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

Li Yue[1,2,3], Bai Xiaoyong※[1,4,5], Zhou Yunchao[1,2,3], Wang Shijie[1,3],
Qin Luoyi[1,3], Tian Yichao[1,4], Luo Guangjie[1,4]

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

2. College of Forestry, Guizhou University, Guiyang, 550000, PR China

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

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

5. 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 $\mathrm{t \cdot km^{-2} \cdot yr^{-1}}$ in carbonate rock intercalated with clastic rock areas and 100 $\mathrm{t \cdot km^{-2} \cdot yr^{-1}}$ 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 >> T, then erosion risk is high despite a low RL. Conversely, if T >> 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 (Bülent Turgut, Merve Ateş. 2016; Nigussie Haregeweyn et al., 2017). However, these factors are less associated with the total lack of inherent soil in such areas (Zhongwu Li et al., 2017; İlknur Gümüş; Xu et al., 2013). Soil is continuously distributed through erosion, and rocky desertification landscapes are frequently generated (Tegegne Molla and Biniam Sisheber 2016). 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 ($t \cdot km^{-2} \cdot yr^{-1}$) 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 Mg $ha^{-1} \cdot yr^{-1}$ 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 Mg km^{-2} yr^{-1} (Zhu et al., 1999). Purple soils are ideal for *T* research conducted over a short time scale given their high formation ra[illegible]hus, 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).~~

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

2 Study area

The study area is located across the Yangtze River and the Pearl River in southwestern China. The approximate coordinates are 22°01'–33°16′N and 98°36′–116°05′E. The area covers Guizhou Province, Yunnan Province, Guangxi Zhuang Autonomous Region, Hunan Province, Hubei Province, Sichuan Province, Chongqing Municipalities, and Guangdong Province (Fig.1). Moreover, the study area belongs to the tropical moist and subtropical moist regions, which include different types of landforms. The southwestern karst mountainous areas are characterized by limestone soil, and the distribution of this soil varies considerably. This area measures 1,951,375 km^2 and lies in the center of the Southeast Asian karst zone. Carbonate rocks are widespread and cover an area of 44,990,000 km^2. Furthermore, the geotectonic foundation is complex. The layer of each geologic period from the Late Proterozoic Sinian period to the Paleozoic and Cenozoic Tertiary period is distributed across different areas, and the carbonate rocks are of various thicknesses. Mountainous regions with world-famous karst rock formations account for 70% of the total area. Finally, this region is under a typical subtropical monsoon moist climate and a natural karst mountainous environment. This area also contains inland plateau lands.

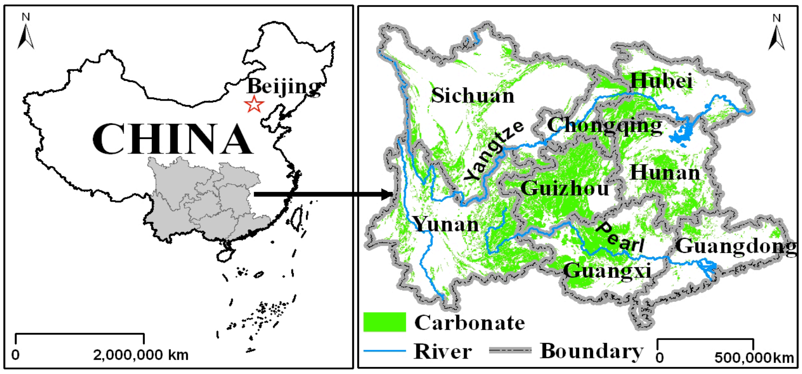

Figure1. Map showing the location and the distribution of carbonate regions in South China

3 Materials and methods

3.1 Construction of a carbonate rock assemblage distribution map

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.

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:

(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).

(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).

(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).

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.

3.2 Method of computing soil information rate

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 specific position and special time. The soil information rate ranges from 30.00–89.70 mm/ka in the carbonate areas of 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 laboratory investigation, the densities of calcite carbonatite and dolomite carbonatite are 2.75 and 2.86 t/m^3, respectively. The soil formation rate of other rock types is 200 t·km^{-2}·yr^{-1} (Li et al., 2006), and the rates of different rock type assemblages serve as their T values.

