

Evaluating the spatial heterogeneity of soil loss tolerance and its effects on erosion risk in the carbonate areas of South China

Yue Li^{1,2}, Xiaoyong Bai^{*1,2,4}, Shijie Wang^{1,2}, Luoyi Qin^{1,2},
Yichao Tian^{1,3}, Guangjie Luo^{1,3}

1. State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, Guizhou, 550002, PR China

2. Puding Comprehensive Karst Research and Experimental Station, Institute of Geochemistry, CAS and Science and Technology Department of Guizhou Province, Puding, Guizhou, 562100, PR China

3. Graduate School of Chinese Academy of Sciences, Beijing 100029, PR China

4. Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu, Sichuan, 610041, PR China

Correspondence to: Bai xiaoyong (baixiaoyong@126.com)

Abstract. Soil loss tolerance (T value) is the ultimate criterion to determine the necessity of erosion control measures and ecological restoration strategy. However, the validity of this criterion in subtropical karst regions is strongly disputed. In this study, T value is computed based on soil formation rate by using a digital distribution map of carbonate rock assemblage types. Results indicated spatial heterogeneity and diversity in such values; moreover, a minimum of three criteria should be considered instead of only one criterion when investigating the carbonate areas of South China given that the “one region, one T value” concept may not apply to this region. T value is proportionate to the amount of argillaceous material in formations that determine surface soil thickness in homogenous carbonate rock areas; such values are 20 and 50 t/(km²·a) in carbonate rock intercalated with clastic rock areas and 100t/(km²·a) in carbonate/clastic rock alternation areas. These three areas are each extremely, severely, and moderately sensitive to soil erosion. This erosion is extreme in karst rocky desertification (KRD) land and reflects the degree of erosion risk. Thus, the relationship between T value and erosion risk is determined with KRD as a parameter. The existence of KRD land is unrelated to T value, although this parameter indicates erosion sensitivity. In fact, erosion risk is strongly dependent on the relationship between real soil loss (RL) and T value rather than on either erosion intensity or the T value itself. If $RL \gg T$, then erosion risk is high despite a low RL. Conversely, if $T \gg RL$, the soil is safe although RL is high. Overall, these findings may clarify T value heterogeneity and its effect on erosion risk in a karst eco-environment; hence, innovative technological assessment solutions need not be invented.

1 Introduction

The fragile ecological environment of karst areas is closely related to surface soil (Nigussie Haregeweyn et al.,

2017; Li et al., 2016; Bülent Turgut, Merve Ateş. 2016; Bai et al., 2013). However, these factors are less associated with the total lack of inherent soil in such areas (Zhongwu Li et al., 2017; Luo et al., 2016; İlknur Gümüş; Xu et al., 2013). Soil is continuously distributed through erosion, and rocky desertification landscapes are frequently generated (Tian et al., 2016; Tegegne Molla and Biniam Sisheber 2016; Bai et al., 2013). Determining soil loss tolerance (T value) is one of the most important criteria in controlling erosion and restoration ecosystems; therefore, this factor must be measured scientifically and rationally. T is expressed in terms of annual soil loss ($t/km^2 \cdot a$) and reflects the maximum level of soil erosion that can occur while allowing the land to sustain an indefinite, economic level of crop productivity (Wischmeier and Smith 1965, 1978). This value is an important criterion in determining the potential erosion risk of a particular soil and often serves as the ultimate erosion control criterion to preserve long-term soil productivity (Duan et al., 2012). Thus, a scientifically determined T value is among the most significant aspects in the planning of soil erosion control on agricultural lands and on other types of lands (Liu et al., 2003). The concept of this value was first proposed in the United States in 1956, and the top 10 factors that influence it were identified for a particular soil (USDA 1956). Although T value determination criteria have often been modified, soil formation rate remains a typical and necessary factor. Early researchers (Smith 1941; Hays and Clark 1941; Browning et al., 1947; Klingebiel 1961) generated empirical proofs to compute this value. In the 1980s, Pierce et al (1983, 1984a) suggested the use of a soil productivity model to calculate T value and initiated the quantitative study of this factor. Worldwide T values obtained based on the soil productivity method range from 116 $t/(km^2 \cdot a)$ to 9300 $t/(km^2 \cdot a)$ depending on location (Pierce et al., 1983, 1984a, 1984b; Skidmore et al., 1982). In India, the default soil loss tolerance limit of $11.2 \text{ Mg ha}^{-1} \cdot \text{yr}^{-1}$ is followed to project soil conservation activities. Scholars who examined related topics opined that criteria should be developed to determine T value limits and that these values should differ for each soil series (Pretorius 1989). Stamey and Smith (1964) proposed a notion model of an estimated T value in relation to the strength of both soil properties and soil formation rates. Skidmore (1982) improved the concept model and calculated this value with soil thickness instead of soil characteristics. Both high and low T limits are incorporated in this approach. According to Bazzoffi (2009), the notion of tolerance erosion based on only soil productivity and soil reformation rate is declining, and the off-site effects of soil erosion should be considered. Therefore, this researcher suggested expanding the concept of hydrogeological risk to soil erosion by implementing the notion of T alongside a new concept, namely, environment risk of soil erosion. Scholars agree that soil loss should stabilize soil fertility and long-term soil productivity in addition to maintaining the balance between soil loss rate and soil formation rate (Schertz 1983; Pierce et al., 1984; Alexander 1988a, b). Lithologic soil, such as the purple soils (entisols) derived from limestone bedrock in China, have a faster formation rate than other soils. Under exposed conditions, the maximum weathering rate of this soil type is $15,000 \text{ Mg km}^{-2} \text{ yr}^{-1}$ (Zhu et al., 1999). Purple soils are ideal for T research conducted over a short time scale given their high formation rate. Thus, the objectives of our research are to: (i) measure the soil formation rate of either the parent materials of purple soil or the bedrock in the field (measured SR) and (ii) compare the measured and estimated SR values as well as determine the T values of purple soil. Although various influencing factors were identified when this value was first presented in the United States in 1956 (USDA 1956), global studies on T are mainly based on soil formation rate (Li et al., 2005).

