National assessment of soil erosion and its spatial patterns in China

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Abstract. The spatial patterns of soil erosion (SE) are an important part of ecological security patterns and critical to erosion control. We assessed the SE and its spatial distribution in China based on geographic information system (GIS) and spatial data sets using the Universal Soil Loss Equation (USLE). The soil erosion area (SEA) and soil erosion amount (SEM) totaled 173.06 million ha and 8.87 billion Mg, respectively, with an average soil erosion rate (SER) of 9.39 Mg ha⁻¹ yr⁻¹. Slight erosion dominated from the aspect of SEA, whereas extreme erosion contributed the most in terms of SEM. Spatial heterogeneity in soil erosion was obvious in China, with heavily eroded areas mainly concentrated in the Loess Plateau, the Three Gorges reservoir area, and the hot, dry valley of the Jinsha River. Regionally, the provinces of Tibet, Sichuan, Yunnan, Xinjiang, Inner Mongolia, Gansu, Shaanxi, Shanxi, Guizhou, and Guangxi, and the basins of the Yangtze River, Yellow River, and southwestern rivers made a large contribution to the SEA and SEM. Geographically, soil erosion increased, then decreased with increasing slope and elevation. Slopes of 15–25° and 8–15° and elevations of 1000–2000 m were the most seriously eroded. Cropland and grassland ecosystems were major sources of SE, with their SEA and SEM accounting for 64.44% and 77.96% of the total. This study revealed the current situation and spatial characteristics of SE in China on the national scale, which can serve as a scientific basis for regional SE control and decision-making policy.

Key words: China; erosion rate; GIS; national risk assessment; soil erosion; spatial pattern; Universal Soil Loss Equation.

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Introduction

Soil erosion (SE) is one of the primary environmental and agricultural problems worldwide, including China (Pimentel et al. 1995). SE not only damages soil resources but also impairs the ability to deliver ecosystem services, threatening sustainability (Verheijen et al. 2009). China’s annual economic losses caused by SE are equivalent to about 3.5% of its GDP (Chen 2012), which seriously hinders the development of the economy. Moreover, erosion-induced land degradation and lake/reservoir siltation are a serious threat to national ecological security, food security, and flood control (Zhang et al. 2004). The loss of cropland due to SE has been found to be as much as 6.7 × 10⁴ ha/yr, resulting in decreased food production in some areas, especially in the western region, where 1.5 billion kg of supplementary food are needed every year (Zhang et al. 2004).

Since the founding of the People’s Republic of China, the loss of reservoir storage capacity due to sediment siltation has increased to 20 billion m³, which significantly reduces flood control capacity and subsequently increases downstream flood risk (Zhang et al. 2004).

The spatial pattern of SE is an important part of the ecological security pattern. Analysis of the spatial characteristics of SE and identification of key areas for erosion control are the foundations of soil and water conservation. Since the 1920s, domestic studies of SE and soil conservation have experienced three stages, which include observation and experimentation, comprehensive control, and in-depth development (Yang et al. 2006). In the last decade, the implementation of large-scale ecological construction projects, such as the Sloping Land Conversion Program and Natural Forest Protection Program (Zhang et al. 2004), have gradually produced the desired effects in some regions (Guan
where \( SE \) is the soil erosion rate (Mg loss (Mg ha\(^{-1}\) yr\(^{-1}\)) per unit of rainfall erosivity index (MJ mm ha\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)) from a cultivated continuous fallow plot; \( LS \) is the topographic factor; and \( C \) is the vegetation cover factor.

Because the USLE is designed to compute average soil losses from sheet and rill erosion, with gully erosion excluded, we added some modifications to account for the contribution of sediment yield from gully erosion for the Loess Plateau (Li et al. 2003) and the northeast black soil region (Fang et al. 2012), where gully erosion is known to occur (E 2008). For the karst region in southwestern China, where the runoff coefficient and \( SE \) are much lower than in non-karst regions (van Beynen 2011, Jiang et al. 2014), the adjustment factor, the ratio of runoff coefficient in the karst region to that in non-karst regions (Wei 2011), was used for the revision.

