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Karst Ecosystem

Spatial Distribution Patterns and the Evolution Process of Carbon Storage in a Typical Karst Canyon Area

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Abstract: Qinglong County in Guizhou, China is a typical karst canyon area. Using quadrat methods and a land use transfer matrix we studied the carbon storage spatial distribution pattern and evolution process over three independent periods (1988, 1999 and 2009) in this area. Based on the results we estimated the carbon pool capacity of the entire karst canyon area in Guizhou and contribution ratios. Carbon storage and average carbon density of the karst area in Qinglong decreased at first, and then increased over the sampling period. The actual carbon storage of the karst canyon area in Guizhou was estimated to be 42.55 Tg. The average carbon intensity of the karst canyon area in Guizhou is far higher than that of national terrestrial ecosystems, especially in vegetation areas. Through cross comparison, we found that karst canyon areas have great carbon sequestration potential and we suggest that it is necessary to control and prevent rocky desertification in karst areas in China.

Key words: carbon storage; evolution process; karst canyon; spatial distribution patterns

1 Introduction

Carbon storage in terrestrial ecosystems plays a crucial role in regulating global carbon cycles and atmospheric CO_2 concentration; hence they are often important factors in the studies of global climate change (Chuai *et al*. 2011). Back in the1950s scholars investigated and analyzed the carbon storage of forests in different countries (Kozlowski 1986; Remezon 1959; Rennie 1955). Most studies on carbon storage have been focused on the analysis of the organic soil carbon pool (Ramita *et al*. 2010; Batjes 1996; Bockheim *et al*. 1990). Carbon storage studies started relatively later in China. For example, Fang and Chen (2001) estimated forest carbon storage in China, and Wang *et al*. (1999) and Pan *et al*. (2008) looked at the Chinese soil carbon pool. However, changes in land use types, whose impacts on terrestrial ecosystem carbon storage and fluxes are far more significant than natural causes, were often underestimated (Liu *et al*. 2004). As a consequence, it is necessary and critical to understand the relationship between land use type changes and carbon storage dynamics. Although there are studies involving the analysis of land use type changes, the study areas were often limited to developed areas in northern and southeastern China (Liu *et al*. 2003a; Yang *et al*. 2008; Liu *et al*. 2003b), and few studies have estimated carbon storage systematically in karst areas.

Bare rocks, thin soils and poor water storage capacities are key characteristics of the environment of karst areas in China. Under such circumstances, vegetation carbon sequestration mechanisms are particular and complicated (Peng *et al*. 2008). Based on these reasons, Guo *et al*. (2011) raised the concern that more attention should be paid to the ecological adaptability of plants and stony desertification control of karst areas. Current research into carbon cycling in karst areas has mainly focused on association of soil type and soil organic carbon content at an ecological micro-scale (Wang *et al*. 2007; Tian *et al*. 2011; Luo *et al*. 2010). Most of these studies were focused on peak-cluster depression and the

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study areas were located in northwest Guangxi (Zhang *et al*. 2013; Fan *et al*. 2011) and Huanjiang in northern Guangxi (Song *et al*. 2010). Little is known about the carbon storage patterns of karst canyon areas. Tan *et al*. (2014) used biomass methods to evaluate carbon storage of different ecosystems in typical canyon areas in the Mengzhai Basin. Tang *et al*. (2014) used potassium dichromate oxidation-external heating and potassium permanganate oxidation dilution methods to measure soil carbon at Huajiang, Zhou *et al*. (2014) used potassium dichromate oxidation-external heating methods to evaluate soil organic carbon at Huajiang. The methods mentioned above do not estimate total carbon storage level at a macro point of view. Carbon storage estimation based on land use methods applied to karst canyon areas was relatively few. This method can be well developed into a spatial distribution, while the effects of land use type changes remain elusive and the estimation of total carbon storage level at a macro point of view is missing. Here, we use the typical karst canyon area of Qinglong county, Guizhou as a study area, and combining carbon density results obtained via area sampling with land use type change we drew a carbon storage distribution map of Qinglong at a macro scale in order to reveal the relationship between carbon storage and land use type changes of the karst canyon areas. Moreover, we predicted the total carbon storage of the karst areas of Guizhou, providing scientific evidence for the significance of carbon sequestration, sustainable usage of land resources and restoration methods for fragile ecosystems.