Specific T value can be calculated with the following equation:

$$T=v \cdot Q \cdot \rho C + R \cdot (1-C) \qquad (1)$$

where T is soil loss tolerance (t·km^{-2}·yr^{-1}); v is the dissolution velocity of carbonate rocks (m^3·km^{-2}·yr^{-1}); Q is the content of acid-insoluble components (%); ρ is carbonate density (t·m^{-3}); C is the proportion of carbonate; and R is the soil formation rate of other rock types.

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

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

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

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

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

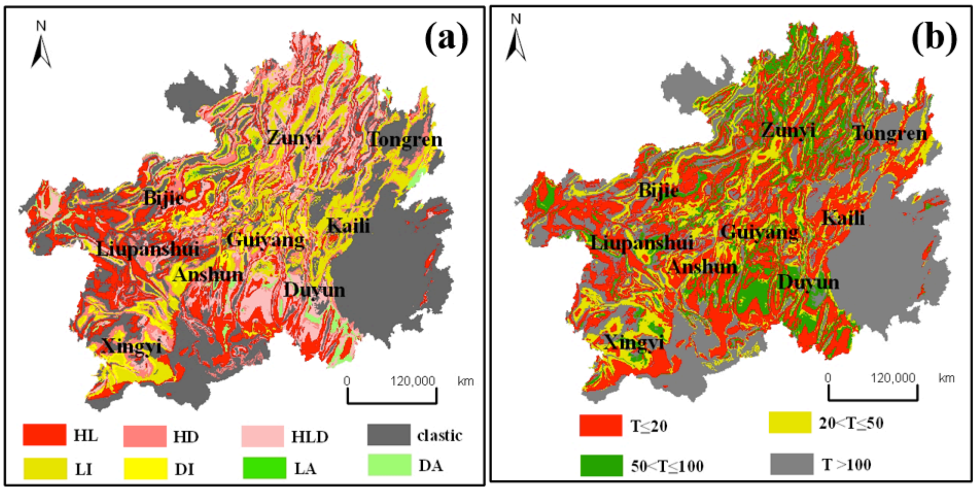

Figure2. Distribution map of carbonate rock assemblage types (a) and T value (b) in Guizhou

The specific technique flowchart followed in this study is illustrated as follows (Fig. 3):