On the basis of the standards for classification and gradation of \( SE \) (SL190-2007) set by the Ministry of Water Resources PRC (2008) and other regional standards published by Ministry of Water Resources PRC (2009\(a, b\)), soil erosion intensity (SEI) can be classified into five levels: slight, moderate, high, severe, and extreme. Tolerable soil erosion rates and erosion consequences in various \( SE \) zones were considered in gradation.

**Parameters**

1. **Rainfall erosivity factor (\( R \)).**—Rainfall erosivity reflects the potential for raindrops and runoff to induce \( SE \) (Liu et al. 2001). This factor is mainly determined by kinetic energy and rainfall intensity (Wischmeier and Smith 1978). In the USLE model, the classical algorithm of \( R \) requires detailed information on rainfall, which is unavailable for most of China. Therefore, in this study, we adopted a daily rainfall erosivity model (Yin et al. 2013), for which only conventional rainfall data (daily precipitation) are needed. This model can be expressed as

\[
\bar{R} = \sum_{k=1}^{24} \bar{R}_k
\]

\[
\bar{R}_k = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=0}^{m} \alpha P_{i,j,k}^{1.7265}
\]

where \( \bar{R} \) is the average annual rainfall erosivity, \( \bar{R}_k \) is the average rainfall erosivity for the \( k \)th half month, \( k \) is 24 half months in a year (\( k = 1, 2, \ldots, 24 \)), \( i \) is the number of years in accordance with rainfall data (\( i = 1, 2, \ldots, n \)), \( j \) is the number of erosive rainfall days in the \( k \)th half month of the \( j \)th year (\( j = 0, 1, \ldots, m \)), \( P_{i,j,k} \) is the daily precipitation (mm) on the \( j \)th erosive rainfall day in the \( k \)th half month of the \( i \)th year, and \( \alpha \) is a parameter to which values of 0.3937 and 0.3101 were assigned for the warm (May–September) and cold (October–December, January–April) seasons, respectively.

2. **Soil erodibility factor (\( K \)).**—Soil erodibility reflects the sensitivity of soil particles to erosive forces and the soil erodibility factor (\( K \)) is an internal factor affecting \( SE \) (Shi and Deng 1993) that is closely related to soil attributes (Zhang et al. 2008). The erosion-productivity impact calculator (EPIC; Williams et al. 1983) was employed to calculate \( K \) using the soil clay, silt, sand,
and organic carbon content. The study conducted by Zhang et al. (2008) was used for subsequent revisions.

3. Topographic factor (LS).—The topographic factor reflects the effects of terrain (slope length and gradient) on SE (Wischmeier and Smith 1978, Van Remortel et al. 2004). LS equals the ratio of soil loss per unit area on a specific slope to that on a standard runoff plot (slope length 22.13 m, slope gradient 9%), with other conditions controlled. Usually, SE increases with increasing slope length and slope steepness to a threshold (Wang and Jiao 1996). As a result, we made a correction for slopes of $>28.81^\circ$ (Rao et al. 2014), based on previous studies conducted under different terrain conditions (McCool et al. 1993, Liu et al. 1994). The slope length was computed with reference to the ArcInfo AML code (Van Remortel et al. 2001), which was implemented in the ArcInfo Workstation (ArcGIS 9.3; ESRI 2008).

4. Vegetation cover factor (C).—The vegetation cover factor reflects the control of vegetation on SE. The interception of precipitation and retention of runoff by vegetative canopies and litter can reduce the kinetic energy of rainfall and transport capacity of runoff. Additionally, the physical properties of soil and its structures can be improved due to the presence of roots, resulting in higher soil permeability and less surface runoff, enhancing anti-scourability and erosion resistance of the soil (Zou et al. 1985, Wei et al. 2002). Values were assigned to $C$ based on references to previous studies (Liu et al. 1999, Wei et al. 2002, Carter and Eslinger 2004, Rao et al. 2014), with different vegetation types and coverage considered. A smaller $C$ was given to a stronger erosion control effect.

