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# Preservation of Soil Organic Carbon (SOC) through Ecosystems' Soil Retention Services in China

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**Abstract:** Soil erosion exerts a profound impact on the stocks of soil organic carbon (SOC), disrupting the carbon cycle and contributing to global warming. Through its role in mitigating soil erosion, the soil retention service of ecosystems holds the potential to stabilize and safeguard the SOC reservoir. This facet has yet to be comprehensively investigated. In this study, we quantified the preservation of SOC resulting from soil retention services in China, achieved by estimating both actual SOC erosion and potential SOC erosion using the Universal Soil Loss Equation (USLE). We find that (1) annually, SOC erosion in China amounted to 0.10 Pg C, primarily concentrated in croplands (47.8%), grasslands (21.2%), and barren lands (15.7%). Noteworthy hotspots emerged within the Soil and Water Conservation Divisions (SWCD) of key regions like the Tibetan Plateau (TP), the southwestern purple soil region (SW), and the karst region (KT). (2) The soil retention service curtailed the loss of a substantial 4.18 Pg C of SOC per year, predominantly attributed to forest ecosystems (66.1%). Hotspots of this preservation were clustered in the SWCD of the southern red soil region (SR), KT, and TP. These outcomes highlighted the critical role of soil retention services in preventing considerable carbon losses from terrestrial ecosystems. It significantly contributes to climate change mitigation and warrants recognition as an important nature-based solution in the pursuit of carbon neutrality. Forest ecosystems emerge as paramount in SOC preservation, which will be further improved with forest restoration. Beyond addressing soil erosion, future endeavors in soil and water conservation must equally address SOC erosion to comprehensively tackle carbon loss concerns.

**Keywords:** soil retention; SOC preservation; SOC erosion; ecosystem service; China



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## 1. Introduction

Soil holds the distinction of being the third-largest reservoir of carbon on earth, trailing only the oceans and lithosphere [1]. In fact, it is the largest organic carbon repository on land, surpassing the vegetative and atmospheric carbon pools by threefold and twofold, respectively [2,3]. Given the intricate carbon interchanges between the atmosphere, biosphere, and soil realm [4], the soil carbon pool is intimately intertwined with the climate system's dynamics [1]. Even minor disruptions to this pool can yield substantial fluctuations in atmospheric $CO_2$ levels, thereby contributing to global warming [5,6]. Consequently, the preservation of the soil carbon pool assumes paramount significance in maintaining the global carbon balance and addressing climate change.

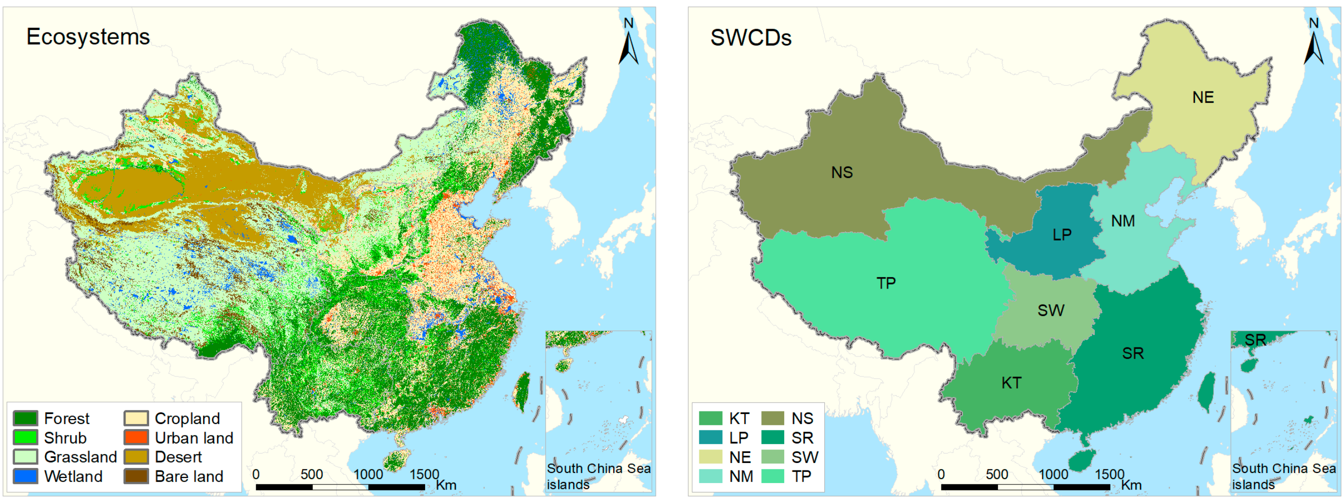
Recent years have witnessed heightened focus on the impact of soil erosion on the soil carbon pool, prompting in-depth investigations into carbon budgets [7–11]. Scholars have delved into the local and global implications of soil erosion on carbon cycling [12–15], the fate of eroded soil carbon [8,16,17], estimations of carbon fluxes induced by erosion [2,9,11,18], and strategies for managing SOC loss mitigation [6,19–21]. Soil erosion, facilitated by erosive agents, strips, transports, and deposits soil particles, causing significant lateral movement of soil organic carbon (referred to as SOC erosion), a process exacerbated by human activities [10]. Global estimates indicate that soil erosion displaces an annual 0.3–5.7 Pg C [15], with accelerated soil erosion resulting in a cumulative removal of approximately 74 ± 18 Pg C of SOC during the period AD 1850–2005 [22].

