Initiative Land Cover) data of the European Space Agency (ESA)[28], of which the resolution is 300 m × 300 m and the format is converted to .tif before calculation. China's crop data (crop types and sown area) are downloaded from the National Data of the National Bureau of Statistics in .csv format. The soil composition data are downloaded from the International Soil Reference and Information Centre (ISRIC). The content of clay, silt, sand, and organic carbon in the soil data is used, of which the resolutions are 250 m × 250 m and the format is .tif. For precipitation data, NDVI, land cover, and crop data, the data in 2000, 2005, 2010, and 2015 are selected.

Table 1 Metadata summary of the Time series of soil erosion dataset in water erosion area of China in five-year increments (2000–2015)

Items	Description
Dataset full name	Time series of soil erosion dataset in water erosion area of China in five-year increments (2000–2015)
Dataset short name	SoilErasionChina_2000-2015
Authors	Li, J. L. Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, lijialei97@163.com Sun, R. H. AAM-6837-2021, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, rhsun@rcees.ac.cn Xiong, M. Q. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, xiongmq@igsnrr.ac.cn Chen, L. D. Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, liding@rcees.ac.cn
Geographical region	Water erosion area of China
Year	2000, 2005, 2010, 2015
Temporal resolution	Annual
Spatial resolution	1 km × 1 km
Data format	.tif
Data size	The data volume is 1.91 GB (compressed into a file, 95.9 MB)
Data files	12 data files for soil erosion values of China in 2000, 2005, 2010 and 2015
Foundation	Ministry of Science and Technology of P. R. China (2017YFA0604704)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	*Data* from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data* & *Discovery*). *Data* sharing policy includes: (1) *Data* are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use *Data* subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute *Data* subject to written permission from the GCdataPR Editorial Office and the issuance of a *Data* redistribution license; and (4) If *Data* are used to compile new datasets, the 'ten per cent principal' should be followed such that *Data* records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[26]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS

3.2 Algorithm Principle

We use the USLE (Universal Soil Loss Equation) model to estimate the soil erosion rate in water erosion areas in 2000, 2005, 2010, and 2015 and make certain adjustments in the newly published methods of factor calculation according to the actual backgrounds in China. The model equation is as follows:

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

where A is the annual soil erosion rate predicted by the model (t·hm^{-2}·a^{-1}); *R* is the rainfall erosivity factor (MJ·mm·hm^{2}·h^{-1}·a^{-1})[29]; *LS*, with *L* being the slope length factor and *S* being the slope factor, is the terrain factor[30], dimensionless and is calculated in this study by using DEM data; *K* is the soil erodibility factor (t·hm^{2}·h·hm^{-2}·MJ^{-1}·mm^{-1})[31,32]; *C* is the vegetation cover and management factor (dimensionless)[33]; *P* factor is the water and soil conservation measure factor (dimensionless)[34]. After each factor was calculated according to the minimum resolution of the input data, all the factors were resampled to a resolution of 1 km × 1 km by bilinear interpolation and multiplied to obtain the soil erosion rate in each year[35].

3.2.1 Calibration of the *R*-factor Based on Climate Zone

The traditional calculation method of *R*-factor requires 30-minute rainfall intensity data as input data[7], which is difficult to complete in a large-scale and long-term serial study. This study used annual precipitation combined with multi-parameter input to calculate the *R*-factor according to different climatic zones. Naipal[20] fitted the regression between *R*-factor value and annual precipitation (*P*, mm), elevation (*Z*, m), and simple precipitation intensity index (*SDII*, mm·day^{-1}) on the basis of the measured data from rainfall stations in different climate zones in the United States:

$$R = (P, Z, SDII) \quad (2)$$

Different calculation equations were used in accordance with different climatic zones, which are classified based on the Koppen-Geiger climate zoning method[27,36]. Naipal's method was used in 6 of these climatic zones[35]. In this study, the following steps were taken to calculate the *R*-factor. Firstly, the annual precipitation of each rainfall station was calculated based on the daily precipitation data. Secondly, the average annual rainfall erosivity was calculated by this method. Lastly, the spatial interpolation of *R*-factor values was predicted by means of the ordinary Kriging interpolation method to achieve its accuracy[37].

3.2.2 Calibration of *C*-factor Based on Land Cover

The *C*-factor is closely related to the types of vegetation and crops[38,39], so Borrelli's method[12] was used in this study to adjust and calculate the *C*-factor of arable and non-arable land in China separately. The *C*-factor of arable land is calculated according to the main crop types and sown areas of arable land in each province issued by the National Bureau of Statistics. Some adjustments were made according to the actual agricultural conditions in China before the classification of the released crops into 10 categories, and the *C* value of the national arable land was calculated by the following equation[35]:

$$C_{\text{crop}} = \sum_{n=1}^{10} \mathrm{C}_{cropn} \times \% Region_{Cropn} \quad (3)$$

where C_{cropn} represents the *C*-factor of the *n*-crop, and % $Region_{Cropn}$ represents the share of this crop in the agricultural land of the given province.

