A procedure for assessing the impacts of land-cover change on soil erosion at basin scale
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ABSTRACT
Accelerated soil erosion is an undesirable process that adversely affects the conservation of water and soil. This paper used a procedure linking the Revised Universal Soil Loss Equation (RUSLE) and geographic information system (GIS) to map the soil erosion level from 1990 to 2010 caused by land-cover change in the Dongjiang River basin, China. Results indicate that the significant land-cover change greatly impacted soil erosion. The overall soil erosion level of the basin belonged to Level II (mild erosion) but the erosion amount shown an uptrend. Erosion areas of Levels I and II occupied more than 90% and other levels (Levels III–VI) occupied less than 10% of the total area. Approximately 90.85% of the area maintained the original levels, 5.84% converted from lower levels to higher levels, and 3.32% converted from higher levels to lower levels. The erosion in the downstream regions was more serious than that in the central and upstream regions. Although soil erosion was mild as a whole in the study region, some local areas underwent intense erosion. The study demonstrated that linking RUSLE with GIS tools is an efficient procedure for mapping soil erosion levels at basin scale. The gradual deterioration condition caused by land-cover changes at present or in the future requires further study.

INTRODUCTION
Soil erosion is one of the most serious and global ecological environmental crises in progress today (Renschler et al. 1999; Natalia et al. 2005). The problems that are caused by soil erosion include decreased soil fertility, increased landslide activity, reservoir sedimentation, contaminant diffusion, rocky desertification, and ecosystem disturbances, all of which significantly impact human development (Syvitski et al. 2005; Jiang et al. 2014). The assessment of soil erosion is critical, considering its significant impact on the ecological environment (Xin et al. 2011). Many methods have been attempted to estimate soil erosion situations. Among these methods, soil erosion models, including empirical models and physical models, are straightforward but effective tools. The first widely used empirical model, Universal Soil Loss Equation (USLE), was developed in 1965 based on numerous observational data and rainfall simulation experiments (Wischmeier & Smith 1965). Limited by some deficiencies, USLE was continuously revised,
leading to a newversion named Revised Universal Soil Loss Equation (RUSLE) in the 1990s (Renard & Ferreira 1992; Renard et al. 1997). This new model can expediently evaluate the average annual soil erosion amount under different land-cover conditions and predict the spatial heterogeneity of soil erosion, providing a basis for soil conservation planning (Tang et al. 2015). Although some physical models, such as the Water Erosion Prediction Project (Foster & Lane 1987), the European Soil Erosion Model (Morgan et al. 1998), the Limburg Soil Erosion Model (De Roo et al. 1996), and the Soil Erosion Model for Mediterranean regions (De Jong et al. 1996) have been proposed in recent decades, their applications are presently limited due to the requirement of many parameters and complex calculation process. Moreover, some data (e.g., temporally continuous rainfall data) are not available for many countries and regions, making them difficult to promote. Benefitting from the convenience in application and compatibility with geographical information systems (GIS), the USLE and RUSLE models are still the most frequently used soil erosion models worldwide.

In this study, an integrated approach linking the RUSLE model with GIS tools was used to assess the soil erosion at basin scale where human activities have altered the physical characteristics of the region. The Dongjiang River basin, an economically advanced and densely populated area in China, chiefly comprises six cities: Ganzhou, Heyuan, Huizhou, Dongguan, Guangzhou, and Shenzhen. The river is the primary water source for these cities as well as Hong Kong. In fact, the proportion of Dongjiang water in Hong Kong’s annual water supply has steadily increased, from only 8.3% in 1960 to approximately 70% or even slightly greater than 80% in recent years (Jiang et al. 2007). It will have huge implications for economic development or even social stability if the water sources were to be affected by long-term pollution events (e.g., pollution caused by water and soil erosion). Moreover, the downstream region of the basin is the most developed area in Guangdong Province (even in China) after years of development. However, this region is currently facing severe ecological and environmental issues including soil erosion caused by tremendous changes in land cover (Liu et al. 2008; Wu & Chen 2012; Liu et al. 2015). A systematic study of soil erosion in the basin is urgently needed.