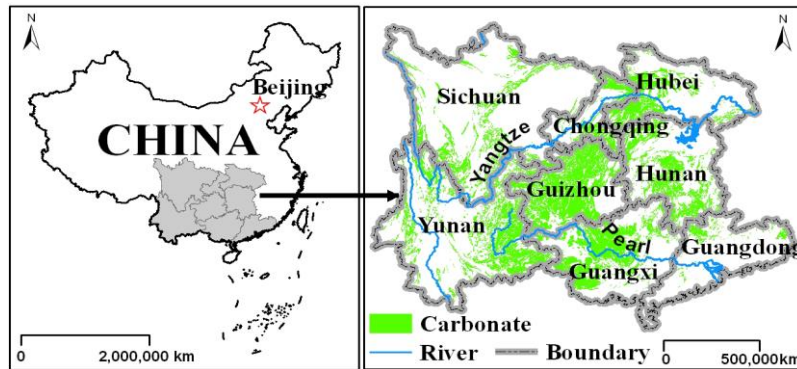
70 In the carbonate mountain areas of South China, soil thickness generally ranges from 30 cm to 50 cm. Once soil
71 is lost, the underlying basement rock is exposed, and karst rocky desertification land appears (Wang et al., 2004).
72 This occurrence, which is caused by soil erosion, is among the most serious eco-environmental problems in this
73 region. Mineralogical and geochemical studies indicate that soil layers are predominantly derived from residues
74 (argillaceous material) that remain after the dissolution of the underlying carbonate rocks and of the thin
75 argillaceous layers interbedded among these rocks (Wang et al., 1999). Owing to the low concentrations of
76 acid-insoluble components, the volume of carbonate rocks tends to decrease sharply in association with the
77 formation of weathering crusts. Highly pure carbonate rocks correspond to low acid-insoluble substance content;
78 therefore, the weathering–pedogenesis of carbonate rocks is the most fundamental and common
79 geological–geochemical process (Liu et al., 2009). This process is also the main soil formation method used in
80 subtropical carbonate regions. The severity of soil erosion depends strongly on the soil formation rate in the
81 background conditions of the geological environment. Therefore, the T in carbonate areas can be determined
82 according to this rate.

83 The objectives of this research were to: (1) Discover the spatial heterogeneity and diversity of soil erosion
84 tolerance in the carbonate areas of south China, and disprove the old “one region, one T value” concept. (2)
85 Proposed a new viewpoint: in karst regions, a large soil erosion modulus does not correspond to severe soil erosion,
86 and clarified the heterogeneity of T values and the effects of this value on the erosion risk in karst
87 eco-environments.

