Assessing soil erosion using USLE model and MODIS data in the Guangdong, China

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Abstract. In this study, soil erosion in the Guangdong, China during 2012 was quantitatively assessed using Universal Soil Loss Equation (USLE). The parameters of the model were calculated using GIS and MODIS data. The spatial distribution of the average annual soil loss on grid basis was mapped. The estimated average annual soil erosion in Guangdong in 2012 is about 2294.47t/(km².a). Four high sensitive area of soil erosion in Guangdong in 2012 was found. The key factors of these four high sensitive areas of soil erosion were significantly contributed to the land cover types, rainfall and Economic development and human activities.

1. Introduction
Soil erosion, as a global environmental crisis in the world, has attracted more attention in the developing countries. The Universal Soil Loss Equation (USLE), because it has a simple form, parameters can be easily obtained and also suitable for material shortage areas, has been widely applied to assess soil erosion in many nations since 1960s. As an empirical model, USLE serves to estimate annual soil loss. Many studies have demonstrated that USLE model can be used to predict effectively soil loss in different scales around the world [1-2]. Therefore, we select USLE model to estimate the annual rate of soil erosion in Guangdong Province, China.

USLE model needs information related to climate, soil type, topography, land use and landform to predict soil loss. In order to obtain these environmental variables effectively, integration of USLE, RS and GIS are often used [2]. Remote sensing data and GIS could provide accurate, timely, and real-time information on various aspects of the study area such as land use, soil distribution, vegetation coverage, etc. In this study, we used MODIS land use/cover product and MODIS NDVI product to evaluate the parameters (C and P factor) of the USLE model. The aim of this study was to determine the soil erosion variables associated with USLE model and spatial distribution of soil loss and evaluate the application of GIS, RS and USLE to determine average annual soil loss.

2. Materials and method
2.1 Study area and data source
The study area, Guangdong Province, is located in the southern China. It lies between E 109° 45’ and E117° 20’ and N20° 09’ and N25° 31’ with an elevation ranges from 0 to 1876 m above

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mean sea level. It covers an area of approximately 179,800 km$^2$ and consists of highlands in eastern, western and northern borders hills and terraces in the middle and plains in the south. Guangdong enjoys a humid subtropical climate with abundant rainfall. The annual average temperature is between 18 °C and 24°C, and the annual mean precipitation reaches 1,700 mm. Winters are short, mild and relatively dry, while summers are long, hot and very wet. In addition, the vegetation coverage in this area is relatively higher than that in the northern China.

The data used in this study mainly include MODIS 500 m land use/cover product and MODIS vegetation indices acquired in 2012. The pedological map of Guangdong with a scale of 1:1,000,000 is a government issued atlas; digital elevation model (DEM) data are from the 90-m Shuttle Rader Topography Mission data of NASA; Daily rainfall data from 1961 to 2012 of the study area are downloaded from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/).

2.2 Method

In this study, the average annual soil loss was calculated using the USLE model, which is defined as:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

Where $A$ is the average annual soil loss in t/(hm$^2$*a); $R$ is rainfall erosivity factor (MJ mm hm$^{-2}$ h$^{-1}$ a$^{-1}$); $K$ is soil erodibility factor (t h MJ$^{-1}$ mm$^{-1}$); $L$ is slope length factor; $S$ is slope steepness factor; $C$ is cover and management factor, and $P$ is the support practice factor. The definition and method of calculation of each factor are laid out in the following sections.

2.2.1 Rainfall erosivity factor ($R$)

Rainfall erosivity is the impact factor of quantitative assessment of soil erosion. It reflects the ability of soil erosion caused by rainfall, which is closely related to rainfall, rainfall energy and rainfall duration. Wischmeier (1965) defined $R$ as the product of rainfall energy and rainfall intensity of maximum 30 min. However, there is no detailed record of rainfall data in weather station in China. Chinese scholars proposed some simple approach to calculate rainfall erosivity. In this study, we used a simple calculation method of $R$ value based on daily rainfall data proposed by Zhang (2002) [3]. Daily precipitation data from 1961 to 2012 collected from over 50 weather stations in Guangdong were used to calculate the mean $R$ value of each station. The average regional $R$ value was then calculated using kriging interpolation in ArcGIS 10.1 to acquire the spatial distribution of $R$ factor.

2.2.2 Soil erodability factor ($K$)

Soil erodability is an important indicator that is used to evaluate the sensitivity of soil from erosion. It reflects the ability of soil detachment and transport by raindrop impact and surface flow. In this study, we use the calculation method of $K$ value presented in EPIC [4] using the soil mechanical composition data derived from the second national soil survey in China.

2.2.3 Topographic factor (LS)

Topographic factor (LS) is the product of slope length factor ($L$) and slope steepness/slope gradient factor ($S$). Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well-defined channel. Slope length factor ($L$) is the ratio of soil loss from the given length of slope to that from land having 22.13 m length of slope. The factor ($L$) from McCool [5] described as follows:

$$L = \left( \frac{\lambda}{22.13} \right)^m$$

Where $\lambda$ is slope length (in meter), $m$ is an exponent with a value between 0.2 and 0.5.