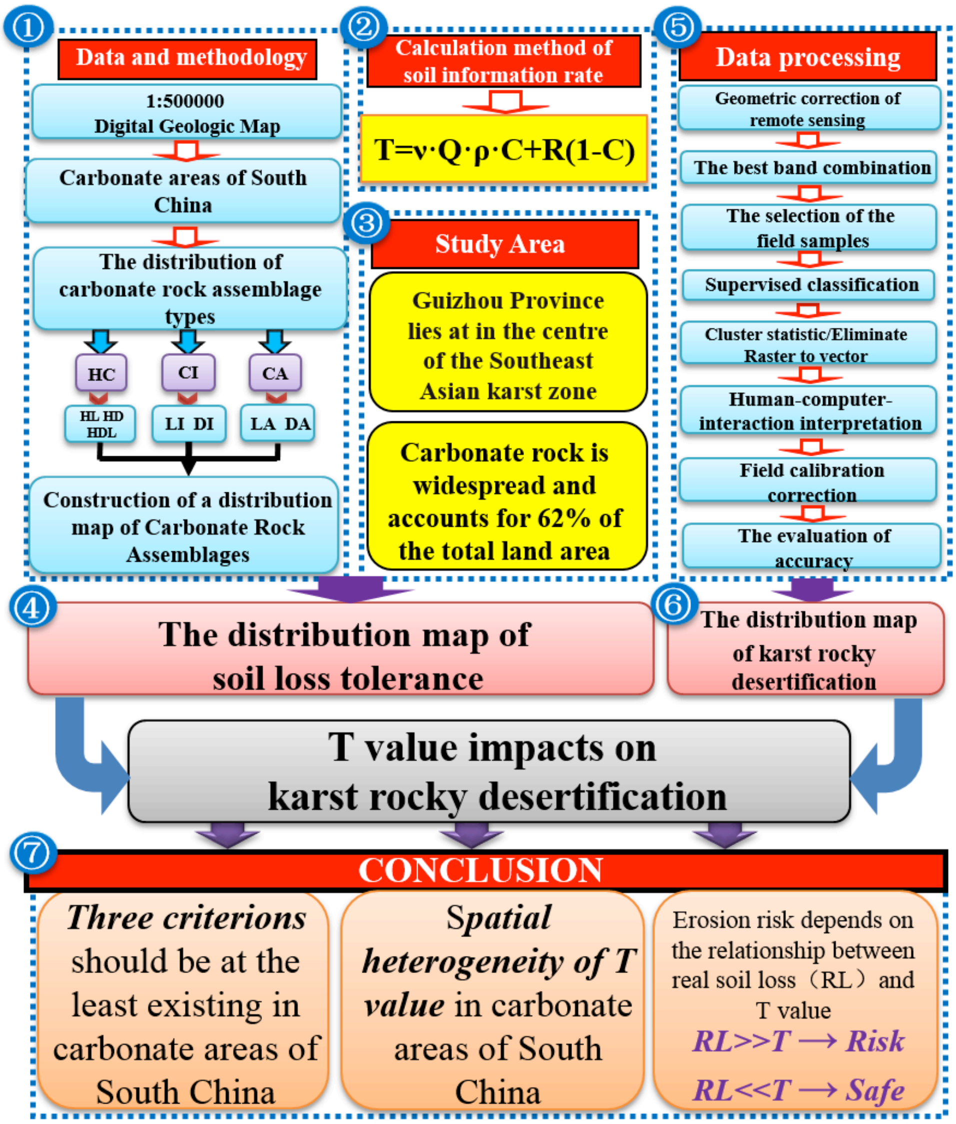

Figure3. The Technique flowchart of evaluating spatial heterogeneity of soil loss tolerance and its impacts on erosion risk in study area

4 Results and Discussion

4.1 Spatial distribution of carbonate rock assemblages

As shown in Fig. 4a and Table 2, carbonate is mainly concentrated in Guizhou, eastern Yunan, center and western Guangxi, western Hubei, Southeastern Chongqing, southern Hunan, northern Guangdong, and southwestern Sichuan. The total area measures 527,196 km^2; 109,416, 108,828, and 81,772 km^2 belong to Guizhou, Yunan, and Guangxi, respectively. HL covers 134,996 km^2 and is primarily distributed in western, southern, and southwestern Guizhou, eastern Yunan, and western Guangxi. However, this limestone is slightly scattered in Hunan. HD covers 58,723 km^2 and is exposed in the form of elongated belts in various places; other assemblage types are scarce. HDL covers 63,819 km^2 and is mainly found in Guangxi and Hunan. Northern central and southern Guizhou. LI covers

148,577 km^2 and is the most widespread type of carbonate rock. DI covers 22,889 km^2 and is chiefly detected in central Guizhou and southwestern Sichuan. LA covers 55,527 km^2 and is mainly detected in southern Guizhou and western Hubei. Finally, DA covers only 42,665 km^2 and is primarily found in southwestern Sichuan and eastern Yunan.