88 2 Study area

89 The study area is located across the Yangtze River and the Pearl River in southwestern China. The
90 approximate coordinates are 22°01'–33°16'N and 98°36'–116°05'E. The area covers Guizhou Province, Yunnan
91 Province, Guangxi Zhuang Autonomo can be considered us Region, Hunan Province, Hubei Province, Sichuan
92 Province, Chongqing Municipalities, and Guangdong Province (Fig.1). Moreover, the study area belongs to the
93 tropical moist and subtropical moist regions, which include different types of landforms, the annual average
94 temperature is 11.0-19.0 degree Celsius; Because of the plenty rain, more than 80% of the area's average annual
95 total precipitation is between 1100 and 1300 mm, the quantity of rain throughout seasons is uneven, more rainfall in
96 May-October, precipitation of June to August accounted for about half of the total, but light and rainfall,
97 temperature change basically synchronous. Carbonate rock covers outcropped area of 522,100km², from the Sinian
98 to Triassic, the thick carbonate formation was deposited in the study area. Yunnan, Qianxi - Qiannan, Western
99 Guangxi is mainly thick layer of bare limestone, dolomite and limestone; Northeast Guizhou, Chongqing, Hubei,
100 Xiangxi trough valley area is mainly dolomite and clastic rocks interbedded; the middle part of Hunan, central
101 Guilin area- southeast Guangxi and Northern Guangdong belong to covered carbonate rock; the west of Sichuan and
102 Yunnan consist primarily of buried limestone. The southwestern karst mountainous areas are characterized by
103 limestone soil, and the distribution of this soil varies considerably. Mountainous regions with world-famous karst
104 rock formations account for 70% of the total area. Finally, this region is under a typical subtropical monsoon moist

105 climate and a natural karst mountainous environment. This area also contains inland plateau lands.



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Figure1. Map showing the location and the distribution of carbonate regions in South China

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3 Materials and methods

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3.1 Construction of a carbonate rock assemblage distribution map

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A 1:500,000 scale digital geological map is constructed that shows the distribution of carbonate rock assemblage types in the carbonate areas of South China; an officially published map is used as a data source.

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The method of constructing a carbonate rock assemblage distribution map is identical to our previously used technique (Wang et al., 2004). The amount of argillaceous material in formations is considered an indicator for distinguishing rock assemblages because this amount indicates surface soil thickness. Thus, assemblages can be divided into three types:

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(1) Homogenous carbonate rock (HC): > 90% carbonate rock, < 10% argillaceous material, and no clear clastic interbed. On the basis of composition, HC can be categorized into three subtypes: homogenous limestone (HL), homogenous dolomite (HD), and mixed dolomite/limestone (HDL).

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(2) Carbonate rock intercalated with clastic rock (CI): 70%–90% carbonate rock, 10%–30% argillaceous material, and a clear clastic interbed. On the basis of composition, CI can be divided into two subtypes, namely, limestone interbedded with clastic rock (LI) and dolomite interbedded with clastic rock (DI).

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(3) Carbonate/clastic rock alternations (CA): 30%–70% and 70%–30% carbonate and clastic rocks, respectively. On the basis of composition, CA can be categorized into two subtypes, namely, limestone/clastic rock alternations (LA) and dolomite/clastic rock alternations (DA).

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The calculation of argillaceous material can be based on 5%, 20%, and 50% for HC, CI, and CA, respectively. In addition, carbonate rock can be computed based on 95%, 80%, and 50% for HC, CI, and CA, respectively.

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3.2 Method of computing soil information rate

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The soil information rate of carbonate rocks is related to temperature, precipitation, hydrology, vegetation and other environmental conditions. This rate changes annually, monthly, daily, and even hourly on the same day (over daytime and nighttime). Average soil information rate can reflect overall characteristics, but it does not represent

131 specific position and special time. The soil information rate ranges from 30.00–89.70 mm/ka in the carbonate areas of
 132 South China as per a long-term field observation; the mean rate is 55.27 mm/ka. As per the results of an in-house
 133 laboratory investigation, the densities of calcite carbonatite and dolomite carbonatite are 2.75 and 2.86 t/m³,
 134 respectively. The soil formation rate of other rock types is 200 t/(km²·a) (Li et al., 2006), and the rates of different
 135 rock type assemblages serve as their *T* values.