Therefore, the main objectives of this study are: (1) to propose a modeling approach of soil erosion using RUSLE and GIS tools and (2) to assess the soil erosion situation in the Dongjiang River basin from 1990 to 2010. The focal point of this study is to explore the spatial dynamic changes of soil erosion caused by land-cover changes at basin scale. The proposed approach can expediently evaluate the spatial heterogeneity and dynamic changes of soil erosion. This study also provides methodological tools for soil conservation planning and soil erosion prevention in the study area, which can be spread to similar regions.

**MATERIALS AND METHODS**

**Study area and data**

The Dongjiang River, a major tributary of the Pearl River, China, is 562 km in length with a drainage area of approximately 27,000 km², accounting for approximately 5.96% of the Pearl River basin (Figure 1). The Dongjiang River basin has a subtropical climate, with a mean annual temperature of approximately 21°C. Front and typhoon-type rainfalls are predominant in the basin, and the annual rainfall ranges from 1,500 to 2,400 mm (Liu et al. 2010). Large seasonal variations in rainfall and runoff exist within the basin, with 80% of the annual rainfall and runoff occurring in the rainy season (from April to September). Being a typical hilly area in south China, the main soil type of the basin is red soil. The basin is divided into three regions according to the economic levels for the sake of convenient analysis (Figure 1).

Digital elevation model (DEM), daily precipitation data, soil type data, and land-cover data were used in this study. DEM data (SRTM30) were available from the CGIAR-CSI SRTM 30 m Database (http://srtm.csi.cgiar.org). Daily precipitation data of 34 rainfall observation stations (Figure 1) from 1960 to 2010 were accessed from the Hydrology Bureau of Guangdong Province (http://www.gdsw.gov.cn/wcm/gdsw/index.html) and the China meteorological data sharing service system (http://www.escience.gov.cn/metadata/page/index.html). Soil type data were obtained from the Food and Agriculture Organization of the United
Nations (http://www.fao.org/home/en/). Land-cover data for 3 years (1990, 2000, and 2010) used for analysis in this study were provided by the Resources and Environment Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/Default.aspx). The data-processing tools included ArcGIS 9.3 and MS Excel. The slope length and steepness factor were estimated from SRTM DEM (30 m). All the above-mentioned data were converted to the spatial resolution of 100×100 m, which means that the Dongjiang River basin consists of approximately three million grids.

**RUSLE model**

The RUSLE model was used to assess soil erosion. This model considers not only the influence of precipitation, soil, topography, and land cover, but also the management of water and soil conservation (Renard et al. 1997). This model has been extensively applied to estimate soil erosion amount and risk (Angima et al. 2002; Xu et al. 2008; Tang et al. 2015). The RUSLE model is expressed as:

\[ A = R \times K \times L \times S \times C \times P \]  

where \( A \) (t/(ha·year)) is the average soil erosion, \( R \) (MJ·mm/(ha·h·year)) is the rainfall erosivity factor, \( K \) (t·ha·h/(MJ·ha·mm)) is the soil erodibility factor, \( L \) is the slope length factor, \( S \) is the slope steepness factor, \( C \) is the land cover and management practice factor, and \( P \) is the conservation support practice factor. The values of \( L \), \( S \), \( C \), and \( P \) are dimensionless.

GIS is used to realize the process of data pre-processing, factor calculating, and result outputting. For the estimation of soil erosion, the main procedure includes: (1) pre-process the data and convert them to grid format; (2) estimate the amount of soil erosion by RUSLE using the ‘raster calculator’ tool of GIS; (3) generate the spatial distribution of soil erosion.

**Rainfall erosivity factor (R)**

The rainfall erosivity factor \( R \), combining the effects of the duration, magnitude, and intensity of rainfall events, can
be used to measure the potential ability of rain to cause erosion. Yu & Rosewell (1996a) proposed a simple statistical regression equation between R and precipitation variables. The equation is based on average daily precipitation and has been extensively used in many regions including some basins in China (Yu & Rosewell 1996a; Xu et al. 2008; Zhang et al. 2010; Ma et al. 2014). The equation used in this paper is described as:

\[
\hat{E}_j = \alpha[1 + \eta \cos (2\pi f_j + \omega)] \sum_{d=1}^{N} R_d^j \quad \text{when } R_d > R_0
\]  