SOC erosion has emerged as a pivotal carbon pathway within the global carbon cycle, consequently being integrated into contemporary carbon budget evaluations [5,23]. In contrast, the influence of ecosystems' soil retention services on SOC erosion mitigation, termed SOC preservation herein, has received comparatively less attention [20,24], despite extensive investigations into soil retention services at both global and regional scales [24–29]. Particularly within China, a nation significantly affected by severe soil erosion [9,30], the SOC stock (up to 1 m depth) ranges between 70–90 Pg C [31,32], with SOC erosion approximated at 0.64–1.04 Pg C annually [9]. Given the substantial mitigation of potential soil erosion [25], the preservation of SOC resulting from soil retention services becomes prominent. In alignment with China's ambitious targets of capping carbon emissions by 2030 and pursuing carbon neutrality by 2060, this research aims to quantify the national SOC preservation due to soil retention services in China. The study seeks to elucidate the geographic distribution of this preservation influence while identifying crucial regions for averting SOC erosion and fostering its conservation. The methodologies and findings hold the potential to furnish vital tools and insights for ecosystem management, facilitating China's journey towards carbon neutrality.

## 2. Material and Methods

### *2.1. Study Area*

China, situated to the eastern side of Eurasia, boasts a diverse and intricate terrain encompassing plateaus, mountains, basins, hills, and plains. The mountainous regions contribute to approximately two-thirds of its total land area. While inland areas deviate, the prevailing climate pattern in China is predominantly monsoonal. This translates to copious and concentrated precipitation, gradually tapering from the southeastern to the northwestern corners. China's landscape supports a rich variety of ecosystems. Notably, grasslands occupy the largest expanse (29%), primarily spanning the Tibetan Plateau and the northern reaches. Forested areas (21%) are predominantly found in the southern and northeastern parts, whereas croplands (18%) are prominent in the Northeast Plain, North China Plain, the middle and lower Yangtze Plain, and the Sichuan Basin (Figure 1a).




(**a**) (**b**)

**Figure 1.** Spatial distribution of (**a**) ecosystems and (**b**) soil and water conservation divisions in China. The figure (**b**) shows the location of the northeastern black soil region (NE), the northern sandstorm region (NS), the northern rocky mountain region (NM), the Loess Plateau (LP), the southern red soil region (SR), the southwestern purple soil region (SW), the southwestern karst region (KT) and the Tibetan Plateau (TP).

To address the issue of soil erosion, the Ministry of Water Resources of China implemented the National Soil and Water Conservation Plan (2015–2030) and launched the national division of soil and water conservation [33]. In the plan, China is divided into eight Soil and Water Conservation Divisions (SWCD), including the northeastern black soil region (NE), the northern sandstorm region (NS), the northern rocky mountain region (NM), the Loess Plateau (LP), the southern red soil region (SR), the southwestern purple soil region (SW), the southwestern karst region (KT) and the Tibetan Plateau (TP) (Figure 1b).

### 2.2. Methods

#### 2.2.1. Estimation of SOC Erosion

SOC erosion is the soil organic carbon displaced by soil erosion, which can be estimated with the soil erosion amount and SOC content. Since SOC content varies greatly at different depths, we calculated it separately in various soil layers from top to bottom, including soil weight and accumulated soil weight, SOC stock and accumulated SOC stock at each layer. The soil erosion amount was compared with the accumulated soil weight, so as to determine the soil erosion depth, above which the soil organic carbon storage was regarded as the SOC erosion. The soil erosion amount was estimated using the Universal Soil Loss Equation (USLE) [34], with parameters calibrated and verified in other studies [35,36].

$$LSW_i = T_i \times BD_i \times (1 - S_i/100) \times 10^4 \tag{1}$$

$$ASW_n = \sum_1^n LSW_i \tag{2}$$

$$LCS_i = LSW_i \times SOC_i/100 \tag{3}$$

$$ACS_n = \sum_1^n LCS_i \tag{4}$$

where $LSW_i$ and $ASW_i$ are the soil weight (t hm$^{-2}$) and accumulated soil weight (t hm$^{-2}$) of layer $i$, respectively; $LCS_i$ and $ACS_i$ are the SOC stock (Mg C hm$^{-2}$) and accumulated SOC stock (Mg C hm$^{-2}$) of layer $i$, respectively; $T_i$ and $BD_i$ are the soil thickness (m) and soil bulk density (t m$^{-3}$) of layer $i$, respectively; $S_i$ and $SOC_i$ are the soil gravel content (%) and soil organic carbon content (%) of layer $i$, respectively.

When soil erosion occurs to the layer $j + 1$, the SOC erosion includes all SOC stock of layer $j$ and above, and part of the SOC stock of layer $j + 1$. Namely,

$$CSLV = ACS_j + \left(SEV - ASW_j\right)/LSW_{j+1} \times LCS_{j+1} \tag{5}$$

$$SEV = R \times K \times LS \times C \tag{6}$$

where $CSLV$ is the SOC erosion (Mg C hm$^{-2}$ a$^{-1}$); $SEV$ is the soil erosion (t hm$^{-2}$ a$^{-1}$); $R$ is the rainfall erosivity factor (MJ mm hm$^{-2}$ h$^{-1}$ a$^{-1}$); $K$ is the soil erodibility factor (t hm$^2$ h hm$^{-2}$ MJ$^{-1}$ mm$^{-1}$); $LS$ is the terrain factor and $C$ is the vegetation cover factor.

#### 2.2.2. Estimation of Potential SOC Erosion

Potential SOC erosion is the soil organic carbon displaced by soil erosion when ecosystems' soil retention service is completely degraded. Similarly, it was calculated by potential soil erosion (soil erosion without vegetation cover) and SOC content of each layer.