For non-arable land, *C*-factor depends on vegetation coverage and land cover types. This study estimated the *C* value in non-arable land by following both the empirical *C* values of various vegetation coverage types in the literatures[12, 19]and land use data and NDVI data [35]:

$$C_{NonArable} = \mathrm{Min}(C_{NA}) + \mathrm{Range}(C_{NA}) \times (1 - F_{cover}) \quad (4)$$

$$F_{cover} = VFC = (NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min}) \quad (5)$$

where Min(C_{NA}) is the minimum value of C_{NA}, Range(C_{NA}) is the difference between the maximum and minimum C_{NA}, and F_{cover} is the vegetation coverage.

3.2.3 Calibration of *P*-factor Based on Topographic Features

The *P*-factor of the USLE/RUSLE model is rarely taken into consideration in large-scale modeling of soil erosion risk[40]. Xiong *et al*. summarizes the differences in *P* values of arable land with different slopes and different soil and water conservation measures on the basis of numerous literatures[41–43]. In this study, based on Xiong *et al*.'s[43] assignment method of *P*-factor and the land use types, different *P* values were assigned. The horizontal paddy field was assigned a value of 0.2, and *P*-factor values in other arable areas were assigned according to the slope. The *P* value for arable land with a slope of 10° or less than 10° was taken as 0.5, the *P* value for arable land with a slope of greater than 10° and less than or equal to 25° was taken as 0.6, the *P* value for arable land with a slope greater than 25° and less than or equal to 45° was taken as 0.8, and *P* value for arable land with a slope greater than 45° was taken as 1. For other non-arable land, the *P* value is 1.

3.2.4 Calculation Methods of Other Factors

This study used the DEM data with a resolution of 30 m × 30 m to calculate the *L*-factor[7,44–45]. The *S*-factor was calculated by following the method in the CSLE model proposed by Liu *et al*.[46] according to the different slope degrees[35]. The soil erodibility factor *K* was calculated by following the EPIC model[47]. The input data included the percentage content of sand, silt, clay, and organic carbon in soil[35].

3.3 Technical Route

The technical route of the dataset development is shown in Figure 1.

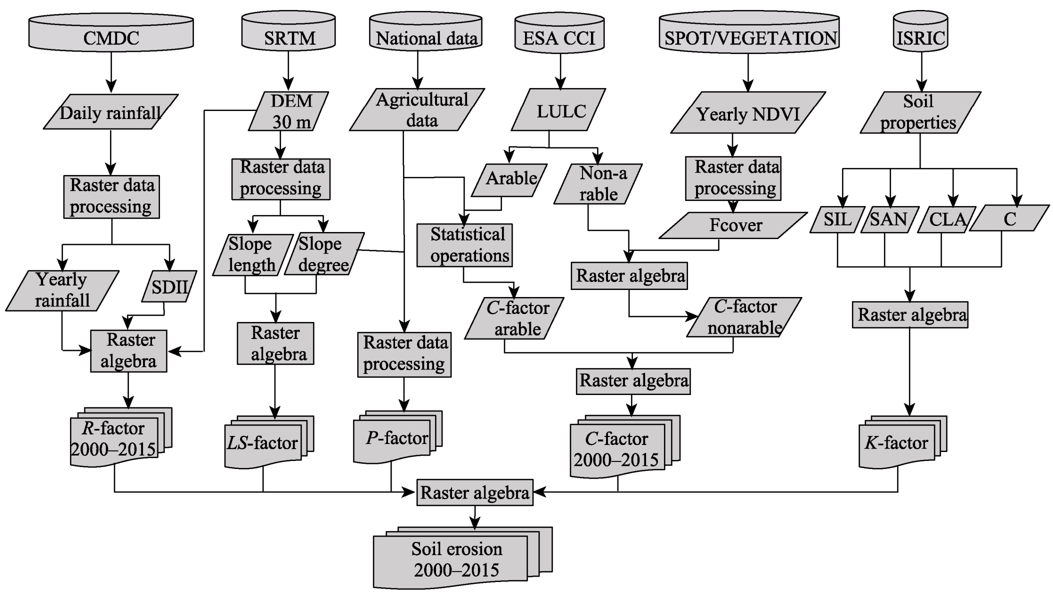

Figure 1 The technical route of the dataset development

4 Data Results and Validation

4.1 Data Composition

The dataset contains 12 files, including 4 soil erosion data and 8 process data (*C*-factor and *R*-factor). The format is .tif. The dataset covers water erosion areas in China in 2000, 2005, 2010, and 2015. The spatial resolution is 1 km × 1 km. The unit of soil erosion data is t·hm^{-2}·a^{-1}, which is the amount of soil erosion per unit area; the *C*-factor data is dimensionless; the unit of *R*-factor data is MJ·mm·hm^{2}·h^{-1}·a^{-1}. The file is named SEyyyy.tif, Cyyyy.tif, and Ryyyy.tif.