(2)

where \( \hat{E}_j \) (MJ·mm/(hm²·h)) is the rainfall erosivity value for the month \( j \) and it is a quantization value measuring the R factor. \( R_d \) (mm) is the daily precipitation of the month \( j \) with \( N \) days. \( R_0 \) is the threshold precipitation amount, which is fixed at 12.7 mm because storm events with less than 12.7 mm rainfall amount are generally discarded in the R factor computations. The coefficient \( f \) is the frequency of the cosine function and \( f = 1/12 \) is recommended (Yu & Rosewell 1996a). The phase parameter \( \omega \) is not particularly sensitive and can be set to \( \omega = 5\pi/6 \). If the annual precipitation is more than 1,050 mm, the relationship between parameters \( \alpha \) and \( \beta \) can be written as in Equation (3); otherwise, the parameters \( \alpha \) will be described as in Equation (4) (Yu & Rosewell 1996b). The relationship between parameter \( \eta \) and the average annual precipitation can be written as in Equation (5).

\[
\log \alpha = 2.11 - 1.57\beta \quad \text{when } R_a > = 1.050 \text{ mm}
\]

(3)

\[
\alpha = 0.395 \left( 1 + 0.098^{26.26 (S_{n}/R_a)} \right)
\]

(4)

when \( R_a < 1.050 \text{ mm} \)

\[
\eta = 0.58 + 0.25R_a/1000
\]

(5)

In Equation (3), the value range of \( \beta \) is 1.2 to 1.8 and \( \beta = 1.5 \) is used in this study according to previous research in similar regions of China (Yu & Rosewell 1996a; Ma et al. 2014). In Equations (4) and (5), \( S_n \) (mm) is the precipitation amount of the next half year, and \( R_a \) (mm) is the average annual precipitation. The rainfall erosivity of each month is calculated using the daily precipitation from 1960 to 2010 for each meteorological station. This paper used the average annual erosivity value as the rainfall erosivity factor and it can be computed by accumulating the monthly rainfall erosivity. The rainfall erosivity factor data were placed into the attribute database for a specific meteorological station and then converted into grid format by the Kriging spatial interpolation method.

**Soil erodibility factor (K)**

The soil erodibility factor \( K \) is difficult to measure and is therefore generally calculated through analyzing soil texture, organic matter, structure, and permeability (Maria et al. 2009). This paper used the modified equation that was proposed by Williams in the Erosion-Productivity Impact Calculator model (Williams et al. 1990) and it has been proved to be suitable for China (Hu et al. 2015). The equation can be expressed as:

\[
K = \left( 0.2 + 0.3 \exp \left[ -0.0256 \frac{San}{100} \right] \right) \times \left( \frac{Sil}{Cla + Sil} \right)^{0.3}
\]

\[
\times \left[ 1 - \frac{0.25 Ca}{Ca + \exp \left( 3.72 - 2.95 Ca \right)} \right]
\]

\[
\times \left[ 1 - \frac{0.7 SN_1}{SN_1 + \exp \left( -5.51 + 22.95 SN_1 \right)} \right]
\]

(6)

where \( San \) (%) is the sand content, \( Sil \) (%) is the silt content, \( Cla \) (%) is the clay particle content, \( Ca \) (%) is the organic carbon content, and \( SN_1 = 1 - San/100 \). Then the values of the soil erodibility factor corresponding to soil type were calculated. As the unit of \( K \) factor calculated by Equation (6) is a US unit (short ton·ac·h/(100ft·short ton·ac·in)), it needs to be converted into an international unit (t·ha·h/(MJ·ha·mm)) by multiplying by 0.1317. Thereafter, soil erodibility factor data were placed into the attribute database of the soil type map and then converted into grid format for further analysis.

**Slope length and steepness factor (L and S)**

The slope length factor \( L \) and slope steepness factor \( S \), respectively, represent the effect of slope length and slope gradient on erosion, and both reflect the effect of
topography on erosion (Lu et al. 2004). Increases in slope length and slope steepness can produce higher overland flow velocities and correspondingly higher erosion. Slope length has been broadly defined as the distance from the point of origin of overland flow to the point where either the flow is concentrated in a defined channel or the slope gradient decreases enough where deposition begins. An empirical equation that was proposed by Wischmeier & Smith (1978) is used to calculate the slope length factor $L$ in this paper and the equation is expressed as:

$$L = (\lambda/22.1)^m$$

where $22.1$(m) is the slope length of a standard plot, and $\lambda$ (m) is the slope length of a horizontal projection. In fact, the Chinese researchers Pan et al. (2010) calculated the average $\lambda$ value of the Dongjiang River basin (Table 1) which is used in this paper. In Equation (7), $m$ is the slope length index which depends on the ratio $\gamma$ between rill erosion and inter-rill erosion. Here $m$ is computed by Equation (8) (McCool et al. 1989).