136 Specific *T* value can be calculated with the following equation:

$$137 \quad T = v \cdot Q \cdot \rho C + R \cdot (I - C) \quad (1)$$

138 Where *T* is soil loss tolerance (t·km⁻²·yr⁻¹); *v* is the dissolution velocity of carbonate rocks (m³·km⁻²·yr⁻¹); *Q* is the
 139 content of acid-insoluble components (%); *ρ* is carbonate density (t·m⁻³); *C* is the proportion of carbonate; and *R* is
 140 the soil formation rate of other rock types.

141 3.3 Construction of a KRD land distribution map in Guizhou Province in 2000

142 On the basis of this classification scheme (Table 1) and in combination with the corresponding 1:100,000 scale
 143 digital land use maps, the human–computer interactive interpreting method was used to construct a 1:100,000 scale
 144 digital hydrogeology map, relief map, soil distribution map, and KRD land distribution maps in the year 2000 from
 145 Landsat images.

146 **Table.1** The classification criterion and characteristic code of KRD types

Classification and code of KRD type	Proportion percentage of bare rock (%)	Distribution character of the exposed rock	Color of the RS image
No KRD (NKRD)	<20	Star	Scarlet
Potential KRD (PKRD)	20-30	Star, Line	Shocking pink
Already KRD (AKRD)	>31	Patch	Pink, Gray, White

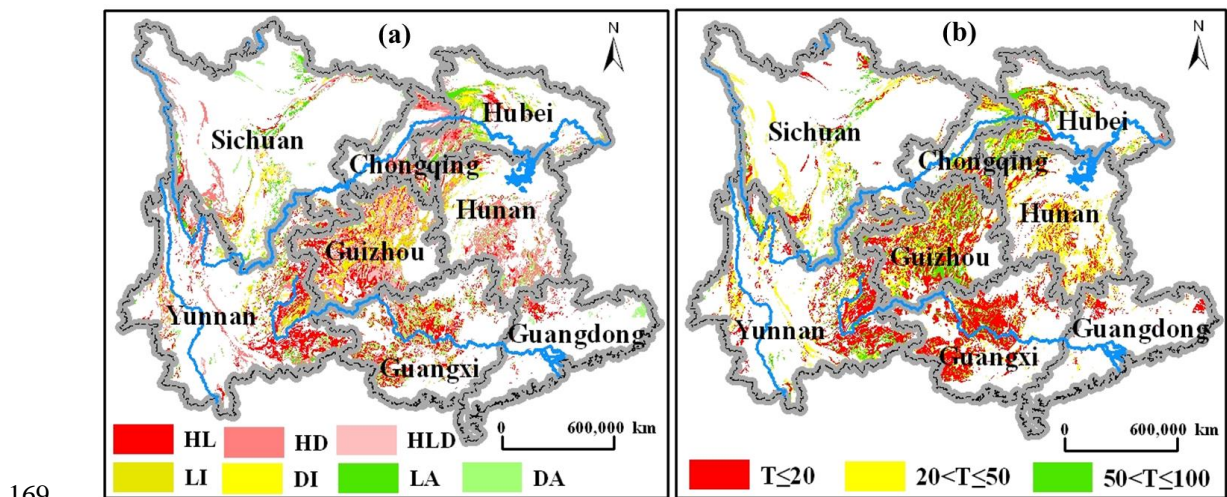
147 *Note: Color of the RS image displayed with Landsat TM bands 4, 3 and 2 (displayed as red, green and blue).*

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 149 The study area measures 1,951,375 km²; therefore, much time and money must be spent for investigation. Guizhou
 150 Province measures 176,000 km² and lies in the center of the Southeast Asian karst zone (Fig. 2). Carbonate rock is
 151 widespread and accounts for 62% of the total land area; in this region, karst rocky desertification is a serious
 152 problem (Wang et al., 2004). Therefore, the relationship between karst rocky desertification and *T* value is
 153 determined when Guizhou Province is taken as an example. As per this classification, a 1:100,000 scale digital map
 154 that shows KRD land distribution overlaps with a *T* distribution map. The spatial relationship between these two
 155 maps is then analyzed.