2 Data and methods

2.1 Study area

Qinglong is locate in the southwest of Guizhou (Fig. 1). This region is a typical karst canyon zone with ragged topography and a contiguous distribution of carbonate. Qinglong has a humid subtropical climate, with mild temperature and abundant precipitation. The entire area is 1327.36 km^2 and the area of outcropping carbonate is 885.27 km^2, which covers 66.70% of Qinglong.

2.2 Data sources

2.2.1 Carbon intensity data

Carbon density data used are listed as below (Table 1). Raw data for grass, shrub, plantation, natural forest, dry land and paddy fields were obtained from Tan *et al*. (2014) with 18 sampling points (quadrat 20m×20m). Carbon intensities of soil and vegetation in different ecosystems were acquired from field tests, water carbon density, construction land and difficult-to-use land data were obtained from published work (Chuai *et al*. 2011; Jiao *et al*. 2007; Wang *et al*. 1999).

2.2.2 Land use data

Land use data were remote sensing images in three independent periods (1988, 1999 and 2009). The Landsat TM image of 1988, ETM+ image of 1999 and Landsat TM image of 2009 all have 30-m resolution after image fusion. Maps of land use were generated by visual interpretation. Geomorphologic landscape of the study area is disperse and broken. Based on landscape characteristics and national land use classification standards issued in 2007,

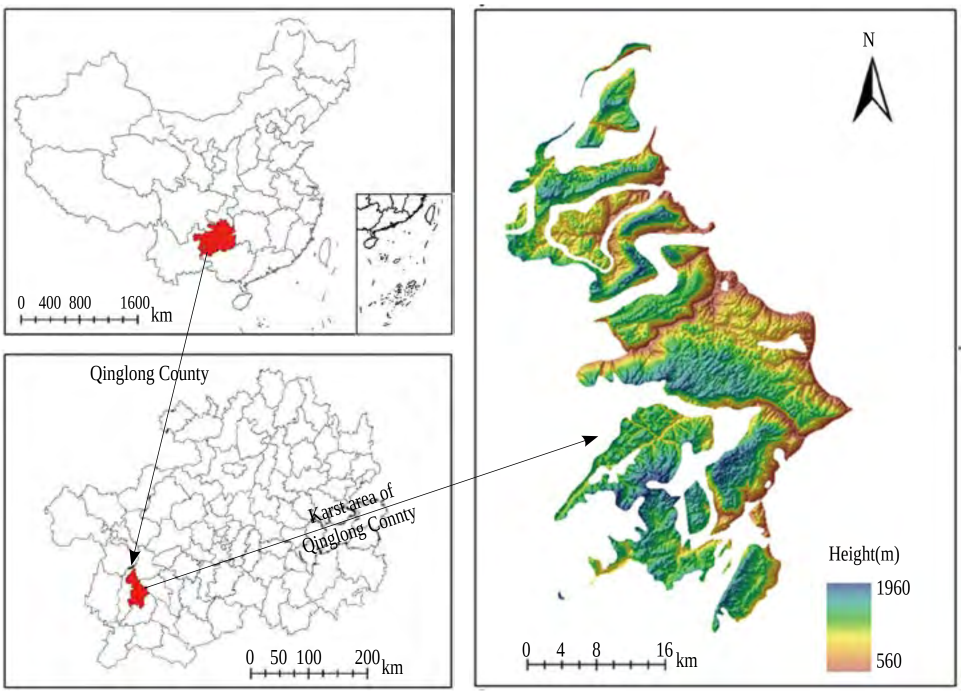

Fig. 1 Geographical location of the study area.

Table 1 Carbon intensity of different ecosystems in Qinglong County (kg C m^{-2}).