**Data sources**

Average annual rainfall erosivity (1980–2010) data at various meteorological stations were provided by Beijing Normal University. The soil map and attribute data were obtained from the second National Soil Survey of China, with a resolution of 1:1 000 000. Digital elevation modeling (DEM) data were acquired from the Shuttle Radar Topography Mission (SRTM) and had a resolution of 90 m. The ecosystem types (2010) and vegetation coverage (2010) data were derived from satellite Thematic Mapper (TM) images and Moderate Resolution Imaging Spectroradiometer (MODIS) data, respectively, provided by the Institute of Remote Sensing Applications of the Chinese Academy of Sciences. The administrative divisions came from the Satellite Environment Center, Ministry of Environmental Protection.

**Results**

**Validation**

The soil erosion area (SEA), calculated based on the USLE model, was compared with the results of the first National Water Census to verify the model’s applicability. This validation covered 18 provinces (autonomous regions/municipalities) in which water erosion dominates: Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Guizhou, and Yunnan. As shown in Fig. 1, the SEA of each province estimated by the USLE model was consistent with the observed value ($R^2 = 0.953, N = 18, P < 0.0001$), implying that the USLE could accurately reflect and eventually be used to assess the SE in China.

**Overview of national SE**

The total SEA in China was about 173.06 million ha, accounting for 18.31% of the total land area. The average soil erosion rate (SER) was 9.39 Mg·ha$^{-1}$·yr$^{-1}$ for the entire country and 14.27 Mg·ha$^{-1}$·yr$^{-1}$ for the water-eroded region. Slight erosion was the main SEI level, accounting for 60.75% of the total SEA, followed by moderate erosion. The area percentages of high, severe, and extreme erosion were similar, accounting for 7.32%, 6.17%, and 7.58% of the total area, respectively. The total soil erosion amount (SEM) was 8.87 billion Mg, among which extreme erosion accounted for 43.26%, and high-or-above erosion (high, severe, and extreme) accounted for 63.42% (Table 1).

Spatially, heavily eroded areas covered the provinces of Gansu, Shaanxi, Shanxi, Inner Mongolia, and Ningxia, which are located in the middle region of the Yellow River and the provinces of Sichuan, Chongqing, Guizhou, and Yunnan in the upstream portion of the Yangtze River. Specifically, the Loess Plateau, Han River

![Fig. 1. Comparison of soil erosion area between the USLE (Universal Soil Loss Equation) prediction and the National Water Census observation.](image-url)
Valley, Three Gorges reservoir area, Jialing River Basin, the hot and dry valley of Jinsha River, southern Hengduan Mountains, southeastern Tibet, the middle and lower reaches of the Lancang River, Yuanjiang River Valley, and the Beipan River Basin all faced heavy SE (Fig. 2).

Regional characteristics of SE

SE in each province

All 31 provinces were subject to SE. Among these, the 10 with the largest SEA included Tibet, Sichuan, Yunnan, Xinjiang, Inner Mongolia, Gansu, Shaanxi, Shanxi, Guizhou, and Guangxi, accounting for 68.51% of the total. Other provinces had relatively small SEA, especially Shanghai, Tianjin, and Jiangsu (Fig. 3A). The 10 provinces with the largest SER were Shaanxi, Shanxi, Chongqing, Ningxia, Sichuan, Gansu, Yunnan, Guizhou, Guangxi, and Fujian, among which Shaanxi and Shanxi were the highest, with SER values of 35.07 and 34.45 Mg·ha⁻¹·yr⁻¹, respectively (Fig. 3B). The 10 provinces with the greatest SEM included Tibet, Sichuan, Gansu, Yunnan, Shaanxi, Shanxi, Guangxi, Xinjiang, Guizhou, and Inner Mongolia, most of which are located in western China, accounting for about 76.15% of the total (Fig. 3C).