When potential soil erosion occurs to the layer $k + 1$, the potential SOC erosion includes all the SOC stock of layer $k$ and above, and part of the SOC stock of layer $k + 1$. Namely,

$$CSLO = ACS_k + (SEO - ASW_k)/LSW_{k+1} \times LCS_{k+1} \tag{7}$$

$$SEO = R \times K \times LS \tag{8}$$

where $CSLO$ is the potential SOC erosion (Mg C hm$^{-2}$ a$^{-1}$) and $SEO$ is the potential soil erosion (t hm$^{-2}$ a$^{-1}$).

#### 2.2.3. Estimation of SOC Preservation

Ecosystems can protect the soil, weaken the rainfall erosivity and reduce the soil loss through soil retention services. Along with the reduced soil erosion, the transport and redistribution of SOC is correspondingly reduced. Therefore, the difference between the potential SOC erosion without vegetation cover and the SOC erosion under current vegetation cover was used to characterize the SOC preservation effect of soil retention service. Namely,

$$CSSR = CSLO - CSLV \tag{9}$$

where $CSSR$ is the SOC preservation (Mg C hm$^{-2}$ a$^{-1}$); $CSLO$ and $CSLV$ represent the potential SOC erosion (Mg C hm$^{-2}$ a$^{-1}$) and the SOC erosion (Mg C hm$^{-2}$ a$^{-1}$), respectively.

### *2.3. Data*

The stratified soil attribute data (including bulk density, soil thickness, and the content of clay, silt, sand, gravel, and soil organic matter) used in this study were from the second national soil survey with a spatial resolution of 1 km [37]. The data were collected in 8 layers according to the soil depth: the first layer (0–4.5 cm), the second layer (4.5–9.1 cm), the third layer (9.1–16.6 cm), the fourth layer (16.6–28.9 cm), the fifth layer (28.9–49.3 cm), the sixth layer (49.3–82.9 cm), the seventh layer (82.9~138.3 cm) and the eighth layer (138.3~229.6 cm), with the maximum depth of investigation being about 2.30 m.

Other data mainly include the maps of digital elevation model (SRTM, Shuttle Radar Topography Mission), the annual average rainfall erosivity factor (1991–2020) calculated using daily precipitation model, the ecosystems (2015) and vegetation coverage (2015) (Table 1, Figure S1). All of the modelling and data processing were performed in ArcGIS10.5, and the spatial resolution of various intermediate and final results was set to be 90 m.

**Table 1.** Principal data sources.

| Data | Spatial Resolution | Sources |
|---|---|---|
| Ecosystems | 90 m | Aerospace Information Research Institute, Chinese Academy of Sciences |
| Vegetation coverage | 250 m | Aerospace Information Research Institute, Chinese Academy of Sciences |
| SRTM | 90 m | Computer Network Information Center, Chinese Academy of Sciences |
| Soil attributes | 1 km | National Tibetan Plateau Data Center |
| Rainfall erosivity factor | 250 m | Beijing Normal University |

## 3. Results

### *3.1. SOC Erosion*

Soil erosion is not only related to climate, soil and topography, but also strongly affected by vegetation cover. In China, the total soil erosion in 2015 was 6.4 billion t a$^{-1}$, with an average soil erosion rate of 6.7 t hm$^{-2}$ a$^{-1}$. Spatially, soil erosion mainly occurred in the Loess Plateau and southwestern China (Figure 2a).

The SOC erosion result from water erosion was 0.10 Pg C a$^{-1}$, with an average SOC erosion rate of 0.11 Mg C hm$^{-2}$ a$^{-1}$. The highest rate was observed in bare lands (0.70 Mg C hm$^{-2}$ a$^{-1}$) and croplands (0.29 Mg C hm$^{-2}$ a$^{-1}$), while most of the SOC erosion occurred in croplands (0.05 Pg C a$^{-1}$), grasslands (0.02 Pg C a$^{-1}$) and bare lands (0.02 Pg C a$^{-1}$), accounting for 47.8%, 21.2% and 15.7% of the total, respectively (Table 2). Spatially, the SOC erosion mainly occurred in southwestern China, southern Tibetan Plateau and southwestern Loess Plateau (Figure 2b).

The top 50% highest value regions were recognized as SOC erosion hotspots, based on the SOC erosion-area curve. Results showed that the hotspot covered 8.8 × 10$^4$ km$^2$ (~0.9% of China's land area) (Figure 2c), most of which were croplands (64.2%), followed by bare lands (16.5%) and grasslands (14.3%) (Figure 2d). Spatially, they were mainly distributed in TP (28.9%), SW (21.5%) and KT (19.9%) (Figure 2e). In spite of their small area, those hotspots contributed most of the SOC erosion in China. They are key regions for controlling SOC erosion and improving SOC preservation.