156 4 Results and Discussion

157 4.1 Spatial distribution of carbonate rock assemblages

158 As shown in Fig. 2a and Table 2, carbonate is mainly concentrated in Guizhou, eastern Yunan, center and western
 159 Guangxi, western Hubei, Southeastern Chongqing, southern Hunan, northern Guangdong, and southwestern
 160 Sichuan. The total area measures 527,196 km²; 109,416, 108,828, and 81,772 km² belong to Guizhou, Yunan, and
 161 Guangxi, respectively. HL covers 134,996 km² and is primarily distributed in western, southern, and southwestern
 162 Guizhou, eastern Yunan, and western Guangxi. However, this limestone is slightly scattered in Hunan. HD covers
 163 58,723 km² and is exposed in the form of elongated belts in various places; other assemblage types are scarce. HDL
 164 covers 63,819 km² and is mainly found in Guangxi and Hunan. Northern central and southern Guizhou. LI covers
 165 148,577 km² and is the most widespread type of carbonate rock. DI covers 22,889 km² and is chiefly detected in
 166 central Guizhou and southwestern Sichuan. LA covers 55,527 km² and is mainly detected in southern Guizhou and
 167 western Hubei. Finally, DA covers only 42,665 km² and is primarily found in southwestern Sichuan and eastern
 168 Yunan.



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 170 **Figure 2.** Distribution map of carbonate rock assemblage types (a) and T value (b) in carbonate areas of South
 171 China.

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 173 **Table 2** Distribution area of different carbonate rock assemblage types in carbonate areas of South China

	Chongqing	Guangdong	Guangxi	Guizhou	Hubei	Hunan	Sichuan	Yunan	Study area (m ²)
Total	82,400	179,800	236,300	176,100	185,900	21,1875	485,000	394,000	1,951,375
Carbonate	29,896	10,440	81,772	109,416	53,146	65,780	67,918	108,828	527,196
HL	6,722	4,603	34,309	30,677	5,184	9,087	7,579	36,835	134,996
HD	2,474	0	3,131	22,991	10,393	4,101	3,458	12,175	58,723
HDL	2,006	3,143	26,162	3,690	4,694	12,071	7,484	4,568	63,819
LI	11,114	2,694	12,355	19,340	14,641	35,683	26,085	26,666	148,577
DI	58	0	260	7,210	2,664	3,193	7,730	1,774	22,889
LA	6,835	0	5,517	25,231	6,374	483	1,889	9,197	55,527
DA	687	0	38	276	9,196	1,161	13,693	17,613	42,665

174 **4.2 Determination of T value and assessment of soil erosion risk**

175 Fig. 2b shows the T values of different carbonate rock assemblages as calculated according to Equation (1). Those
 176 in the HC, HL, and HDL areas are 17.22, 17.51, and 17.36 t/(km²·a), respectively, whereas the T values in the LI
 177 and DI areas are 46.08 and 46.02 t/(km²·a), respectively. The T values in LA and DA areas are 103.80 and 107.95
 178 t/(km²·a). These values indicate the spatial heterogeneity in the carbonate areas of South China; this heterogeneity is
 179 closely related to the amount of argillaceous material in formations that determine surface soil thickness. The “one
 180 region, one T value” concept cannot fully reflect the essence and the real circumstances in the area, and this
 181 inadequacy may explain the diverse results obtained by different researchers. An incorrect value is typically
 182 obtained regardless of the calculated T value, and three criteria should be considered instead of only one criterion.
 183 The T values of the HC, CI, and CA areas are 20, 50, and 100 t/(km²·a), respectively. These areas contain the least,
 184 lesser, and great amounts of argillaceous materials; therefore, the three areas are each extremely, severely, and
 185 moderately sensitive to soil erosion. Hence, the T values in the carbonate areas of South China are spatially
 186 heterogeneous. (Tab.3)

187 **Table.3** Criterion of T value and sensitivity of soil erosion in carbonate areas of South China

Carbonate Rock Assemblages	T value t/(km ² ·a)	Area (km ²)	Proportion (%)	Sensitivity of soil erosion
Homogenous carbonate rock	20	257538	48.85%	Utmost
Carbonate rock intercalated with clastic rock	50	171466	32.52%	Severe
Carbonate/clastic rock alternations	100	98192	18.63%	Moderate