SE in each river basin

The Yangtze River Basin had the largest SEA, occupying 28.37% of the total, followed by the Yellow River Basin and the basin of southwestern rivers, which accounted for 15.93% and 15.59%, respectively. The remaining basins, in descending order, were as follows: the basin of northwestern rivers, Pearl River Basin, Liaohe River Basin, Songhua River Basin, Haihe River Basin, the basin of southeastern rivers, and the Huaihe River Basin. The

| SEI    | Area Millions of ha | SEM Millions of Mg | % of Total |
|--------|---------------------|--------------------|------------|
| Slight | 105.13              | 1013.88            | 60.75      |
| Moderate| 31.46              | 859.92             | 18.18      |
| High   | 12.67               | 704.53             | 7.32       |
| Severe | 10.68               | 1084.27            | 6.17       |
| Extreme| 13.11               | 3839.00            | 7.58       |

Table 1. Soil erosion intensity (SEI) in China, by total land area and soil erosion amount (SEM).

Fig. 2. Spatial pattern of soil erosion intensity in China.
Yellow River Basin had the highest SER (27.29 Mg ha⁻¹ yr⁻¹), followed by the basin of southwestern rivers (21.31 Mg ha⁻¹ yr⁻¹) and the Yangtze River Basin (15.20 Mg ha⁻¹ yr⁻¹). The SER values of the Pearl River Basin and the basin of southeastern rivers were 11.26 and 9.99 Mg ha⁻¹ yr⁻¹, respectively. The Yangtze River Basin also had the highest SEM (2706.19 million Mg; 1 Mg = 1 metric ton), accounting for 30.50% of the total, followed by the Yellow River Basin (2169.72 million Mg) and the basin of southwestern rivers (1814.72 million Mg), accounting for 24.45% and 20.45%, respectively. The contribution of other river basins was relatively small (Fig. 4).

Geographic distribution of SE

**Slope distribution of SE**

The slope gradient was classified into six groups (Table 2), according to the standards for classification and gradation of SE (SL190-2007). Both the SEA and SEM were the largest with slopes of 15–25°, accounting for 27.90% and 33.88%, respectively, of the total. This was followed by slopes of 8–15°, which accounted for 23.34% and 23.74%, respectively, whereas the percentages were 22.05% and 24.17%, respectively, for slopes >25° (Table 2). Overall, both the SEA and SEM peaked at slopes of 15–25°, after which they decreased gradually as the slope decreased or increased, with slopes of <5° excluded.

In terms of the SEI (Fig. 5), slight erosion dominated in each slope group (area percentage of slight erosion: 54.85–67.93%). Additionally, the percentages of extreme erosion were the highest at slopes of 15–25° (10.57%) and 8–15° (10.25%), whereas those of severe erosion were the highest at slopes of 5–8° (8.56%) and 8–15° (8.40%). For high erosion, the slope of 5–8° had the highest area percentage. In general, the area percentage of high-or-above erosion peaked at 8–15° and then decreased gradually as the slope decreased or increased.

**Elevation distribution of SE**

The altitude was classified into six groups (Table 3) according to terrain features. Both the SEA and SEM were the largest at elevations of 1000–2000 m, accounting for 25.38% and 29.82% of the total, respectively. The percentages were similar for elevations of 200–500 m, 500–1000 m, 2000–4000 m, and >4000 m, whereas those <200 m were the smallest (Table 3). Overall, both the SEA and SEM peaked at elevations of 1000–2000 m and decreased gradually as the elevation changed, excluding >4000 m.

As shown in Fig. 6, slight erosion dominated each
elevation group when SEI was evaluated (area percentage of slight erosion: 50.11–74.56%). Moreover, the percentages of extreme erosion were the highest at elevations of 500–1000 m (10.39%) and 1000–2000 m (10.39%), whereas those of severe erosion and high erosion were the highest at 1000–2000 m (8.75% and 9.56%). Overall, the percentage of high-or-above erosion peaked at 1000–2000 m and then decreased gradually as the elevation changed.