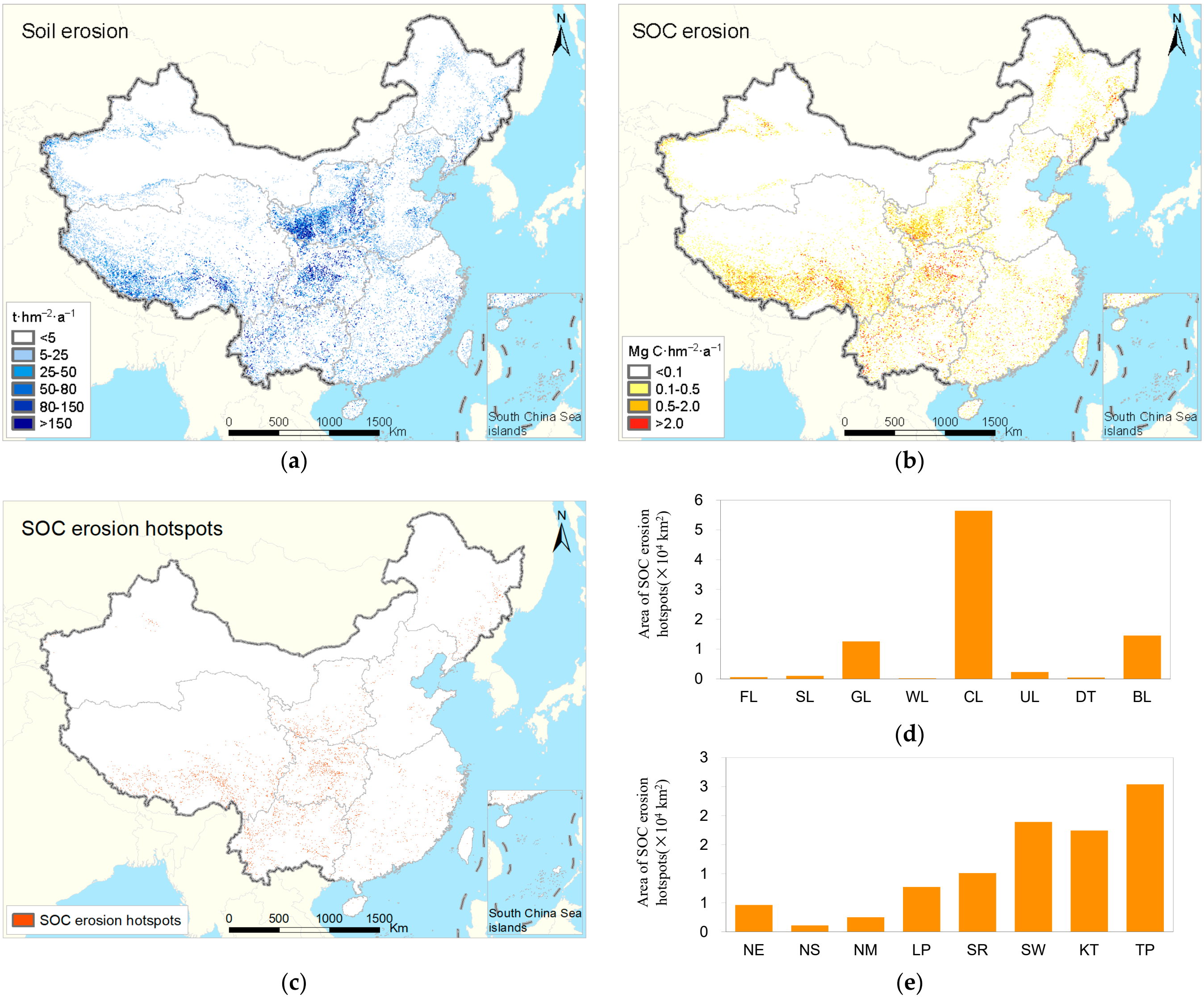



**Figure 2.** Spatial distribution of (**a**) soil erosion, (**b**) SOC erosion, and (**c**–**e**) SOC erosion hotspots. The figure (**d**) shows the area of SOC erosion hotspots in ecosystems of forests (FL), shrubs (SL), grasslands (GL), wetlands (WL), croplands (CL), urban lands (UL), deserts (DT) and bare lands (BL). The figure (**e**) shows the area of SOC erosion hotspots in SWCDs of the northeastern black soil region (NE), the northern sandstorm region (NS), the northern rocky mountain region (NM), the Loess Plateau (LP), the southern red soil region (SR), the southwestern purple soil region (SW), the southwestern karst region (KT) and the Tibetan Plateau (TP).

## *3.2. Potential SOC Erosion*

Potential soil erosion is the soil erosion without vegetation cover, which is mainly related to climate, soil and topography. The results showed that the total potential soil erosion was 211.6 billion t $a^{-1}$, with an average erosion rate of 220.4 t $hm^{-2}$ $a^{-1}$, which is much higher than the actual soil erosion. Spatially, potential soil erosion would mainly occur in the vast southern China and the Loess Plateau (Figure 3a).

**Table 2.** The SOC stock, SOC erosion and SOC preservation in various ecosystems.

| Ecosystems | SOC Stock | | SOC Erosion | | Potential SOC Erosion | | SOC Preservation | |
|---|---|---|---|---|---|---|---|---|
| | Mg C hm$^{-2}$ | Pg C | Mg C hm$^{-2}$a$^{-1}$ | Tg C a$^{-1}$ | Mg C hm$^{-2}$a$^{-1}$ | Tg C a$^{-1}$ | Mg C hm$^{-2}$a$^{-1}$ | Tg C a$^{-1}$ |
| Forest | 110.7 | 22.0 | 0.03 | 6.6 | 13.94 | 2772.0 | 13.91 | 2765.3 |
| Shrub | 93.2 | 6.0 | 0.08 | 4.9 | 8.63 | 553.7 | 8.55 | 548.8 |
| Grassland | 80.2 | 22.1 | 0.08 | 21.8 | 2.09 | 575.5 | 2.01 | 553.7 |
| Wetland | 134.5 | 3.8 | 0.01 | 0.2 | 0.83 | 23.2 | 0.82 | 22.9 |
| Cropland | 84.3 | 14.5 | 0.29 | 49.2 | 1.78 | 305.7 | 1.49 | 256.5 |
| Urban land | 80.1 | 2.2 | 0.11 | 3.0 | 0.93 | 26.2 | 0.83 | 23.1 |
| Desert | 23.1 | 3.0 | 0.01 | 0.9 | 0.01 | 1.0 | 0.00 | 0.1 |
| Bare land | 66.9 | 1.5 | 0.70 | 16.2 | 0.76 | 18.0 | 0.06 | 1.8 |