The application of $S$ is limited to slopes below 18% because it is the upper bound in USLE. We used USLE for slopes below 18% and the equation proposed by Liu (1994) for steeper ones [6].

2.2.4 Cover management factor ($C$)

The $C$ factor measures the combined effect of all interrelated cover and management variables that can be easily changed to reduce erosion. It was proven that the $C$ factor is closely related to vegetation cover. Thus, we used MODIS NDVI product to produce vegetation cover map for 2012 with 500 m resolution. The relationship between $C$ factor and vegetation cover can be found in Ma (2002) [7].

2.2.5 Support practice factor ($P$)
Support practice factor is basically the ratio of soil loss from a land having specified conservation practices to that from a land ploughed in a direction parallel to the slope if all other conditions remain unchanged. These practices affect erosion by modifying the flow pattern, grade or direction of the surface runoff and by reducing the amount and rate of runoff. Generally, support practice factor is determined with help of land use land cover map. In this study, we used MODIS land use land cover product and related literature [7-8] to produce the spatial distribution of P value in the study area.

3. Results and discussion
The spatial distribution of average annual soil loss in the study area was calculated by multiplying cell-based USLE parameters in the specified 500 m cells for the year 2012(Figure 1). The average annual soil losses were divided into 6 classes: low erosion, mild erosion, moderate erosion, very serious erosion, and severe erosion. Various statistic indictors of different soil erosion intensity in 2012 were presented in Table 1. From Table 1, we can see that the average annual total erosion is $4.04 \times 10^8$ t and the average annual erosion is 2294.47 t/(km².a) in Guangdong in 2012, which demonstrates that the whole performance of the intensity of soil erosion in Guangdong is low erosion. The soil erosion intensity in the study area is mainly focus on low erosion and mild erosion, with an area of 57.62% and 22.11%, respectively.

![Figure 1. The spatial distribution of average annual soil loss in Guangdong in 2012.](image)

As can be seen from the erosion amount percentage, the contribution of the severe erosion is the most, occupied 39.66% of the average annual total erosion; the second contribution of soil erosion level is very serious erosion, with an area of 18.82%; serious erosion, very serious erosion and severe erosion with an area of 11.26% of the total area, but the contribution to the erosion amount reaching 71.66% of the total erosion amount, which is the key area of the soil and water conservation in the future. According to the analysis of the spatial distribution of soil erosion map in Guangdong in 2012, four high sensitive area of soil erosion was found. These areas include the southern part of Lianzhou City in the northern mountainous region, the junction of Liannan County and Yangshan County, the northern part of Qingxin County, the northern and western parts of Yingde City; West of the cloud fog mountain area of Xinyi, northeast of Gaozhou City, northwest and southwest of Yangchun City; Deqing County in the central west, the northern part of Yunfu City and Gaoyao City; southern Xinhui City and the junction of Taishan City, the southern region of Zhongshan City.
The spatial difference of soil erosion was obvious. The high sensitive area of soil erosion in west is mainly caused by land use/cover types. And slope land is the main land type in the western mountainous region. The north of the study area is the typical Karst area, which was easy to cause soil erosion under heavy rainfall. The southeast of Jiangmen and the southern of Zhongshan were contributed to the rapid development of economy of Pearl River Delta and impact of human activities.

### Table 1. Various statistic indictors of different soil erosion intensity in 2012

| Intensity          | Area/ km² | Percentage/ % | Average annual erosion module/ (t.km⁻².a⁻¹) | Average annual total erosion/ (10⁴ t.a⁻¹) | Erosion amount/ % |
|--------------------|-----------|---------------|--------------------------------------------|------------------------------------------|------------------|
| Low erosion        | 101430.00 | 57.62         | 90.04                                      | 913.32                                   | 2.26             |
| Mild erosion       | 38919.25  | 22.11         | 1250.10                                    | 4865.30                                  | 12.04            |
| Moderate erosion   | 15868.25  | 9.01          | 3571.89                                    | 5667.96                                  | 14.03            |
| Serious erosion    | 8439.25   | 4.79          | 6311.45                                    | 5326.39                                  | 13.19            |
| Very serious erosion| 7086.75  | 4.03          | 10727.20                                   | 7602.10                                  | 18.82            |
| Severe erosion     | 4303.25   | 2.44          | 37223.80                                   | 16018.33                                 | 39.66            |
| Total              | 176046.75 | 100.00        | 2294.47                                    | 40393.40                                 | 100.00           |

### 4. Conclusions

In supports of GIS and MODIS data, the USLE parameters were calculated and the spatial distribution of average annual soil loss of Guangdong was mapped. The average annual soil erosion in Guangdong in 2012 was estimated about 2294.47t/ (km².a). The soil erosion intensity in the study area mainly focuses on low erosion and mild erosion areas, with an area of 57.62% and 22.11%, respectively. The area of serious erosion, very serious erosion and severe erosion just occupied about 11.26% of the total study area, but the contribution to the average annual soil loss reaching 71.66% of the total erosion amounts. In addition, four high sensitive area of soil erosion in Guangdong for the year 2012 was identified. In general, USLE integrating MODIS data provide an effective way to assess soil erosion quantitatively and efficiently.

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