**Ecological distribution of SE**

In various ecosystem categories, cropland and grassland had the largest SEA, accounting for 32.72% and 31.72% of the total, respectively. This was followed by shrubs, which comprised about 21.21% of the total. The SEA of the forest was 17.49 million ha, or 9.17% of the forest area. The cropland had the highest SER (27.61 Mg ha\(^{-1}\) yr\(^{-1}\)), followed by shrubs (12.36 Mg ha\(^{-1}\) yr\(^{-1}\)). The SER of the remaining categories decreased in the following order: grassland, bare land, city, forest, and desert. As shown in Table 4, cropland also had the

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**Table 2.** Soil erosion on various slopes in China, by total land area, soil erosion area (SEA), and soil erosion amount (SEM).

| Slope (°) | Area |  | SEA |  | SEM |
|----------|------|---|-----|---|-----|
|          | Millions of ha | % | Millions of ha | % | Millions of Mg | % |
| <5       | 511.98 | 54.18 | 29.37 | 16.97 | 1011.34 | 11.40 |
| 5–8      | 74.62  | 7.90  | 16.86 | 9.74  | 649.22  | 7.32  |
| 8–15     | 134.96 | 14.28 | 40.40 | 23.34 | 2106.71 | 23.74 |
| 15–25    | 129.32 | 13.68 | 48.28 | 27.90 | 2962.00 | 33.38 |
| 25–35    | 69.12  | 7.31  | 27.81 | 16.07 | 1600.54 | 18.04 |
| >35      | 25.00  | 2.65  | 10.35 | 5.98  | 544.18  | 6.13  |
highest SEM, with a contribution rate of 56.29%, followed by grassland (21.67%), shrubs (9.74%), and bare land (8.09%).

**Discussion**

China is facing the most serious SE in the world. In 2010, the SEM was \(~8.87\) billion Mg nationwide, equivalent to 11.83% of the global total of 75 billion Mg (Pimentel et al. 1995), although its land area percentage was only 6.8% (Li et al. 2008). The national average SER was 9.39 Mg·ha\(^{-1}\)·yr\(^{-1}\), and the value was 14.27 Mg·ha\(^{-1}\)·yr\(^{-1}\) for the water erosion region, far below the national average level of 14.70 Mg·ha\(^{-1}\)·yr\(^{-1}\) (Yang et al. 2003) in the 1980s and the average level of 38.00 Mg·ha\(^{-1}\)·yr\(^{-1}\) (Li et al. 2008) for the water erosion region at the end of the last century, implying a significant improvement of the SE condition in China (Li et al. 2008).

Obvious spatial heterogeneity was observed in China’s SE. Soil loss was highly concentrated in some local areas with great SEI, even at this resolution of analysis. Overall, 63.42% of the SEM occurred in 3.86% of the land area, where the SEI was high, severe, or extreme. Heavily eroded areas were mainly located in the Loess Plateau, Han River Valley, Three Gorges reservoir area, Jialing River Basin, the hot and dry valley of Jinsha River, southern Hengduan Mountains, southeastern Tibet, the middle and lower reaches of the Lancang River, Yuanjiang River Valley, and the Beipan River Basin, where better policy recommendations should be given to erosion control.

River basins are an important unit for SE research and control. The sediment deposition and water quality in rivers usually depend on the SE condition in basins. In

![Fig. 5. Soil erosion intensity on various slopes. The y-axis shows the percentage of area in five different erosion intensity levels (slight to extreme), by specified slopes.](image)

**Table 3.** Soil erosion at various altitudes in China, by total land area, soil erosion area (SEA), and soil erosion amount (SEM).