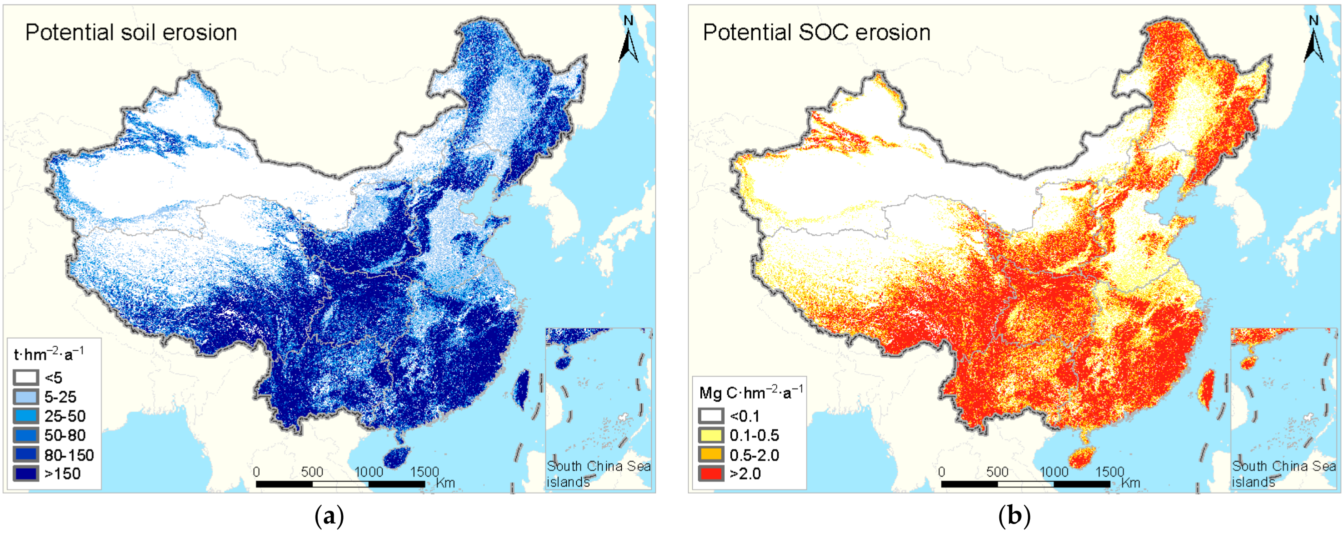



**Figure 3.** Spatial distribution of (**a**) potential soil erosion and (**b**) potential SOC erosion.

The potential SOC erosion was 4.28 Pg C a$^{-1}$ in total, and the average potential SOC erosion rate was 4.46 Mg C hm$^{-2}$ a$^{-1}$. The highest rate would have occurred in ecosystems of forests (13.94 Mg C hm$^{-2}$ a$^{-1}$) and shrubs (8.63 Mg C hm$^{-2}$ a$^{-1}$), and most of the potential SOC erosion would have occurred in ecosystems of forests (2.77 Pg C a$^{-1}$), accounting for about 64.7% of the total (Table 2). Spatially, affected by spatial distributions of both potential soil erosion and SOC content, the potential SOC erosion would have occurred mainly in southern China (Figure 3b).

### *3.3. SOC Preservation through Soil Retention Service*

Through soil retention, ecosystems curtail the displacement of SOC, thereby upholding the stability of the soil carbon pool and carbon cycle. Comparing the potential SOC erosion and SOC erosion, the SOC preservation result from soil retention service was 4.18 Pg C a$^{-1}$, with an average SOC preservation rate of 4.35 Mg C hm$^{-2}$ a$^{-1}$. The highest preservation rate was observed in ecosystems of forests (13.91 Mg C hm$^{-2}$ a$^{-1}$) and shrubs (8.55 Mg C hm$^{-2}$ a$^{-1}$), and the most SOC preservation occurred in forests (2.77 Pg C a$^{-1}$), accounting for 66.1% of the total (Table 2). Spatially, the SOC preservation clustered mainly in mountains of southern China. The Changbai Mountains and the Great Khingan Mountains in the northeast also exhibit a high SOC preservation (Figure 4a).