4.2 Data Products

The average annual soil erosion in China in 2000, 2005, 2010, and 2015 are 38.63, 37.35, 49.03, 47.84 t·hm^{-2}·a^{-1}, respectively. The range of soil erosion rate is between 0–2,880 t·hm^{-2}·a^{-1}. The spatial distribution of soil erosion is shown in Figure 2. According to the Soil Erosion Classification and Grading Standards[48] issued by the Ministry of Water Resources of the People's Republic of China, soil erosion in China is divided into 6 degrees, which are micro, slight, moderate, intense, extremely strong, and severe. Most of the areas in China (over 60%) are characterized by water erosion of micro degree. The areas with strong water erosion in China are mostly distributed in southern China dispersedly. For example, water erosion of severe degree can be found in the areas between the Yunnan-Guizhou Plateau and the Sichuan Basin, especially in Guizhou province. The areas with severe water erosion in northern China are mostly concentrated in the Loess Plateau, the Shandong hills, the Greater Khingan Range, and the junction of the Kunlun Mountains and the Tarim Basin.

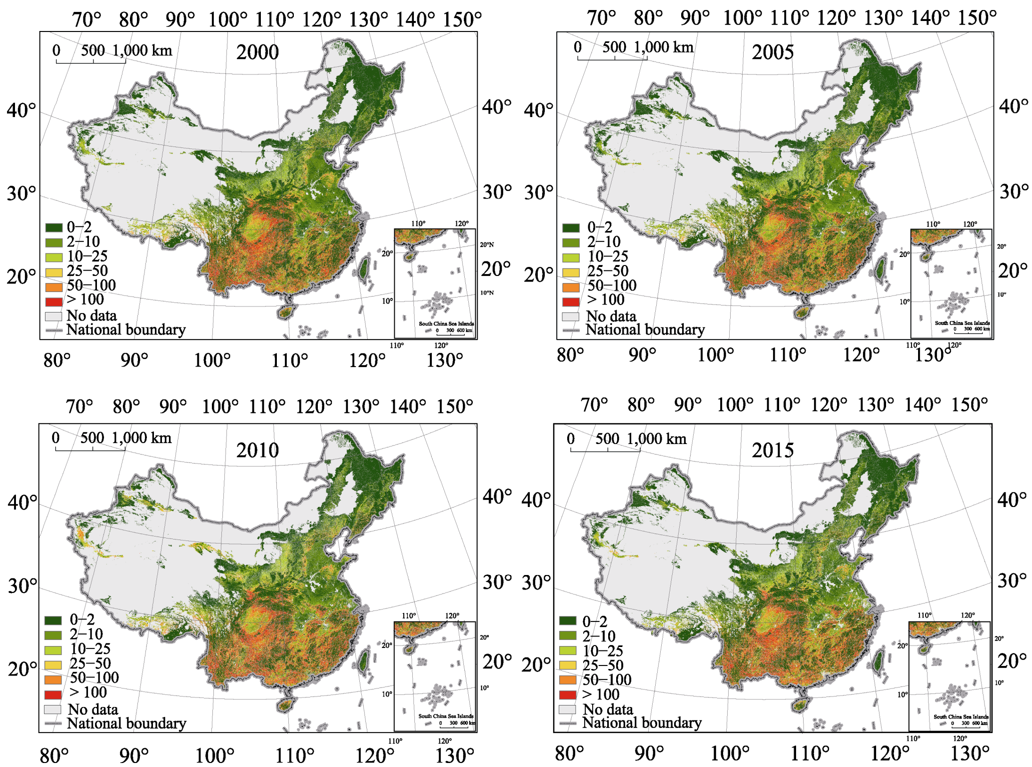

Figure 2 Distribution of soil erosion in China

4.3 Data Validation

It is difficult to obtain runoff data for large-scale plot experiments. Based on the literatures[49], this study collects global runoff plot data which contributes to the selection of the plot data in China. The comparison between the modeled data (average of 4 years) and the plot data (Figure 3) shows that the errors in the tropic zone are the largest in all climatic zones. Although the modeled values are different from the measured values in other climatic regions, the trend differences between the climatic regions are generally similar.