| Elevation (m) | Area | % | SEA | % | SEM | % |
|--------------|------|---|-----|---|-----|---|
| <200         | 147.42 | 15.60 | 14.41 | 8.33 | 639.48 | 7.21 |
| 200–500      | 112.29 | 11.88 | 27.95 | 16.15 | 1196.67 | 13.49 |
| 500–1000     | 149.79 | 15.85 | 29.20 | 16.87 | 1611.12 | 18.16 |
| 1000–2000    | 232.47 | 24.60 | 43.93 | 25.38 | 2646.56 | 29.82 |
| 2000–4000    | 113.97 | 12.06 | 29.45 | 17.02 | 1117.71 | 12.60 |
| >4000        | 189.05 | 20.00 | 28.12 | 16.25 | 1662.46 | 18.73 |
China, SE primarily occurs in three river basins (the Yangtze River Basin, Yellow River Basin, and the basin of the southwestern rivers, accounting for about one-third of China’s land area), with their contributions of SEA and SEM being 59.89% and 75.40%, respectively. The Yangtze River Basin had the largest SEA (28.37%) and SEM (30.50%) because of its abundant rainfall, undulating terrain, heavy clay soil texture, and poor permeability (Li and Liu 2006). The SEA (15.93%) and SEM (24.45%) of the Yellow River Basin were the second largest, while its SER (27.29 Mg ha$^{-1}$ yr$^{-1}$) was the highest, making it the most eroded area in China. This is because of the region’s low soil organic matter content, loose soil texture, weak anti-scourability, high proportion of steep slopes, and intense and diverse anthropogenic impact (Zhou et al. 1991, Zhang et al. 2001). The SER in the basin of the southwestern rivers was also high, just below that of the Yellow River Basin, owing to its steep slope and tattered (topographically dissected) landform (Chen et al. 2012). Further, geological disasters such as mud-rock flows and landslides have been triggered by SE in this region because of the complex geological structures and fragile environment (Chen et al. 2012).

The SE situation of a region varies greatly with slope gradient and altitude. The SEA and SEM peaked at slopes of 15–25°, and the proportion of high-or-above erosion peaked at slopes of 8–15°. All three factors (SEA, SEM, and high-or-above erosion percentage) gradually decreased with changing slope gradients. For slopes,

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**Fig. 6.** Soil erosion intensity at various altitudes. The y-axis shows the percentage of area in five different erosion intensity levels (slight to extreme), by specified elevations.

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**Table 4.** Soil erosion in various ecosystems in China, by total land area, soil erosion area (SEA), soil erosion amount (SEM), and soil erosion rate (SER).

| Ecosystem types | Area | SEA | SEM |
|-----------------|------|-----|-----|
|                 | Millions of ha | %   | Millions of ha | %   | Millions of Mg | %   | SER (Mg ha$^{-1}$ yr$^{-1}$) |
| Forest          | 190.78 | 20.19 | 17.49 | 10.11 | 267.99 | 3.02 | 1.40 |
| Shrub           | 69.92  | 7.40  | 36.71 | 21.21 | 864.33 | 9.74 | 12.36 |
| Grassland       | 284.52 | 30.11 | 54.89 | 31.72 | 1923.00 | 21.67 | 6.76 |
| Cropland        | 180.91 | 19.14 | 56.62 | 32.72 | 4995.17 | 56.29 | 27.61 |
| City            | 25.43  | 2.69  | 0.87  | 0.50  | 71.88  | 0.81  | 2.83  |
| Desert          | 44.94  | 4.76  | 0.75  | 0.43  | 33.72  | 0.38  | 0.76  |
| Bare land       | 106.59 | 11.28 | 5.73  | 3.31  | 717.91 | 8.09  | 6.74  |
>25°, the percentages of SEA (22.05%) and SEM (24.17%) were not as large as expected. This was due to the relatively small land area of steep slopes, as well as the effects of cropland conversion and ecological restoration in recent years. On the basis of these findings, we can deduce that cropland conversions at slopes >25° are detrimentally insufficient to reverse the damage done by SE. Meanwhile, new policies are urgently needed to manage the slopes of 15–25° and 8–15°, where the land area is much larger and human activity is more pervasive. Similarly, the SEA, SEM, and area percentage of high-or-above erosion all peaked at 1000–2000 m and then decreased with increased elevations. These areas are mainly located at China’s second step of topography (the terrain of China gradually descends from west to east like a staircase, with the second step located between the Tibetan Plateau and the plains in eastern China), which covers the Loess Plateau, the Inner Mongolia Plateau, and the Yunnan-Guizhou Plateau. As an important farming–pastoral ecotone and ecologically fragile district, this area has a rugged relief, broken terrain, marked patterns of human disturbance, and other transitional features. The combined effects of these natural and anthropogenic factors make this region a key area for erosion control.