$$m = \gamma/(1 + \gamma)$$

The ratio $\gamma$ can be computed by Equation (9) based on the slope $\theta$ (degree) if the soil sensibility between rill erosion and inter-rill erosion is the same (Foster et al. 1977).

$$\gamma = \left(\frac{\sin \theta}{0.0896}\right)/[3.0 \times (\sin \theta)^{0.8} + 0.56]$$

As the general equation for the slope steepness factor in the RUSLE model was based on the US terrain, it may cause errors when using this equation (McCool et al. 1989). In response to this issue, the Chinese researchers Liu et al. (1994, 2000) proposed an equation for use in south China. The equation is expressed as:

$$S = \begin{cases} 
10.8 \sin \theta + 0.03 \theta < 5' \\
16.8 \sin \theta - 0.5 \; 5' \leq \theta < 10' \\
21.9 \sin \theta - 0.96 \; \theta \geq 10' 
\end{cases}$$

where $S$ is the slope steepness factor and $\theta$ (degree) is the slope.

Both the factors of $L$ and $S$ were calculated using the raster calculator tool of Arc.GIS 9.3 according to Equations (7)–(10) and were merged as a $LS$ factor.

**Land cover and management practice factor (C)**

The land cover and management practice factor $C$ is used to reflect the effect of cropping and management practices on soil erosion rates in agricultural lands, and the effects of vegetation canopy and ground covers on reducing the soil erosion in forested regions (Renard et al. 1997). This factor considers the variability of the vegetation cover and methods of land management, reflecting their protective function to the topsoil (Xiao et al. 2015). The $C$ factor is generally determined by the Normalized Difference Vegetation Index (NDVI) (Maria et al. 2009; Chen et al. 2011) or land-cover type (Xu et al. 2008; Pan & Wen 2014). NDVI tends to focus on the vegetation situation, but the land-cover type considers more comprehensive terrestrial situations, such as cultivated land, forest land, grassland, mudflat, urban land, construction land, bare land, and water body. Therefore, this paper used the land-cover type to estimate the $C$ factor (Table 2) by referring to relevant studies in south China. This paper mainly referred to the studies of Chen et al. (2007) and Lu et al. (2011) as their study regions were close to the Dongjiang River basin and had similar natural conditions.

**Support practice factor (P)**

The support practice factor $P$ (ranging from 0 to 1) is the soil-loss ratio with a specific support practice to the corresponding soil erosion with upslope and downslope tillage.
The P factor is set to 1 in the regions without any soil and water conservation measures in general and to 0 in the regions where water and soil erosion will not occur. A lower P factor value indicates effective conservation practice at reducing soil erosion. In fact, an authoritative and universal method to determine the P factor has not been found so far, making this factor an uncertain factor in the RUSLE model. This paper referred to the experimental method of Lu et al. (2014) that considers both the land-cover type and the slope (Table 3). The study region of Lu et al. (2014) was close to the Dongjiang River basin and their results were based on the investigation of soil and water conservation, providing a reliable reference for this paper. Then, the P factor values were assigned to the raster for further analysis.

RESULTS AND DISCUSSION

Land-cover change

The land-cover in the Dongjiang River basin was grouped to 15 types in this paper. Figure 2 and Table 4 show that the overall land-cover composition has significantly changed from 1990 to 2010. Evidently, more dramatic changes occurred in the downstream region than in the up- and midstream regions. The paddy field, non-irrigated farmland, closed forest land, shrubbery, open forest land, high coverage grassland, and rural residential areas have in total decreased by 1,175.79 km² in the past two decades. Approximately 58.06% and 20.29% of these areas, respectively, were converted into urban and construction lands. The urban land rapidly increased from 191.22 km² in 1990 to 873.92 km² in 2010. Moreover, the construction land increased from 64.07 to 302.62 km², and the area of garden plots increased from 1,134.17 to 1,353.53 km² in the same time period. However, water body, low coverage grassland, mudflat, and bare land showed little change.