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 189 In addition, the T values of limestone and dolomite are similar given the same amount of argillaceous material.
 190 According to the result of our in-house laboratory investigation, however, the dissolution velocity of calcite is 16
 191 times that of dolomite (Drever 1997). These two types of mineral constituent rocks differ by 1.5–2 times as per both
 192 in-house laboratory and field observations (Cao et al., 2009). In the same season and under similar spring conditions,
 193 the carbonate content of the dolomite area in the water exceeds that of the limestone area (Jiang et al., 1997). In
 194 terms of lithology, dolomite voidage is uniform and dense, such that the specific surface area of water–rock
 195 interaction can be increased. As a result, conditions are set for water retention and interaction time extension (Cao et
 196 al., 2009). Dolomite weathering is extremely intense and induces the loosening and easy formation of storage
 197 cataclases given the uniformity of this process. This occurrence establishes conditions for plant growth. Biological
 198 processes accelerate dissolution velocity further; in addition, dolomite releases abundant magnesium ions during the
 199 weathering–pedogenesis of carbonate rocks as the main action in the formation of clay mineral. By contrast,
 200 limestone cannot supply a sufficient amount of such ions. These phenomena accelerate the dissolution velocity of
 201 dolomite and supplement the deficiency. This mechanism may explain the similarity in the T values of limestone
 202 and dolomite.

203 **4.3 Effect of T value on karst rocky desertification**

204 As illustrated in Tab.4, the AKRD land measured 18,491, 10,955, and 9,456 km² in the extremely, severely, and
 205 moderately sensitive areas, respectively. KRD land is concentrated in the extremely sensitive area ($T = 20$) and
 206 covers over 47% of the total area in Guizhou Province. Of the total AKRD land, 28.16% is in severely sensitive ($T =$
 207 50), and 24.31% is moderately sensitive ($T = 100$).

208 **Table.4** Karst Rocky desertification area under different sensitivity

	AKRD (km ²)	PKRD (km ²)	NKRD (km ²)
Moderate sensitivity	9,457	7,889	8,169
Severe sensitivity	10,955	6,004	9,599
Utmost sensitivity	18,491	17,926	20,957

209 *Note: AKRD means already karst rocky desertification, PKRD means potential karst rocky desertification, NKRD*
 210 *means no karst rocky desertification*

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212 These findings suggest that a low T value corresponds to a large KRD land. The KRD land area is coherent in
 213 relation to the T value criterion. Nonetheless, the relationship between NKRD land and T value is unchanged. Based
 214 on the information provided in the paragraphs above, the areas of background value in different T value regions ($T =$
 215 20, 50, 100) were 57,375, 26,558, and 25,515 km². The distribution area of KRD land is strongly affected by the
 216 area of the background regions. Therefore, AKRD land area may not reflect the appearance of this land in different
 217 regions, although this area indicates the distribution situation.

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219 Tab.5 exhibits the generation of KRD land relative to different regions that are sensitive to soil erosion. This
 220 occurrence is maximized at 41.25%, 37.06%, and 32.23% in the severely, moderately, and extremely sensitive areas,
 221 respectively. This finding proves that the occurrence of AKRD land is unrelated to T value. In other words, this
 222 value is not the real factor that determines the KRD appearance in carbonate areas; thus, T value cannot reflect soil
 223 erosion risk although it reflects the sensitivity of soil erosion.

224 **Table.5** Karst Rocky desertification area percentage under different sensitivity

	AKRD (%)	PKRD (%)	NKRD (%)
Moderate sensitivity	37.06	22.61	32.02
Severe sensitivity	41.25	22.61	36.14
Utmost sensitivity	32.23	31.24	36.53

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226 Erosion risk depends on the relationship between RL and T value rather than on soil erosion intensity or T value
 227 itself. If $RL \gg T$, then risk is high although RL is low. Conversely, if $RL \ll T$, then the soil is safe although RL is
 228 high (Tab.6)

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Table.6 Criterion for risk assessment of soil erosion in carbonate areas of South China

Types	Range	RL /T value	Erosion risk grade
		$R > 2$	Utmost safe
Safe	Above-critical	$1.5 < R \leq 2$	Severe safe
		$1 < R \leq 1.5$	Moderate safe
Intermediate	Equal	R=1	Critical point
		$0.5 \leq R < 1$	Utmost danger
Danger	Below-critical	$0.2 \leq R < 0.5$	Severe danger
		$R < 0.2$	Moderate danger

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The occurrence of KRD land is highest in the severely sensitive area (41.25%). This result indicates that RL is considerably greater than the T value and that the situation is extremely dangerous. However, these values do not necessarily imply that RL remains considerably smaller than T value in the moderately and extremely sensitive areas. Conversely, the occurrences of KRD land are 37.06% and 32.23% in these areas; such values clearly indicate a high degree of soil erosion. Thus, the severely sensitive area is the most hazardous area.