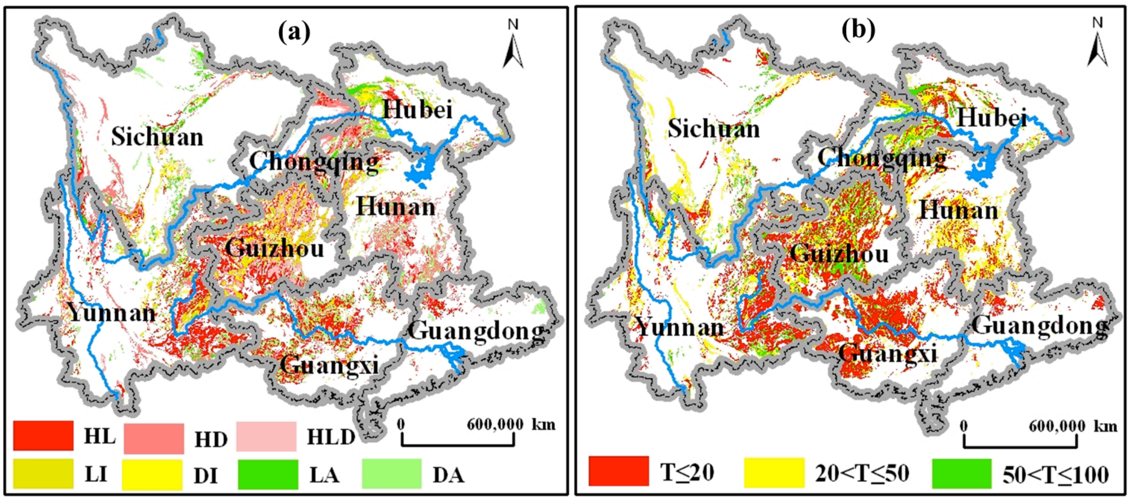

Figure4. Distribution map of carbonate rock assemblage types (a) and T value (b) in carbonate areas of South China.

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

4.2 Determination of T value and assessment of soil erosion risk

Fig. 4b shows the T values of different carbonate rock assemblages as calculated according to Equation (1). Those in the HC, HL, and HDL areas are 17.22, 17.51, and 17.36 t·km^{-2}·yr^{-1}, respectively, whereas the T values in the LI and DI areas are 46.08 and 46.02 t·km^{-2}·yr^{-1}, respectively. The T values in LA and DA areas are 103.80 and 107.95 t·km^{-2}·yr^{-1}. These values indicate the spatial heterogeneity in the carbonate areas of South China; this heterogeneity is closely related to the amount of argillaceous material in formations that determine surface soil thickness. The "one region, one T value" concept cannot fully reflect the essence and the real circumstances in the area, and this inadequacy may explain the diverse results obtained by different researchers. An incorrect value is typically obtained regardless of the calculated *T* value, and three criteria should be considered instead of only one criterion. The *T* values of the HC, CI, and CA areas are 20, 50, and 100 t·km^{-2}·yr^{-1}, respectively. These areas contain the least, lesser, and great amounts of argillaceous materials; therefore, the three areas are each extremely, severely, and moderately sensitive to soil erosion. Hence, the *T* values in the carbonate areas of South China are spatially heterogeneous. (~~Tab.3~~)

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}·yr^{-1})	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

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

4.3 Effect of T value on karst rocky desertification

As illustrated in Tab.4, the AKRD land measured 18,491, 10,955, and 9,456 km^2 in the extremely, severely, and moderately sensitive areas, respectively. KRD land is concentrated in the extremely sensitive area (T = 20) and covers over 47% of the total area in Guizhou Province. Of the total AKRD land, 28.16% is in severely sensitive (T = 50), and 24.31% is moderately sensitive (T = 100).

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

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

These findings suggest that a low T value corresponds to a large KRD ~~land~~. The KRD ~~l~~and area is coherent in relation to the T value criterion. Nonetheless, the relationship between NKRD land and T value is unchanged. Based on the information provided ~~in the paragraphs~~ above, the areas of background value in different T value regions (T = 20, 50, 100) were 57,375, 26,558, and 25,515 km^2. The distribution area of KRD ~~land~~ is strongly affected by the area of the background regions. Therefore, AKRD land area may not reflect the appearance of this land in different regions, although this area indicates the distribution situation.

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

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

Erosion risk depends on the relationship between RL and T value rather than on soil erosion intensity or T value itself. If RL >> T, then risk is high although RL is low. Conversely, if RL << T, then the soil is safe although RL is high (Tab.6)

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

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

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.

4.4 T value criteria in different countries

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 2.2 and 11.2 t·hm^{-2}·yr^{-1}. This standard is still being used at present. Several countries in Africa reported sand and clay *T* values of 1.5 and 1.8 t·hm^{-2}·yr^{-1}, respectively. The ~~Soviet Union~~ presented a *T* value range of 3.4–10.9 t·hm^{-2}·yr^{-1}, whereas India put forward a range of 4.5–11.2 t·hm^{-2}·yr^{-1}. In China, *T* values of 10, 2, and 5 t·hm^{-2}·yr^{-1} 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·hm^{-2}·yr^{-1}, respectively (Tab. 7).