Ecosystem	Plant	Ground cover	Soil	Aboveground	Underground	Total
Grass	3.605	0.047	15.312	2.206	16.758	18.964
Shrub	7.088	0.582	5.769	6.093	7.346	13.439
Plantation	27.242	0.396	6.040	24.941	9.201	34.141
Natural forest	22.961	1.834	12.611	23.499	13.907	37.406
Dry land	–	–	11.531	–	11.531	11.531
Paddy field	–	–	11.226	–	11.226	11.226
Water	–	–	–	–	–	2.269
Construction land	–	–	–	–	–	1.467
Difficult-to-use lands	–	–	–	–	–	0.120

the research area was classified into nine different land use types: grassland, shrub, plantation, natural forest, dry land, paddy field, water, construction land and difficult-to-use land. Based on the combination of provincial forestry investigation data and field validation, we verified the accuracy of these nine kinds of land use type vector map, the results showed that accuracy in the three periods was 77.12%, 83.53% and 86.74%, respectively. This satisfies the accuracy requirements of further analysis.

2.3 Methodology

In order to understand the relationship of the evolution process between distribution patterns of carbon storage and land use, the implementation process shown in Fig.2 was used. Firstly, LUCC (Land-Use and Land-Cover Change) were obtained by GIS and RS techniques through interpreting remote sensing images. At the same time, carbon densities of various land use types were acquired via area quadrat and subsequent standard chemical analysis. By combining land use maps and usage transformation maps with carbon density maps, we generated comprehensive maps of carbon storage spatial distribution patterns. Finally, we provide scientific evidence for the implementation of sustainable use of land sources and restoration of fragile ecosystem policies in karst areas on the basis of the socioeconomic status of the study area.

2.3.1 Calculation of carbon storage and rate of change

Both aboveground and underground carbon storages were taken into account. Carbon storage was calculated as the summation of the product of carbon density and the area of each land use type, expressed as:

$$V=\sum_{i}^{n}(S_i\times C_i) \tag{1}$$

where, V is carbon storage; n is the total number of land use types; i denotes the i^{th} type of land use; and C_i and S_i represent the carbon intensity and the area of i^{th} land use type.

The maximum carbon storage was calculated under ideal circumstances when the entire area is covered by natural forests. But the ideal circumstance is unrealistic due to human activities, in this study the theoretical maximum value of carbon storage was computed under the circumstance that construction land, farming land (includes dry land and paddy field) and natural forest were all taken into account. After the implementation of ecosystem restoration policies in recent years, the original grass land,

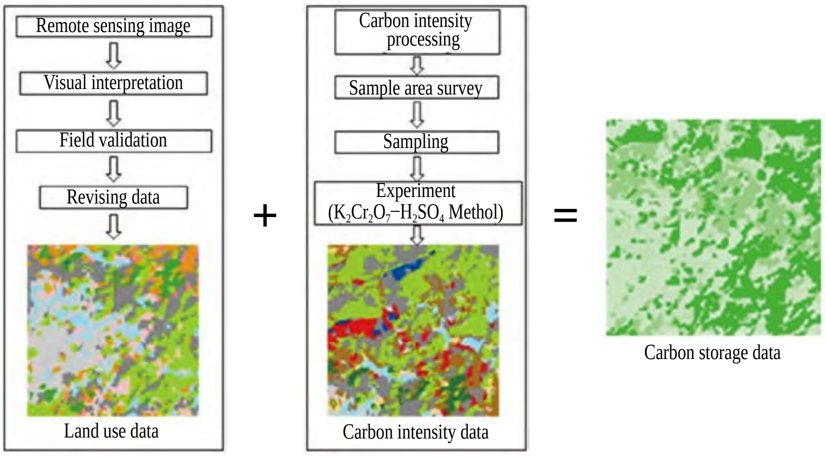

Fig. 2 Implementation process of carbon storage evaluation.

shrub and plantation have transformed to shrub, plantation and natural forest dramatically. Therefore, the reachable maximum value of carbon storage in the near future was estimated in the scenario that all grass, shrub and plantation lands are replaced by shrub, plantation and natural forest lands.