The land-cover variation related greatly to the increasing regional economy. A large area of paddy field, forest land, and grassland was invaded by urban land, construction land, and garden plots, especially in the downstream region. A typical example is that Shenzhen City used to be a small fishing village in south Guangdong Province three decades ago but now has become an overwhelming megacity, tremendously changing the original land cover. The expansion of urban land displays rapid urbanization and intensive human activities, meaning that humans have also changed the original ecosystem causing huge pressure on water and soil conservation.

Factor characteristics

The rainfall erosivity factor R was calculated by Equations (2)–(5) based on daily precipitation data from the 34 rainfall observation stations. The Kriging interpolation was used to produce the spatial distribution map based on the annual average rainfall erosivity values in each station. Figure 3(a)
indicates that the basin’s annual rainfall erosivity ranges from 5,225.89 to 10,844.2 MJ mm/(ha·h·year) with an average value of 6,822.78 MJ mm/(ha·h·year) and a Cv value of 0.1496. The abundant precipitation in the basin causes large rainfall erosivity values in general, indicating a high potential collapsing force to topsoil. The large value of Cv
reveals the uneven spatial-temporal distribution. Relatively larger values of Cv are mainly distributed in the southeast and the central west of the basin. Rainfall erosivity in the downstream region is at the middle level and in the upstream region at the lower level. From south to north, the rainfall erosivity decreases overall. Both the values of the rainfall erosivity and their spatial distribution are consistent with that of Luo et al. (2010).

There are 22 soil types in the Dongjiang River basin and the soil erodibility factor was calculated by Equation (6) based on the soil type data. The spatial distribution map of soil erodibility (Figure 3(b)) and soil types in Table 5 show that the main soil types include hydromorphic paddy soil, pitted lateritic red soil, page latosolic red soil, pitted yellow soil, pitted red soil, pitted yellow-red soil, yellow-page soil, and red-page soil, which in total account for approximately

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Soil type</th>
<th>Area ratio (%)</th>
<th>K factor value</th>
<th>Serial number</th>
<th>Soil type</th>
<th>Area ratio (%)</th>
<th>K factor value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alkaline purplish soils</td>
<td>0.19</td>
<td>0.416</td>
<td>12</td>
<td>Pitted yellow soil</td>
<td>2.77</td>
<td>0.2657</td>
</tr>
<tr>
<td>2</td>
<td>Mountain shrubby meadow soil</td>
<td>0.10</td>
<td>0.2221</td>
<td>12</td>
<td>Pitted red soil</td>
<td>17.25</td>
<td>0.2590</td>
</tr>
<tr>
<td>2</td>
<td>Fluvo-aquic soil</td>
<td>0.47</td>
<td>0.2228</td>
<td>14</td>
<td>Acid skeletal soil</td>
<td>0.09</td>
<td>0.2568</td>
</tr>
<tr>
<td>4</td>
<td>Acid lithosol</td>
<td>0.10</td>
<td>0.2162</td>
<td>15</td>
<td>Yellow-page latosolic red soil</td>
<td>0.24</td>
<td>0.2555</td>
</tr>
<tr>
<td>5</td>
<td>Acid purplish soils</td>
<td>0.79</td>
<td>0.2040</td>
<td>16</td>
<td>Pitted yellow-red soil</td>
<td>2.25</td>
<td>0.2491</td>
</tr>
<tr>
<td>6</td>
<td>Hydromorphic paddy soil</td>
<td>17.26</td>
<td>0.2016</td>
<td>17</td>
<td>Bleached paddy soil</td>
<td>0.25</td>
<td>0.2485</td>
</tr>
<tr>
<td>7</td>
<td>Pitted lateritic red soil</td>
<td>16.21</td>
<td>0.2988</td>
<td>18</td>
<td>Eroded latosolic red soil</td>
<td>0.28</td>
<td>0.2458</td>
</tr>
<tr>
<td>8</td>
<td>Volcanic soils</td>
<td>0.07</td>
<td>0.2958</td>
<td>19</td>
<td>Yellow-page soil</td>
<td>4.20</td>
<td>0.2255</td>
</tr>
<tr>
<td>9</td>
<td>Ergogenic paddy soil</td>
<td>0.68</td>
<td>0.2812</td>
<td>20</td>
<td>Red-page soil</td>
<td>12.42</td>
<td>0.2195</td>
</tr>
<tr>
<td>10</td>
<td>Lateritic red soil</td>
<td>0.69</td>
<td>0.2704</td>
<td>21</td>
<td>Eroded red soil</td>
<td>0.01</td>
<td>0.2116</td>
</tr>
<tr>
<td>11</td>
<td>Page latosolic red soil</td>
<td>20.44</td>
<td>0.2664</td>
<td>22</td>
<td>Reservoir</td>
<td>1.74</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: The soil type under the reservoir was undetected and the K factor value was set to 0; the unit of K factor is (short ton·h/100 ft·short ton·ac·in), which is a US unit.
94.10% of all the soil types. The $K$ factor value ranges from 0.2216 to 0.416 and the average value is 0.2652 with a Cv of 0.1696. The soil erodibility factor values in the basin are overall relatively small, indicating that the topsoil in the Dongjiang River basin has some anti-erosion ability. An overall lower $K$ factor was found in the north as compared to that in the southern region of the basin.