Although the simulation results have been improved by collecting high-resolution data and improving factors, there are errors in large-scale model estimation compared with small-scale measured data. The reason may be that the estimation of soil erosion has a spatial scale effect on the large scale[50]. The other reason that causes the different results may be that the differences of the precision of the input data and the method of large-scale models (Table 4). For example, the average annual soil erosion in Jiangxi province calculated by the USLE model on different scales has a large gap. In general, different research scales, calculation methods, and data sources can lead to uncertainties and different results in many studies. Moreover, this research is mainly devoted to water erosion areas. Generally, other large-scale studies would include non-water erosion areas, such as wind erosion areas. This dataset can be regarded as a source of change trend analysis of soil erosion in China and a comparison of large-scale soil erosion for future research.

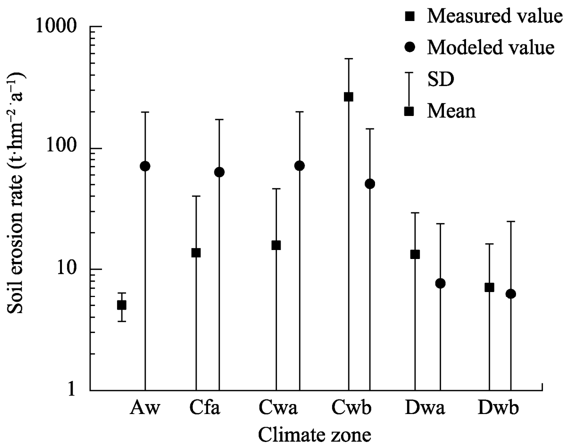

Figure 3 Comparison of the soil erosion rate simulated by the model and the experimental measurement (Note: The naming method of the climate zone is a combination of letter abbreviations. The meaning of the letter abbreviations is A: Tropical, B: Arid, C: Temperate, D: Cold, a: Hot Summer, b: Warm Summer, k: Cold, f: Without dry season, w: Dry Winter.)

Table 2 Average annual soil erosion rate in different regions ($t\cdot hm^{-2}\cdot a^{-1}$)

Research area	Other study	This study
Jiangxi Province	63.75[17] 0.92[51] 3.54[52]	90.60
Guangdong Province	22.94[53] 1.88[51]	115.19
Yanhe River basin	144.58[54]	2.20
Loess Plateau	24.05[18]	8.27
The southern hill region of China	4.22[52]	108.20
South of Gansu and northwest of Sichuan	13.39[55]	11.53

5 Discussion and Conclusion

This dataset is the distribution pattern of soil erosion in China calculated based on the empirical model USLE. The USLE model is normally applied to the field scale, thus it is difficult to apply it directly to the large scale. This dataset can simulate the intensity and dynamics of soil erosion on a national scale by calibrating the factors. Specifically, based on the characteristics of natural and social conditions in China, this dataset improves the accuracy of some specific factors. For example, the *C*-factor is assigned according to the agricultural background and natural vegetation of different provinces, the *R*-factor is calibrated according to different climatic zones, and *P*-factor is improved according to management measures in farmland.

Among the original data in this dataset, the resolution of the terrain data is 30 m × 30 m and the resolution of the NDVI data is 1 km × 1 km. The results are resampled to 1 km × 1 km. Compared with related national-scale studies[51], the resolution of our terrain data has been increased from 90 m × 90 m to 30 m × 30 m, and the *C*- and *P*-factors of arable land have been optimized more detailedly according to the actual conditions of crop planting in each province; therefore, the precision of the simulation has been improved. In addition, a more complete dataset has been formed in the time series including the years of 2000, 2005, 2010 and 2015.

There are certain difficulties in the quantitative estimation of large-scale soil erosion, especially the trade-off between the feasibility of calculation and the accuracy of the results. The mechanism of the empirical model ignores the process and dynamics of soil erosion[56], The subsequent verification of model lacks a lot of measurement data for comparison. The main goal of making this dataset is to analyze the variation of soil erosion in China and provide a basis for the identification of potential hot-spots of soil erosion. Moreover, this dataset also aims to provide a comparison for other soil erosion studies in the future, as well as provide a reference for further studies on improving parameters and mechanisms for USLE model. It is also expected to lay a foundation for the identification of driving factors of soil erosion changes in the future researches.

Author Contributions

Sun, R. H. made the overall design for the development of the dataset; Li, J. L. contributed to the data processing and analysis, did data verification, and wrote the data paper; Xiong, M. Q. designed the algorithms of dataset; Chen, L. D. provided modification ideas and opinion.

Conflicts of Interest

The authors declare no conflicts of interest.

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