2.3.2 Processing land use data dynamic changes

Regional differences in land use change rate can be quantitatively assessed using the land use dynamic model (Liu *et al*. 2002):

$$S=\frac{1}{t}\times\sum_{ij}^{n}\left(\frac{\Delta S_{i-j}}{S_i}\right)\times 100\% \tag{2}$$

where, s_i is the area of ith land use type at the beginning of measurement; $\Delta s_{i\text{-}j}$ is the transformed area from type i to type j during studying period; t is the duration of measurement; and S is the change rate of land use.

Transfer matrix is the main approach to estimate the transfer quantities and directions between different land use types, which specifically reflect the structural characteristics of land use change and changing directions (Bai *et al*. 2009). The mathematical form of the transfer matrix is expressed as:

$$P=\begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ P_{n1} & P_{n2} & \cdots & P_{nn} \end{bmatrix} \tag{3}$$

where, P is the area; and p_{ij} is the area transferred from the i^{th} to the j^{th} land use type.

3 Results

3.1 Spatial distribution patterns of carbon storage and carbon densities in Qinglong karst areas

Combining the area of each land use type with their corresponding carbon density, we calculated the carbon storage of major ecosystems of Qinglong from 1988 to 2009 (Fig. 3). Our results show that the total carbon storage of Qinglong karst areas in 1988 was 1.22 Tg C, decreasing to 1.08 Tg C in 1999, and rebounding to 1.31 Tg C in 2009. In these three historical periods, the carbon storage of grass remained the highest among all land use types, while that of water, construction land, and difficult-to-use was constantly low. Our results also show that vegetation land including grass, shrubs, plantations and natural forests are the major carbon pools of Qinglong, while human usage lands and difficult-to-use land have lost most of their carbon sequestration capability due to the destruction of surface cover and inner soil constitution.

3.1.1 Evolution process of carbon storage geographical spatial distribution patterns

We overlaid carbon storage maps with geomorphological maps and the results reveal the spatial distribution of Qinglong county's carbon storage in karst areas (Fig. 4). Statistical analysis demonstrated that areas with higher levels of carbon storage generally are large grass areas with steeper slopes. Additionally, carbon enriched areas gradually shifted from high altitude areas to low altitude areas from 1988–2009, and eastern and central northern regions had the highest carbon storage, while the carbon storage of other regions stayed at a very low level. From 1988 to 1999, high carbon storage areas were usually located on steep slopes (>15˚) and high altitude regions where human activities are not impactful. These regions were diverted from eastern and central regions to central regions and carbon storage in the southern regions was relatively high. In contrast, from 1999 to 2009, higher carbon storage areas transformed to areas with steady slopes (<15˚), while the eastern and southeastern regions were higher carbon storage areas, and the central northern and southern regions took the second place. These phenomena may be caused by the reason that regions with steep slopes and high altitudes were less accessible for human interference in the early 1990s, and therefore vegetation was naturally preserved. However, with the expansion of construction and cultivation, destruction of vegetation in these regions may be responsible for the decline in carbon storage. Due to the implementation of the Green for Grain project in 2002 the ecology of steady regions where forestation was possible has been restored, leading to an increase in carbon storage.

3.1.2 Spatial distribution patterns of carbon densities in different land use types

By overlaying maps of different land use types and their carbon intensities, we acquired the spatial distribution maps of carbon intensity in different historical periods (Fig. 5). Statistical analysis shows that the distribution of

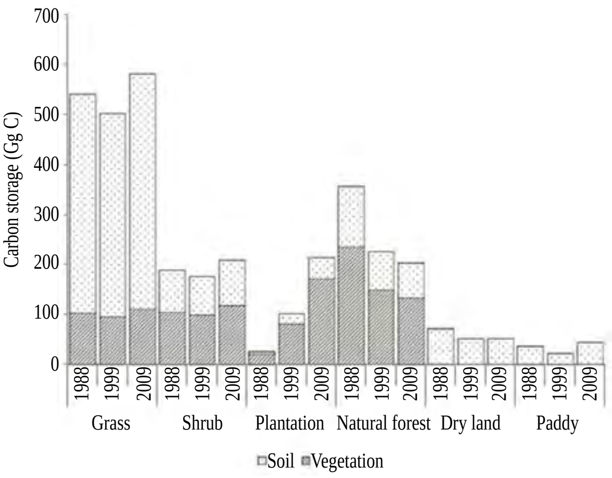

Fig. 3 Major ecosystems' carbon storage of Qinglong from 1988 to 2009 (Gg C).