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4.4 T value criteria in different countries

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To develop a scientific and reasonable T value standard, scientists in certain countries refer to adequate research and learn from one another. Subsequently, these researchers propose T values with reference to the different conditions of their respective countries. The United States Department of Agriculture Soil Conservation Bureau established a systematic T value system in 1973, and the values herein range between 220 and 1120 $t/(km^2 \cdot a)$. This standard is still being used at present. Several countries in Africa reported sand and clay T values of 150 and 180 $t/(km^2 \cdot a)$, respectively. The Soviet Union presented a T value range of 340–1090 $t/(km^2 \cdot a)$, whereas India put forward a range of 450–1120 $t/(km^2 \cdot a)$. In China, T values of 1000, 200, and 500 $t/(km^2 \cdot a)$ are reported for the Loess Plateau, the phaeozem region of northeast China and the northern Rocky Mountain, and the hilly red soil region of southern China and the southwest Rocky Mountain, respectively. In this work, the T values in the HC, CI, and CA areas are 20, 50, and 100 $t/(km^2 \cdot a)$, respectively.

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Some senior scholars and scientists have conducted preliminary studies on soil erosion in the countries. Duan X.W modified soil productivity index model was established to calculate a quantitative T for different black soil species in the black soil region of Northeast China. The T values of the 21 black soil species in the study area ranged from 68 to 358 $t/(km^2 \cdot a)$, with an average of 141 $t/(km^2 \cdot a)$. This average T value is 29.5% less than the current national standard. The T value of the three different soil subgroups in the study area were: albic black soil, 106 $t/(km^2 \cdot a)$; typical black soil, 129 $t/(km^2 \cdot a)$; and meadow black soil, 184 $t/(km^2 \cdot a)$. (Duan et al., 2012); Shui J.G based on the view of soil nutrient balance and test data, it was suggested that soil loss tolerance in Q_2 red clay derived red-earth should be lower than 300 $t/(km^2 \cdot a)$. (Shui et al., 2003); Yuan Z.K has been determined soil loss tolerance of the purple rock hilly area in

258 central Hunan less than $120 \text{ t}/(\text{km}^2 \cdot \text{a})$. (Yuan et al., 2005); Chen Q.B based on theoretical analysis, field examination
259 and investigation, it is considered that the $200 \text{ t}/(\text{km}^2 \cdot \text{a})$ is the rational soil loss tolerance of sloping field in semi-arid
260 hill-gully area of the Loess Plateau during the long period according to soil formation velocity, top soil nutrient balance,
261 land productivity stability in sloping field, sediment transport tolerance of the Huanghe River course, and regional
262 economic development and so on. (Chen et al., 2003)

263 In karst area, some scholars have done countless research in this respect, such as: Chai Z.X according to corroded
264 ratio and content rate of carbonate rocks count up promise amount of soil loss tolerance which is $68 \text{ t}/(\text{km}^2 \cdot \text{a})$ in karst
265 area of Guangxi Autonomous Region. (Chai et al., 1989); Chen L.J through measuring the accumulated and loss
266 amounts of soil nutrient for the top layer soil in forest land, and analyzing the balance of N.P.K and the rate of soil
267 formation, the amount of soil allowed loss is approached. It is hold that, under the upper reaches of the Changjiang
268 River climatically condition, the upper line of soil allowed loss is $50 \text{ t}/(\text{km}^2 \cdot \text{a})$ for developing soil from lime stone, that
269 is $100 \text{ t}/(\text{km}^2 \cdot \text{a})$ for developing soil from non-carbonaceous rock. (Chen et al., 1993); Wei Q.P worked out the T values
270 of the calcareous soil area in the karst area ranged from 0.522 to $1.285 \text{ t}/(\text{km}^2 \cdot \text{a})$, if not consider the eluviation and
271 normal erosion in the soil-forming process, the scope of the T value ranged from 3.24 to $8.10 \text{ t}/(\text{km}^2 \cdot \text{a})$, but there are
272 some part of the argillaceous limestone, such as non-pure carbonate rocks, the soil loss tolerance could be increased to
273 $16.2\text{-}40.5 \text{ t}/(\text{km}^2 \cdot \text{a})$, and believe that the upper line of soil allowed loss is $50 \text{ t}/(\text{km}^2 \cdot \text{a})$ for karst area. (Wei et al., 1996);
274 Li Y.B with the average weathering dissolving rate of carbonate rocks in Guizhou being $49.67\text{mm}/\text{ka}$ the pedogenesis
275 rates of different petrologic assemblages in carbonate area have been calculated and used as the value of soil loss
276 tolerance in carbonate areas. The soil loss tolerance in homogenous carbonate rocks area is lower than $6.84 \text{ t}/(\text{km}^2 \cdot \text{a})$,
277 $45.53 \text{ t}/(\text{km}^2 \cdot \text{a})$ in carbonate rock intercalated with clastic rock areas and $103.46 \text{ t}/(\text{km}^2 \cdot \text{a})$ in carbonate/clastic rock
278 alternations areas.