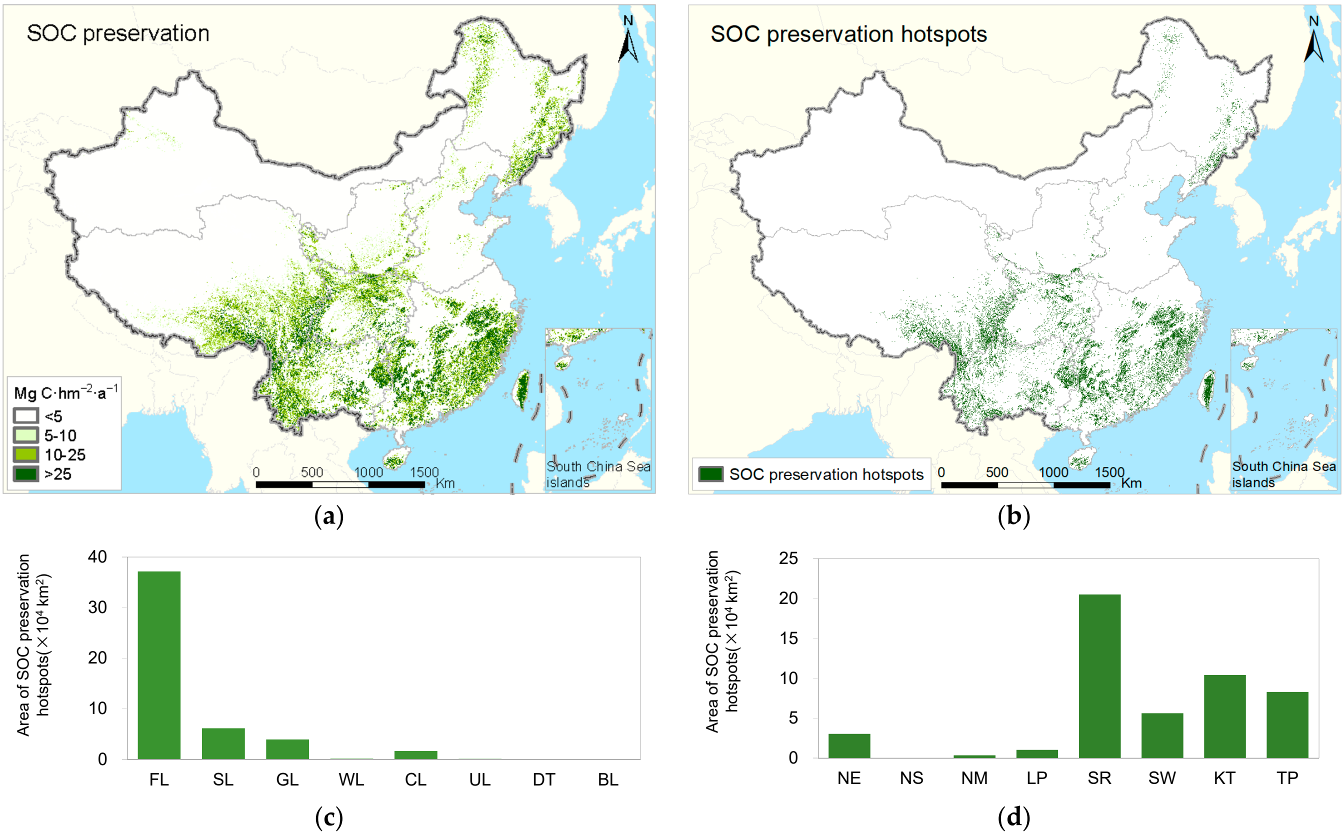



**Figure 4.** Spatial distribution of (**a**) SOC preservation and (**b**–**d**) SOC preservation hotspots. The figure (**c**) shows the area of SOC preservation hotspots in ecosystems of forest (FL), shrub (SL), grassland (GL), wetland (WL), cropland (CL), urban land (UL), desert (DT) and bare land (BL). The figure (**d**) shows the area of SOC preservation hotspots in SWCDs of the northeastern black soil region (NE), the northern sandstorm region (NS), the northern rocky mountain region (NM), the Loess Plateau (LP), the southern red soil region (SR), the southwestern purple soil region (SW), the southwestern karst region (KT) and the Tibetan Plateau (TP).

The top 50% highest value regions were recognized as SOC preservation hotspots, based on the SOC preservation-area curve. Results showed that the hotspot covered $49.2 \times 10^4$ km$^2$ (~5.1% of China's land area) (Figure 4b), most of which were forests (75.5%), followed by shrubs (12.5%) (Figure 4c). Spatially, they were mainly distributed in mountains of SR (41.7%), KT (21.2%) and TP (16.8%) (Figure 4d). Both the potential SOC erosion and SOC preservation were high in these hotspots, which can be treated as key regions for preventing SOC erosion and maintaining SOC preservation.

## 4. Discussion

### *4.1. SOC Erosion and Its Sources*

In China, the annual estimation of SOC erosion in 2015 was approximately 0.10 Pg C, closely aligned with the findings from 1995 to 2012 (0.18 ± 0.08 Pg C) by Yue et al. [38]. However, this estimation was lower than the range of 0.64–1.04 Pg C annually for the period 1982 to 2011, as established by Zhang et al. [9]. This divergence can be attributed in part to the adoption of varying enrichment rates (ER), which signifies the ratio of eroded soil's SOC content to that of the parent soils, with a value of 1 employed in our research and that of Yue et al. [38]. Additionally, it could be attributed to notable reductions in soil erosion due to ecological protection and restoration efforts in China since the 1990s [20,39]. Notably, data from the Ministry of Water Resources of China [40] indicated a marked decline in sediment discharge across major river basins within the country in recent decades. These findings suggest the reasonableness of our estimation and the reduction of SOC erosion in China, largely attributable to soil and water conservation measures. Despite this, it is essential to acknowledge that a comprehensive global carbon budget without accounting for SOC erosion can still pose challenges [41].

Croplands, grasslands and bare lands are the main sources of erosion-induced carbon losses in China, which is consistent with the pattern found on a global scale [22]. Croplands, in particular, merit attention because of their high soil erosion rate and strong link between SOC content and soil fertility [7,18,42]. Furthermore, agricultural tillage practices intensify soil organic matter mineralization [21,43], resulting in pronounced erosion and soil carbon losses in cropland areas [35,44]. In contrast, grasslands have historically received less attention, mainly due to lower precipitation and erosion rates [45–47]. However, China's zonal distribution of soil erosion dictates that the most severe erosion is concentrated in the farming-pastoral ecotone, marked by inadequate vegetation cover [35]. Additionally, widespread grassland degradation, driven by overgrazing and over-exploitation [36], amplifies the significance of addressing grassland erosion and subsequent SOC loss.