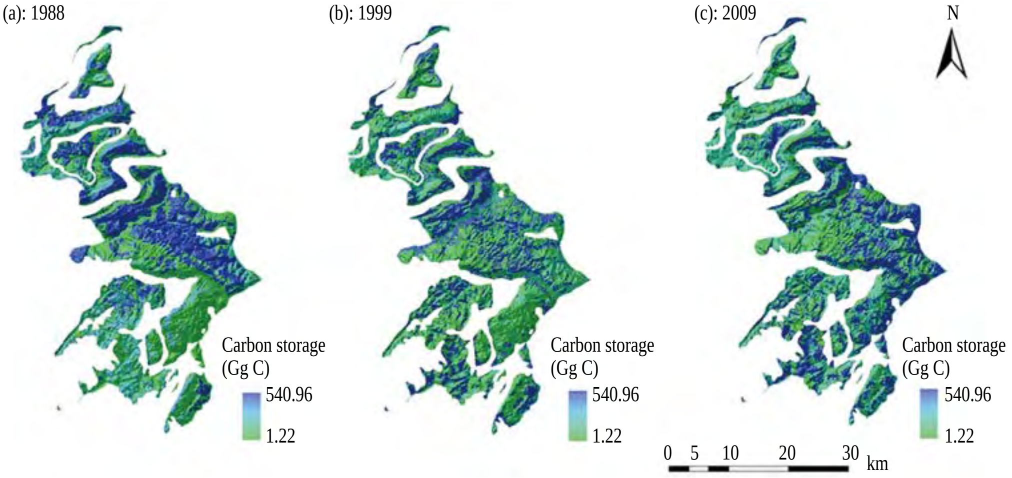

Fig. 4 Spatial distribution of carbon storage across Qinglong karst areas (Gg C).

carbon density was consistent with the geographic spatial distribution for each land use/cover type. The average carbon density in 1988, 1999 and 2009 for Qinglong was 13.80, 12.22 and 14.74 kg C m^{-2}, respectively, displaying a similar trend to carbon storage. The reduction of average carbon density from 1988 to 1999 was mainly caused by land use type transformation from natural forests, plantation and shrub to grass and difficult-to-use land. The conversion of grasslands and difficult-to-use lands into plantation, grass and shrub lands increased carbon storage significantly from 1999 to 2009. In these three historical periods, most of the high carbon density areas were difficult-to-use land, grasslands and shrub lands, while grasslands, shrub lands and natural forests contribute to most of the total carbon storage. Although the area of difficult-to-use land was large, their contribution to carbon storage was minimal due to a low carbon density (0.12 kg m^{-2}). At different periods, carbon intensities of plantations, grasslands, water and construction lands expanded dramatically, while natural forests, dry lands and difficult-to-use lands display shrinking trends on the spatial carbon density distribution.

3.2 Relationship between carbon storage and land use type transformation

To reveal the relationship between land use type transformation and spatial distribution of carbon storage we integrated a land use transfer matrix with spatial distribution maps of carbon density. Land use type transformation contributes significantly to the evolution of carbon storage (Fig. 6). Statistical analysis indicated that due to land use type transformation, carbon storage decreased 0.14 Tg from 1988 to 1999, and increased 0.23 Tg in the next ten years, showing a net increment of 0.08 Tg in carbon storage from 1988 to 2009. The total count of land use type change is 72 during this period, of which 21 types had more than 1% area of change. To note, diverse transformation types but small changes in area is one of the characteristics of land use transformation in the study area.