SE status differs significantly among ecosystem types depending on their soil conservation capacities and external environment. Cropland was still the main source of SE (Pimentel et al. 1995), which was an important reason for implementation of the Grain for Green Project (Fu et al. 2011). The SEA and SEM of cropland accounted for up to 32.72% and 56.29%, respectively, of the total due to the seasonal bareness and frequent disturbances from farming practices. This was followed by grassland, which had a SEA and SEM accounting for 31.72% and 21.67%, respectively. The heavy SE of grassland was closely related to its wide distribution, overgrazing, and excessive land reclamation, which resulted in land degradation, desertification, and salinization (Xu and Li 2003, Wang et al. 2007). Shrubs had a high SER, which was just below that of the croplands. This is because shrubs are often the secondary ecosystem appearing on degraded forests after long-term disturbances, while natural shrubs are usually distributed in areas with poor environments that are sensitive to soil erosion.

Conclusions

In 2010, the total SEA and SEM of China were 173.06 million ha and 8.87 billion Mg, respectively, with an average SER of 9.39 Mg ha\(^{-1}\) yr\(^{-1}\). Although the SE conditions are still poor, improvement has been made. Apparent heterogeneity was observed in China’s SE, with heavily eroded areas mainly concentrated in the Loess Plateau, Three Gorges reservoir area, dry–hot valley of Jinsha River, and the southern Hengduan Mountains. The provinces of Tibet, Sichuan, Yunnan, Xinjiang, Inner Mongolia, Gansu, Shaanxi, Shanxi, Guizhou, and Guangxi contributed 68.51% and 76.15%, respectively, to the total SEA and SEM, whereas the basins of the Yangtze River, Yellow River, and southwestern rivers contributed 59.89% and 75.40%, respectively. Further, a significant difference in SE on the various slopes and different altitudes was observed, with slopes of 15–25° and 8–15° and elevations of 1000–2000 m being the most seriously eroded; accordingly, these areas should be the focus of SE control and ecological security maintenance. Cropland and grassland are the major sources of SE; therefore, SE control on both cropland and grassland should be strengthened.

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Literature Cited

Carter, H. J., and D. L. Eslinger. 2004. Nonpoint source pollution and erosion comparison tool (N–SPECT) technical guide. Version 1. NOAA-CSC (National Oceanic and Atmospheric Administration-Coastal Services Center). http://coast.noaa.gov/digitalcoast/~/pdf/N–SPECT_TechnicalGuide.pdf?redirect=301ocm

Chen, L. 2012. Implement the central decision and deployment thoroughly, and write a new chapter of soil and water conservation and ecological construction with Chinese characteristics. Ministry of Water Resources of the People’s Republic of China, Beijing, China.

Chen, L., C. Xie; C. Zhang, S. Li, N. Fan, C. Zhang, S. Pei, and L. Ge. 2012. Spatial distribution characteristics of soil erosion in Lancang River Basin. Resources Science 34:1240–1247.

E. J. 2008. Summary report on scientific integrated survey of Chinese soil erosion and ecological security. Soil and Water Conservation in China 12:3–7.

ESRI. 2008. ArcGIS. Version 9.3. Environmental Systems Research Institute, Redlands, California, USA.

Fang, H., L. Sun, D. Qi, and Q. Cai. 2012. Using 137 Cs technique to quantify soil erosion and deposition rates in an agricultural catchment in the black soil region, Northeast China. Geomorphology 169–170:142–150.

Fang, X., W. Zhang, B. Wei, and L. Hu. 2008. History of soil erosion evolution in China. Bulletin of Soil and Water Conservation 28:158–165.