### *4.2. Contribution of SOC Preservation to Climate Change Mitigation*

Our research indicates that ecosystems' soil retention services have the potential to significantly curb soil erosion by approximately 205.2 billion tons annually. Correspondingly, SOC erosion could be diminished by approximately 4.18 Pg C each year, accounting for 97.6% of potential SOC erosion. This reduction translates to a decrease of about 0.85 Pg C of carbon emissions attributed to erosion, assuming an approximate 20% mineralization rate [2]. While acknowledging the rough nature of this estimation, it underscores the role of ecosystems not only as carbon sinks, but also as crucial agents in preventing substantial carbon emissions through their soil retention services. This aspect significantly contributes to the global carbon equilibrium and climate change mitigation [23]. Thus, intensifying efforts to protect ecosystems, enhancing soil retention services, and mitigating erosion-induced SOC loss holds promise in achieving the dual goal of carbon neutrality.

Among ecosystems, forest ecosystems emerge as pivotal in stabilizing and conserving the SOC pool. This is attributed to their ample precipitation and high potential soil erosion rates, coupled with the erosion-reducing effects of their multi-layered structure [48,49]. Furthermore, substantial litter inputs facilitate dynamic replacement, ensuring effective SOC preservation. Despite substantial afforestation efforts in China over recent decades [50], challenges exist, including slowed forest area growth and a predominance of artificial and youthful forests offering limited soil retention services [51]. Nonetheless, as forest quality gradually improves, the potency of soil retention services and SOC preservation is expected to strengthen further.

### *4.3. Key Regions for SOC Erosion and SOC Preservation*

The spatial distribution of SOC erosion within China diverges from that of soil erosion due to the spatial heterogeneity of SOC content. The Loess Plateau, for instance, is renowned for its severe soil erosion and has garnered significant attention. However, the SOC content within this region tends to be low, resulting in less severe SOC erosion compared to the Tibetan Plateau. Despite lower soil erosion rates, the latter area witnesses larger soil erosion coverage and more enriched SOC. Effectively curbing soil erosion within the Tibetan Plateau could lead to a 32% reduction in China's SOC erosion (Table 3), with this proportion potentially being even higher considering projected accelerated soil erosion due to climate change [52]. Hence, it becomes imperative to accord greater attention to SOC erosion alongside traditional soil erosion in future carbon loss considerations.

In order to efficiently tackle erosion-induced carbon losses, we have employed SOC erosion and preservation hotspots to delineate pivotal regions for SOC erosion control and SOC erosion prevention, respectively. Our analysis reveals that reinforcing soil erosion controls in croplands within SW and KT, as well as grasslands and bare lands within TP, can yield effective SOC erosion reduction (Figure 5a). Similarly, bolstering ecological protection measures in forests within SR and KT, as well as forests and grasslands within TP, can contribute to SOC preservation and prevent SOC erosion (Figure 5b).

**Table 3.** The SOC stock, soil erosion and SOC erosion in various SWCDs.

| SWCDs | SOC Stock | | Soil Erosion | | SOC Erosion | |
|---|---|---|---|---|---|---|
| | Mg C $hm^{-2}$ | Pg C | t $hm^{-2}$ $a^{-1}$ | Gt $a^{-1}$ | Mg C $hm^{-2}a^{-1}$ | Tg C $a^{-1}$ |
| NE | 141.6 | 18.0 | 2.2 | 0.2 | 0.06 | 6.9 |
| NS | 42.9 | 10.5 | 1.2 | 0.3 | 0.02 | 3.7 |
| NM | 72.5 | 5.9 | 5.4 | 0.4 | 0.06 | 4.7 |
| LP | 56.8 | 3.2 | 25.5 | 1.4 | 0.18 | 9.7 |
| SR | 80.7 | 9.0 | 6.9 | 0.8 | 0.12 | 14.1 |
| SW | 92.0 | 4.4 | 21.7 | 1.1 | 0.32 | 16.2 |
| KT | 100.4 | 6.2 | 11.1 | 0.8 | 0.22 | 15.0 |
| TP | 94.9 | 19.6 | 6.4 | 1.4 | 0.15 | 32.7 |

Note: NE, the northeastern black soil region; NS, the northern sandstorm region; NM, the northern rocky mountain region; LP, the Loess Plateau; SR, the southern red soil region; SW, the southwestern purple soil region; KT, the southwestern karst region; TP, the Tibetan Plateau.