The slope length factor ($L$) and the steepness factor ($S$) were merged as a topography factor ($LS$) in this paper. The $LS$ factor value ranges from 0 to 29.4, with an average value of 8.86. However, the Cv reached 0.8691, suggesting that spatial topography variation is considerable in this hilly basin. Figure 3(c) shows that the lower values are mainly distributed in the downstream regions and the higher values are mainly in the western part of the basin. An overall higher $LS$ factor was found in the north than in the southern region.

The land cover and management practice factor ($C$) and support practice factor ($P$) were determined based on the land covers. The distribution of these factors is closely related to the distribution characteristics of land cover in the basin. For the $C$ factor, the average values, reflecting the level of land cover and management practice of the basin, were respectively 0.0235, 0.0247, and 0.0278 in 1990, 2000, and 2010, which show an increasing trend. The quite low values indicate that many management practices have been taken to guard against soil erosion but the uptrend indicates that these practices remain to be gradually increased and strengthened. For the $P$ factor, the average values that reflect the level of support practice of the basin are 0.6440, 0.6467, and 0.6551 in 1990, 2000, and 2010, respectively, which also shows an increasing trend. Although many support practices have been taken to prevent the erosion, the quite large values indicate that these practices need to be improved. Figure 4 shows the spatial distribution maps of both the $C$ factor and $P$ factor.

### Potential annual soil erosion

Rainfall erosivity, soil erodibility, and topographic factor are three natural factors determining the erosion process in the RUSLE model. The land cover and management practice and support practice factors are the social factors that are greatly impacted by human actions. The potential annual soil erosion can be regarded as the result of the three natural factors. Assuming no cover and management practices or support practices, the $C$ and $P$ factors were set to 1 and potential annual soil erosion could be computed using the following simplified equation (Tang et al. 2015):

$$A = R \times K \times L \times S$$

(11)

The spatial distribution map of potential soil erosion was then produced using the GIS technique. Figure 5 shows that the potential annual soil erosion ranges from 0 to 12,277.2 t/(ha·year), with an average value of 2,070.25 t/(ha·year), suggesting that rain-wash without restraint will cause a large amount of soil erosion. Relatively larger values are mainly distributed in the southeast and the central west due to large rainfall erosivity and relatively large values of LS factor. However, the upstream and the downstream regions are at lower levels. Although the values of the LS factor are large in the upstream, the rainfall erosivity values in the upstream regions are obviously smaller than in other regions, causing the $R$ factor to play a dominant role in weakening the potential annual soil erosion. However, the values of the LS factor are relatively small in the downstream regions, causing the LS factor to dominate the potential annual soil erosion with lower levels. The potential annual soil erosion is unevenly distributed in space in general, which can be reflected by a high Cv value of 0.9158. The spatial distribution map can identify the potentially high-risk erosion areas, which can provide a reference for the human actions in the basin. For example, agricultural activities, deforestation, and mining explorations should take various measures to prevent water and soil erosion in the potential high-risk erosion areas.