Table.7 T value criteria in different countries

<table>
<tr><th>Country</th><th>America</th><th>Africa</th><th>India</th><th>Soviet Union</th><th colspan="2">China</th></tr>
<tr><td rowspan="5">T value
t·hm^{-2}·yr^{-1}</td><td rowspan="5">2.2-11.2</td><td rowspan="2">1.5
(sand)</td><td rowspan="5">4.5-11.2</td><td rowspan="5">3.4-10.9</td><td>10.0</td><td>Loess Plateau</td></tr>
<tr><td rowspan="2">2.0</td><td>Phaeozem region of northeast China</td></tr>
<tr><td rowspan="3">1.8
(clay)</td><td>Northern rocky mountain</td></tr>
<tr><td rowspan="2">5.0</td><td>Hilly red soil region of southern China</td></tr>
<tr><td>Southwest rocky mountain</td></tr>
<tr><td colspan="7">This paper : Carbonate Areas of South China</td></tr>
<tr><td>Rock Characteristics</td><td colspan="2">homogenous carbonate rock</td><td colspan="2">carbonate rock intercalated with clastic rock</td><td colspan="2">carbonate/clastic rock alternations</td></tr>
<tr><td>T value
(t·km^{-2}·yr^{-1})</td><td colspan="2">20</td><td colspan="2">50</td><td colspan="2">100</td></tr>
</table>

5 Conclusions

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

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

(2) *T* value is proportionate to the amount of argillaceous material in formations that determine surface soil thickness. The *T* values in the HC, CI, and CA areas are 20, 50, and 100 t·km^{-2}·yr^{-1}, respectively. These three areas are extremely, severely, and moderately sensitive to soil erosion.

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

Acknowledgements. The authors gratefully thank for the financial support provided by the auspices of National Key Research Program of China (No. 2016YFC0502300, 2016YFC0502102, 2014BAB03B00), National Key Research and Development (No. 2014BAB03B02), Agricultural Science and Technology Key Project of Guizhou Province of China (No. 2014-3039), Science and Technology Plan Projects of Guiyang Municipal Bureau of Science and Technology of China (No. 2012-205), Science and Technology Plan of Guizhou Province of China (No. 2012-6015)

Reference

Alexander, E.B (1988a) Rates of soil formation: Implications for soil-loss tolerance. Journal of Soil Science 145(1): 37-45.

Alexander, E.B (1988b) Strategies for determining soil-loss tolerance. Environmental Management 12(6): 791-796.

Browning, G.M., Parish, C.L., Lass, J.G. A method for determining the use and limitations of rotations and conservation practices in the control of erosion in Iowa. Journal of the American Society of Agronomy 39(1): 65-73,1947.

Bülent Turgut, Merve Ateş. Determining the variation of soil properties in the Batumi Delta. Solid Earth Discuss. doi: 10.5194/se-2016-101, 2016.

Cao, J.H., Jiang, Z.C., Yang, D.S., Tong, L.Q., Pei, J.G., Luo, W.Q., Yang, H. Soil and water loss, desertification controlled by karst environment in Guizhou Karst region. Soil and Water Conservation in China 1:20-23. 2009

Drever, J.I., Stillings, L.L. The role of organic acids in mineral weathering. COLLOIDS AND SURFACES A-PHYSICOCHEMICAL AND ENGINEERING ASPECTS 1-3(120): 167-181,1997.

Duan, X.W., Xie, Y., Liu, B.Y., Liu, G., Feng, Y.J., Gao, X.F. Soil loss tolerance in the black soil region of Northeast China. Journal of Geographical Sciences 22(4): 737-751,2012.

Hays, O.E., Clark, N. Cropping system that helps control erosion. USA: University of Wisconsin, Bulletin No.452, 1941.

İlknur Gümüş. Effects of Spent Mushroom Compost on Physicochemical Properties of Degraded Soil. Solid Earth Discuss. doi: 10.5194/se-2016-122, 2016.

Jiang, Z.C., Xie, Y.Q., Zhang, C., Weng, J.T. A projected protection scheme for the karst. Geological landscape in Xishan region, Beijing. Natural Resources.6:60-73,1997.

Klingebiel, A.A. Soil factors and soil loss tolerance. In: Soil Loss Prediction, North and South Dakota, Nebraska, and Kansas. USA: Soil Conservation Service. United States Department of Agriculture.1961.