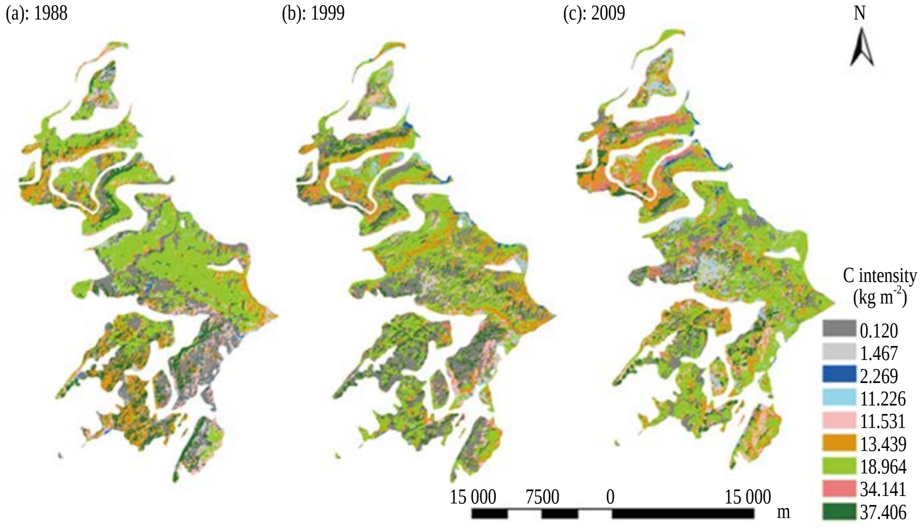

Fig. 5 Spatial distribution maps of carbon intensity of Qinglong karst areas (kg m^{-2}).

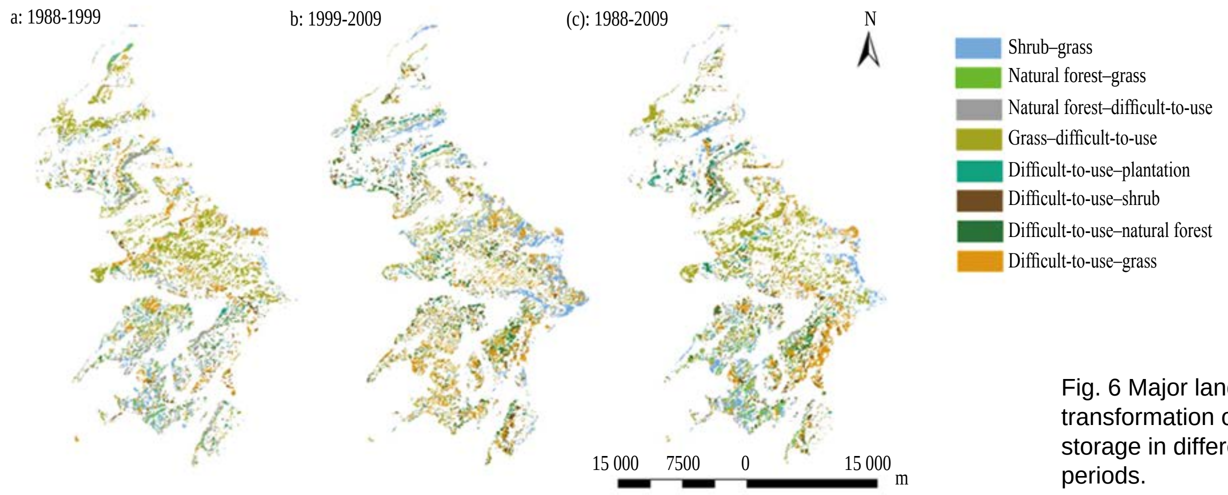

Fig. 6 Major land use transformation of carbon storage in different periods.

Generally, transformation from grasslands to difficult-to-use lands, from natural forests to difficult-to-use lands, from natural forests to grass and from shrubs to grass do not benefit carbon sequestration and often lead to carbon storage reduction. In contrast, transformations from difficult-to-use land to grass, plantation, natural forest and shrub contribute to carbon fixation, and increased carbon storage. Variations in paddy, water and dry land have little influence on carbon storage.