### Soil erosion assessment

As the potential annual soil erosion does not consider social factors, it only reflects the rainfall erosion vulnerability based on geographical and geological environment conditions but cannot reflect the actual situation of erosion in the Dongjiang River basin. A large value of potential soil erosion does not mean severe erosion will actually occur. For example, an appropriate irrigation system and soil management practices can greatly reduce soil erosion, demonstrating that these human actions are capable of reducing the potential effect to a certain extent. Human activities...
can be reflected by the land cover as displayed by the C and K factor in the RUSLE model. The land-cover types of 1990, 2000, and 2010 were selected and the influence of human activity was mainly focused on the dynamic changes of the land-cover type. As the six factors – rainfall erosivity factor \( R \), soil erodibility factor \( K \), slope length factor \( L \), steepness factor \( S \), cover and management practice factor \( C \), and support practice factor \( P \), have all been calculated, the soil erosion amount was calculated by Equation (1). The calculation results show that the soil erosion amounts ranges are 0 to 4,265.72, 0 to 4,265.72, and 0 to 4,999.69 t/(ha·year) in 1990, 2000, and 2010, respectively. The results were then classified into six levels according to the Standards for Classification and Gradation of Soil Erosion (SL 190–2007).
published by the Ministry of Water Resources of the People’s Republic of China in (2008). The classification standards, with a unit of t/(ha·year), were set as follows: Level I (tiny erosion), \( A < 5 \); Level II (mild erosion), \( 5 \leq A < 25 \); Level III (moderate erosion), \( 25 \leq A < 50 \); Level IV (intense erosion), \( 50 \leq A < 80 \); Level V (more intense), \( 80 \leq A < 150 \); and Level VI (extreme intense), \( A \geq 150 \). The higher the level is, the greater soil erosion will be.

For the entire basin, the annual average soil erosion in 1990, 2000, and 2010 is, respectively, 12.63, 13.08, and 15.31 t/(ha·year), all belonging to Level II, suggesting that the soil erosion situation was mild on the whole in the past two decades. However, the \( Cv \) values respectively reached 3.13, 3.10, and 3.75, suggesting that quite notable spatial variation exists in the basin. Figure 6 shows that most of the areas belong to Level I and Level II. Areas of Levels III–VI are sparse and scattered across the basin. Table 6 shows that the areas of Levels I and II occupy, respectively, 92.9%, 92.4% and 91.15%, while the other levels only occupy 7.10%, 7.60%, and 8.85% in total in 1990, 2000, and 2010, respectively. The areas of Level I decrease but Levels II–VI increase slightly in general. Since 1990, the overall soil erosion situation in the Dongjiang River basin has been considered to be not severe. However, some local areas, such as the western Huiyang, face a critical situation of soil erosion. The study of Pan et al. (2010) indicated that the annual average soil erosion is 18.73 t/(ha·year) in 2009 while our study is 15.31 t/(ha·year) in 2010. This difference is partly because their study region included the Zengcheng River basin which occupies 3,160 km² and the average level of soil erosion in the Zengcheng River basin is higher than that of our study areas. Therefore, the soil erosion situation between the two studies would be basically the same excluding this small basin.

For different regions, the characteristic values of soil erosion are shown in Table 7. Evidently, the annual average value increases from upstream to downstream, suggesting that the soil erosion in the downstream region is more severe than that in the upstream region. In addition, the mean values increased from 1990 to 2010 among the three regions, including the whole basin. From upstream to downstream, the soil erosion situation becomes more serious from a space perspective. Meanwhile, erosion has slightly increased in the past two decades from a time perspective.

To analyze the change in the soil erosion levels, a conversion map was produced and is shown in Figure 7. According to the statistics in Table 8, approximately 27,516 km² (90.85%) maintained the original levels but approximately 2,771 km² (9.15%) changed, of which approximately 1,767 km² (5.84%) was converted from lower levels to higher levels, but approximately 1,004 km² (3.32%) was converted from higher levels to lower levels.

The above assessment and analysis indicate that the overall soil erosion situation in the Dongjiang River basin since 1990 was not severe as most of the areas belong to Level I and Level II. This is because, first, the Dongjiang River basin is located in the subtropical zones of south China. Abundant rain, warm temperature, and fertile land
result in lush vegetation throughout the basin (Liu et al. 2010). Even if destroyed, the vegetation will quickly repair itself under the favorable environment. The self-healing feature of the vegetation is a necessity for conserving soil and water in the destructive and vulnerable areas. Second, numerous protection measures have been taken in the last two decades. For example, 45 first-class and 41 second-class protection zones were set up to protect the water sources (DRBA 2007). Unreasonable human activities in these zones, such as draining sewage, building factories, farming and grazing, have been under great restrictions, tremendously improving the resistance to water and soil erosion. In view of the serious soil erosion problems in some local areas, a large number of measures have been