Fu, B., Y. Liu, Y. Lü, C. He, Y. Zeng, and B. Wu. 2011. Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. Ecological Complexity 8:284–293.

Guan, J. 1996. Soil and water conservation principle. China Forestry Press, Beijing, China.

Jiang, Z., Y. Lian, and X. Qin. 2014. Rocky desertification in Southwest China: impacts, causes, and restoration. Earth-Science Reviews 132:1–12.
Li, Y., J. C. Yang, B. Fu, and J. H. Zhang. 2003. Evaluating gully erosion using Cs-137 and Pb-210/Cs-137 ratio in a reservoir catchment. Soil and Tillage Research 69:107–115.

Li, Z., W. Cao, B. Liu, and Z. Luo. 2008. Present status and dynamic variation of soil and water loss in China. Soil and Water Conservation in China 12:7–10.

Li, Z., and B. Liu. 2006. Calculation on soil erosion amount of main river basin in China. Science of Soil and Water Conservation 4:1–6.

Liu, B., S. Liu, and S. Zheng. 1999. Soil conservation and coefficient of soil conservation of crops. Research of Soil and Water Conservation 6:32–36.

Liu, B., Y. Xie, and K. Zhang. 2001. Soil loss prediction model. China Science and Technology Press, Beijing, China.

Liu, B. Y., M. A. Nearing, and L. M. Risse. 1994. Slope gradient effects on soil loss for steep slopes. Transactions of the ASAE [American Society of Agricultural and Biological Engineers] 37:1835–1840.

Lu, H., J. Gallant, I. P. Prosser, C. Moran, and G. Priestley. 2001. Prediction of sheet and rill erosion over the Australian continent, incorporating monthly soil loss distribution. Technical Report 13/01. CSIRO Land and Water, Canberra, Australia.

McCool, D. K., G. O. George, M. Freckleton, C. L. Douglas, and R. I. Papendick. 1993. Topographic effect on erosion from cropland in the northwestern wheat region. Transactions of the ASAE [American Society of Agricultural and Biological Engineers] 36:1067–1071.

Ministry of Water Resources PRC. 2008. Standards for classification and gradation of soil erosion. People’s Republic of China Water Industry Standard SL 190–2007. Ministry of Water Resources, Beijing, China.

Ministry of Water Resources PRC. 2009a. Techniques standard for comprehensive control of soil erosion and water loss in karst region. People’s Republic of China Water Industry Standard SL 461–2009. Ministry of Water Resources, Beijing, China.

Ministry of Water Resources PRC. 2009b. Techniques standard for comprehensive control of soil erosion in the black soil region. People’s Republic of China Water Industry Standard SL 446–2009. Ministry of Water Resources, Beijing, China.

Ministry of Water Resources PRC. 2013. Bulletin of first national water census for soil and water conservation. Soil and Water Conservation in China 10:2–3.

Pham, T. N., D. Yang, S. Kanae, T. Oki, and K. Musiakie. 2001. Application of RUSLE model on global soil erosion estimate. Annual Journal of Hydraulic Engineering 45:811–816.

Pimentel, D., et al. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117–1123.

Rao, E., Z. Ouyang, X. Yu, and Y. Xiao. 2014. Spatial patterns and impacts of soil conservation service in China. Geomorphology 207:64–70.

Shi, X., and X. Deng. 1993. Status and prospects of soil erodibility research. Soil and Water Conservation in China 5:25–29.

van Beynen, P. E., editor. 2011. Karst management. Springer, Utrecht, The Netherlands.

d. van der Knijff, J. M., R. J. A. Jones, and L. Montanarella. 2000. Soil erosion risk assessment in Europe. European Soil Bureau, European Commission Directorate General, Joint Research Centre, Brussels, Belgium.

Van Remortel, R., M. Hamilton, and R. Hickey. 2001. Estimating the LS-factor for RUSLE through iterative slope length processing of digital elevation data within ArcInfo grid.