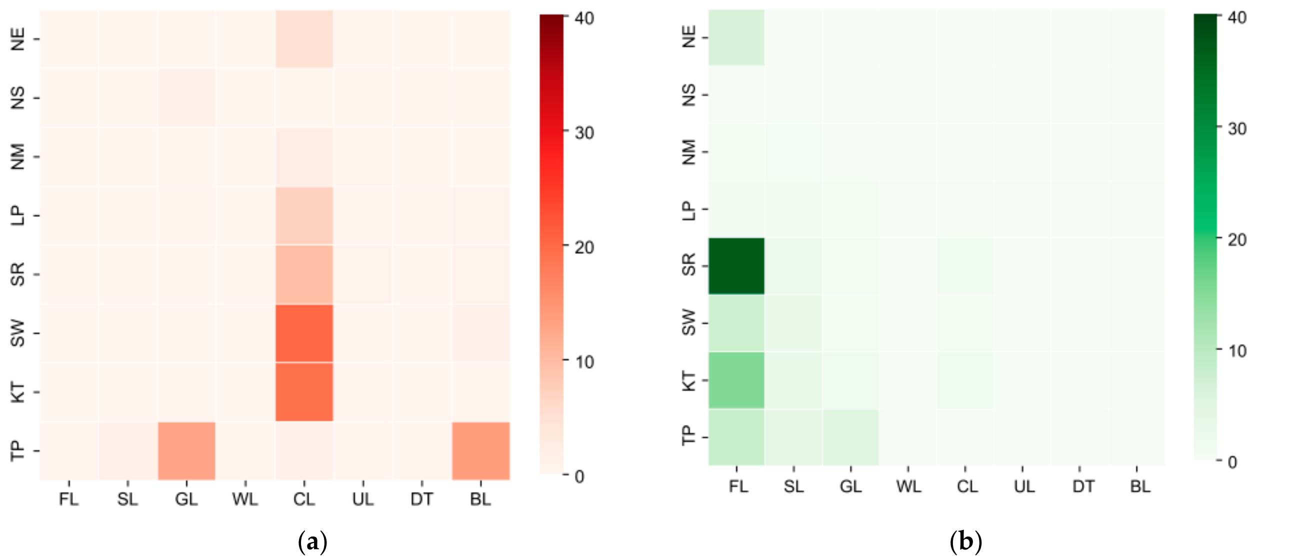



**Figure 5.** Area proportion of key regions for (**a**) SOC erosion control and (**b**) SOC erosion prevention. The grid represents area proportion (%) of key regions located in specific ecosystem of specific Soil and Water Conservation Division (SWCD), with a darker color means a larger proportion. Ecosystems include forests (FL), shrubs (SL), grasslands (GL), wetlands (WL), croplands (CL), urban lands (UL), deserts (DT) and bare lands (BL), and SWCDs include the northeastern black soil region (NE), the northern sandstorm region (NS), the northern rocky mountain region (NM), the Loess Plateau (LP), the southern red soil region (SR), the southwestern purple soil region (SW), the south-western karst region (KT) and the Tibetan Plateau (TP).

Effective management practices hold the potential to significantly enhance ecosystem SOC preservation and diminish SOC erosion [12]. Research has demonstrated that strategies like conservation tillage, crop cover maintenance, fertilization, and no-tillage approaches can collectively augment global cropland SOC by 0.4 to 0.8 Pg C annually [21,53]. Notably, conservation tillage alone can sequester carbon at rates of 0.1 to 1 Mg C $hm^{-2}$ $a^{-1}$ [53]. Similarly, retaining crop residues has been observed to mitigate greenhouse gas emissions by 0.05 Mg C $t^{-1}$ [54], and terracing techniques have yielded a substantial 32.4% increase in SOC sequestration [55]. In grasslands, prudent grazing management measures can amplify global grassland SOC by 0.01 to 0.3 Pg C $a^{-1}$ [53], while China's 'Returning Grazing Land to Grassland Project' is estimated to foster a carbon sink effect of 14.7 ± 6.0 Tg C annually [56].

Likewise, the restoration of vegetation in bare lands can engender changes in SOC content and stability, thereby effectively curtailing SOC erosion [20,57].

### 4.4. Uncertainties

While the USLE model employed herein for soil erosion calculation is broadly recognized and validated [25], and the estimated SOC erosion aligns with other research [22,38], there remain uncertainties necessitating further refinement. First, the methodologies for estimating SOC erosion and preservation are simplified, primarily focusing on static assessments while omitting the intricacies of complex carbon exchange dynamics. Second, the soil data utilized in this study derive from the second national soil survey conducted in the 1980s, potentially leading to the removal of topsoil during erosion and alterations in soil properties, particularly within croplands [5,43]. Encouragingly, the launch of the third national soil survey in 2022 holds promise for enabling more detailed and pragmatic estimations in the future. Furthermore, as SOC erosion embodies a multitude of intricate processes interplaying at diverse temporal and spatial scales [58], the question of whether soil erosion acts as a carbon source or sink remains unresolved [8,58]. Despite these uncertainties, SOC erosion and preservation remain pivotal components within the global carbon cycle and budget, given their substantial magnitude [22,41].

## 5. Conclusions

Using the USLE model and pertinent soil data, our quantitative exploration of SOC preservation stemming from soil retention services in China is achieved by estimating both SOC erosion and potential SOC erosion. Our findings underscore the following conclusions: (1) The SOC preservation effect arising from soil retention services signifies a potent safeguard against significant carbon losses, thereby making a substantial contribution to climate change mitigation. (2) This preservation effect is primarily provided by forest ecosystems, with the potential for further enhancement through forest restoration initiatives. (3) SOC erosion predominantly transpires in croplands, grasslands, and bare lands, advocating for conservation tillage, grazing management, and vegetation restoration, among other strategies. (4) The spatial distribution of SOC erosion diverges from that of soil erosion, advocating for heightened attention to SOC erosion in the broader context of carbon loss considerations. Our results accentuate the profound role of SOC erosion within the global carbon budget and emphasize the necessity of integrating soil retention service-induced SOC preservation into carbon neutralization strategies. Additionally, they shed light on pivotal regions pertaining to SOC erosion and preservation, offering a novel perspective that can inform soil and water conservation efforts and ecological protection initiatives.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12091718/s1.

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