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Areas and ratios of different levels of soil erosion</th>
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<tbody>
<tr>
<td>Year</td>
<td>Area (km²)</td>
</tr>
<tr>
<td>1990</td>
<td>14,289.30</td>
</tr>
<tr>
<td>2000</td>
<td>14,053.78</td>
</tr>
<tr>
<td>2010</td>
<td>13,701.14</td>
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<table>
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<tr>
<th>Table 7</th>
<th>Characteristic values of soil erosion in different regions and years</th>
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<tbody>
<tr>
<td>Year</td>
<td>Upstream</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>1990</td>
<td>11.26</td>
</tr>
<tr>
<td>2000</td>
<td>11.27</td>
</tr>
<tr>
<td>2010</td>
<td>11.82</td>
</tr>
</tbody>
</table>
adopted by the Guangdong government, such as engineering measures, biological measures, and agrotechnical measures. The engineering measures mainly included building small reservoirs, planting shelter forests, and building terraced fields in the potential erosion areas. The biological measures, such as afforestation and conversion of farmland to forest or grass, were included in the ecologically vulnerable areas. Agrotechnical measures, such as sprinkler irrigation, plastic film mulching, rotation tillage, and inter-planting, were taken in the cultivation areas. These measures can effectively reduce water and soil loss. Therefore, both natural and human factors are applied to the mild erosion in the Dongjiang River basin on the whole.

Even so, the soil erosion situation requires more attention. First, the increased annual average values, areas of higher levels (Levels IV–VI), and areas that were converted from lower levels to higher levels indicate accelerated soil erosion from 1990 to 2010. Despite taking many measures, the rapid expansion of urban areas occupying a large amount of paddy fields, grasslands, and forestlands has greatly changed the characteristics of the original soil ecosystem conditions, causing an accelerated soil erosion process that adversely affects the conservation of water and soil. Second, the different intensity of human activities resulted in a great regional difference in the erosion degree across the basin. For example, the annual average value of the downstream regions reached 35.66 t/(ha·year) (Level III, moderate erosion) in 2010, but only 11.82 and 14.43 t/(ha·year) (Level II, mild erosion) in the up- and midstream regions. Some downstream areas, such as the western Huiyang, face a particularly serious erosion problem and some erosion sites even reached 4,999.69 t/(ha·year) (Level VI, extreme intense erosion). Finally, the pressure for water and soil conservation will be greater in the future due to the continuous and strengthening human activities. The cities in the mid- and downstream regions are presently eager to develop the economy, which may lead to more intensive land-cover changes. Similarly, the upstream regions will also face much more pressure by a developing economy in the future, posing great challenges to the basin’s soil and water conservation. Therefore, the soil erosion situation requires attention at present and in the future. Given the important economic and political status in Guangdong Province, successful and efficient
conservation measures are thus still highly imperative to safeguard water and soil resources in the Dongjiang River basin.

**CONCLUSION**

The study proposed an approach that links RUSLE and GIS tools to assess and map soil erosion at basin scale. The procedure was applied on the Dongjiang River basin (south China) where human activities have altered physical characteristics of the basin. The following conclusions are drawn from the study:

- The procedure linking RUSLE and GIS tools was found to be an efficient approach to assessing and mapping soil erosion on basin scale.
- Land-cover change in the Dongjiang River basin greatly impacted soil erosion and the erosion amount increased on the whole from 1990 to 2010 and the erosion in the downstream region is more serious than that in the mid- and upstream region.
- The total areas of Levels I and II (mild erosion) occupied approximately 92.9%, 92.4%, and 91.15% in 1990, 2000, and 2010, respectively, while the other high levels of erosion occupied less than 10% in the study region. The overall soil erosion situation in the Dongjiang River basin is mild but extreme intense erosion occurs in some local areas.
- Approximately 90.85% of the areas maintained the original levels of erosion, but 9.15% changed. Among the changed areas, 5.84% converted from lower levels to higher levels and 3.32% converted from higher levels to lower levels.

The gradual deterioration condition caused by land-cover changes at present or in the future requires more attention. These results are important in terms of soil conservation planning and prevention, the reduction of water and soil erosion, and other applications in the region, while the procedure is worth applying in other regions.

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