279 In this study, T value was calculated using digital-distribution map of carbonate rock assemblages type, based on
280 pedosphere system theory, results indicated spatial heterogeneity and diversity in such values. T value is proportionate
281 to the amount of argillaceous material in formations that determine surface soil thickness in homogenous carbonate
282 rock areas; such values are 20 and $50 \text{ t}/(\text{km}^2 \cdot \text{a})$ in carbonate rock intercalated with clastic rock areas and $100 \text{ t}/(\text{km}^2 \cdot \text{a})$
283 in carbonate/clastic rock alternation areas. In fact, erosion risk is strongly dependent on the relationship between real
284 soil loss (RL) and T value rather than on either erosion intensity or the T value itself. These findings may clarify T value
285 heterogeneity and its effect on erosion risk in a karst eco-environment; hence, innovative technological assessment
286 solutions need not be invented. Overall, this paper presents a method that provides experience and data for reference on
287 the related research of soil erosion of karst landform areas of international counterparts. However, the deficiency of this
288 article is: This study can't fully consider dry and wet deposition in atmosphere and the contribution of acid rain to soil
289 forming rate, it may cause a certain impact to the accuracy.

290 5 Conclusions

291 This study may clarify the heterogeneity of T values and its effects on erosion risk in a karst eco-environment as
292 an alternative to inventing innovative technological assessment solutions. Our main findings are listed as follows:

293 (1) T values are spatially heterogeneous, and a minimum of three criteria should be considered instead of only
294 one when investigating the carbonate areas of South China. Apparently, the "one region, one T value" concept may
295 not apply to this region.

296 (2) T value is proportionate to the amount of argillaceous material in formations that determine surface soil
297 thickness. The T values in the HC, CI, and CA areas are 20 , 50 , and $100 \text{ t}/(\text{km}^2 \cdot \text{a})$, respectively. These three areas

298 are extremely, severely, and moderately sensitive to soil erosion.

299 (3) The generation of KRD land is unrelated to T value, although this value reflects erosion sensitivity. Erosion
300 risk depends strongly on the relationship between RL and T value instead of on erosion intensity or the T value itself.
301 If $RL \gg T$, then risk is high despite the low RL. On the contrary, if $RL \ll T$, then the soil is safe despite the high
302 RL.

303 Overall, firstly, we report the following discovery: T values are spatially heterogeneous, and a minimum of
304 three criteria should be considered instead of only a single criterion in karst areas. In fact, our findings disprove the
305 old “one region, one T value” concept. Secondly, we proposed a new viewpoint: in karst regions, a large soil erosion
306 modulus does not correspond to severe soil erosion. Although T value can reflect soil sensitivity, this value cannot
307 indicate soil erosion risk. Thus, a low T value indicates that the local soil is highly sensitive; however, the soil
308 erosion risk is not necessarily high. Therefore, this risk depends strongly on the ratio between real soil loss (RL) and
309 T value instead of on erosion intensity or on T value itself.

310 As the result of determination time of natural erosion and environmental background conditions are not very
311 clear, research object, method and consideration factors of soil loss tolerance are different. Therefore, it is necessary
312 to make further efforts to define and specify the connotation and research methods of the natural erosion and soil
313 loss tolerance, at the same time it studies the natural erosion and soil loss tolerance in different types of soil and
314 water loss comprehensively and systematically. **In addition to this, we can be considered try to evaluate the damage
315 of soil and water loss in karst area in two stages: Under the premise of soil coverage, using soil erosion modulus to
316 evaluate the harm of water and soil loss; When soil erosion is serious and many bare rocks on the hillside, that is
317 rock exposed rate is very high, we can evaluated the harm of water and soil loss by the increase of rocky
318 desertification area.**

319
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