L, L., Zhou, Z.H., Liu, G. C. The present situation and conceive of soil loss tolerance study. (In Chinese.) Adv. Earth Science. 20: 65-72,2005.

Liu, G.C., Li, L., Wu, L., Wang, G., Zhou, Z., Du, S. Determination of soil loss tolerance of an Entisol in Southwest China. Soil Science Society of American Journal 73(2): 412–417,2009.

Liu, Q.M., Wang, S.J., Piao, H.C., Ouyang, Z.Y. The changes in soil organic matter in a forest-cultivation sequence traced by stable carbon isotopes. Australian Journal of Soil Research 41(7): 1317-1327,2003.

Nigussie Haregeweyn, Atsushi Tsunekawa, Jean Poesen, Mitsuru Tsubo, Derege Tsegaye Meshesha, Ayele Almaw Fenta, Jan NyssenEnyew Adgo. Comprehensive assessment of soil erosion risk for better land use planning in river basins: Case study of the Upper Blue Nile River. Science of the total environment. 574: 95-108, 2017.

P. Bhattacharyya., Bhatt, K.V., Mandal, D. Soil loss tolerance limits for planning of soil conservation measures in Shivalik-Himalayan region of India. CATENA 73: 117-124,2008.

Paolo, Bazzoffi. Soil erosion tolerance and water runoff control: minimum environmental standards. Regional Environmental Change 9:169-179,2009.

Pierce, F.J., Dowdy, R.H., Larson, W.E (1984a). Soil productivity in the corn belt: An assessment of erosion's long-term effects. Journal of Soil and Water Conservation 39(2): 131-136.

Pierce, F.J., Larson, W.E., Dowdy, R.H. Productivity of soils: Assessing long-term changes due to erosion. Journal of Soil and Water Conservation 38(1): 39-44,1983.

Pierce, F.J., Larson, W.E., Dowdy, R.H (1984b). Soil loss tolerance: Maintenance of long-term soil productivity. Journal of Soil and Water Conservation 39(2): 136-138.

Pretorius, J.R., M, Sc., Cooks, J (1989). Soil Loss Tolerance Limits: An Environmental Management Tool. Geography Journal 19(1): 67-75,1989.

Skidmore, E.L. Soil loss tolerance. In: Determinants of Soil Loss Tolerance. American Society of Agronomy. ASA Special Publication No.45: 87-94,1982.

Skidmore, E.L. Soil loss tolerance. In: Determinants of Soil Loss Tolerance. American Society of Agronomy, *ASA Special Publication* No.45: 87-94,1982.

Smith, D.D. Interpretation of soil conservation data for field use. Agriculture Engineering 22: 173-175,1941.

Stamey, W.L., Smith, R.M. A conservation definition of erosion tolerance. Soil Science 97(3): 183-186,1964.

Tegegne Molla and Biniam Sisheber. Estimating Soil Erosion Risk and Evaluating Erosion Control Measures for Soil Conservation Planning at Koga Watershed, Highlands of Ethiopia. Solid Earth Discuss. doi:10.5194/se-2016-120, 2016.

Wang, S.J., Ji, H.B., Ouyang, Z.Y., Zhou, D.Q., Zheng, L.P., Li, T.Y. Preliminary study on weathering and pedogenesis of carbonate rock. Sci China (Ser D) 29(5): 441-449 (in Chinese),1999.

Wang, S.J., Liu, M., Zhang, D.F. Karst rocky desertification in southwestern China: Geomorphology, landuse, impact and rehabilitation. Land Degradation and Development 15: 115-121,2004.

Wischmeier, W.H., Smith, D.D (1965). Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains. USA: United States Department of Agriculture, *Agriculture Handbook*. No.282, Washington, D.C.

Wischmeier, W.H., Smith, D.D (1978). Predicting rainfall erosion losses: A guide to conservation planning. USA: United States Department of Agriculture, Agriculture Handbook. No.537, Washington, D.C.

Zhongwu Li, Chun Liu,Yuting Dong, Xiaofeng Chang, Xiaodong Ni, Lin Liu, Haibing Xiao,Yinmei Lu,Guangming Zeng. Response of soil organic carbon and nitrogen stocks to soil erosion and land use types in the Loess hilly–gully region of China. Soil and Tillage Research. 166: 1-9, 2017.