4 Discussions

4.1 Estimation of total carbon storage of karst canyon areas in Qinglong

Based on the carbon densities of each ecosystem in karst areas of Qinglong, we estimated the total carbon storage of Qinglong (Fig. 7). The results show that carbon storage is closely related to the area of each land use type. This study calculated four circumstances of Qinglong county's carbon storage which included the actual situation, reachable maximum, theoretical maximum and ideal circumstances. Under ideal circumstances of natural forests being the only land use type, the maximum carbon storage in Qinglong karst areas can reach 3.20 Tg C. Taking 2009 as an example, the theoretical and reachable maximum carbon storage were calculated to be 2.91 and 1.86 Tg C, respectively. In contrast, the actual carbon storage in 2009 was 1.31 Tg C, accounting for 41.10% of the ideal maximum, 45.26% of the theoretical maximum and 70.79% of the reachable maximum.

4.2 Estimation of total carbon storage and the contribution rate of karst canyon areas in Guizhou province

We analyzed the geomorphological map and the area of karst canyon was calculated to be 27 675.80 km^2. When natural forests are the only land use types, the ideal maximum carbon storage is expected to be 103.54 Tg, with an average of carbon density of 37.41 kg m^{-2}. Similarly, the actual value, theoretical maximum and reachable maximum of carbon storage in Guizhou karst canyon areas were 42.55, 60.11 and 94.12 Tg, respectively. Moreover, corresponding average carbon densities were estimated to be 16.26, 21.72 and 33.97 kg m^{-2}.

The actual carbon density of Guizhou karst canyon areas is much higher than that of the terrestrial ecosystems

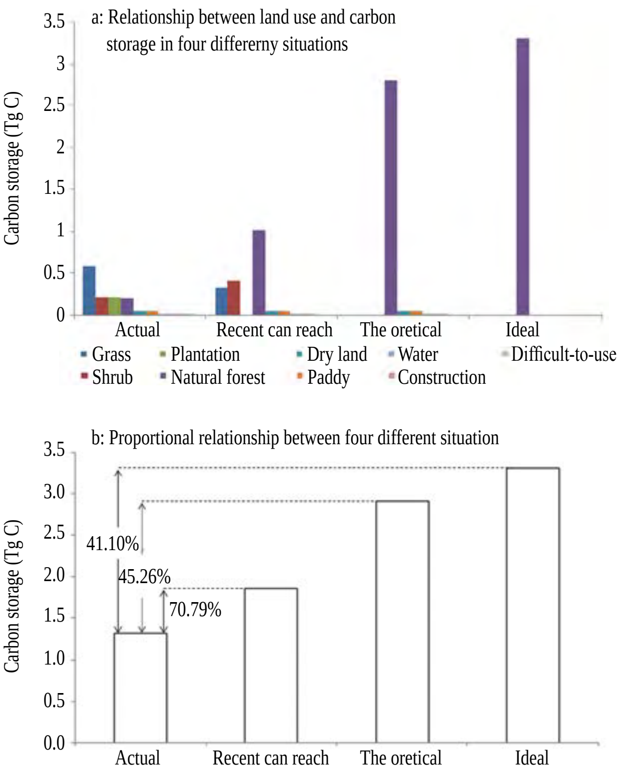

Fig. 7 Estimation of carbon storage of Qinglong karst canyon area.

in China, as computed by Li *et al*. to be 10.64 kg m^{-2} (Li *et al*. 2003). The theoretical maximum carbon density is about 3.19 times the national average, suggesting the great potential for carbon sequestration of Guizhou karst canyon areas.

4.3 Comparison of average carbon density between Guizhou karst canyon areas and other areas

The carbon storage of karst canyon areas in Guizhou has received little attention and so we compared the average carbon density with the results obtained in other areas (Fig. 8). Our result is consistent with other studies (Zhong *et al*. 2014; Qiu *et al*. 2012; Ding *et al*. 2012; Zhou *et al*. 2011), which demonstrate the specificity of karst areas and the validity of our estimation methods. Furthermore, our estimation of soil carbon density is approximate to that of non-karst areas (Pan *et al*. 2008; Li *et al*. 2004; Chen *et al*. 2007), but far less than northeastern regions (Wang *et al*. 2001a) and Chinese forests (Zhou, 2000) possibly because of organic substance abundance, high fertility and higher capability for carbon sequestration in northeastern regions and forests. Interestingly, our estimation of vegetation carbon density is much higher than Chinese terrestrial ecosystems (Zhou *et al*. 2000; Wang *et al*. 2001b) and forest ecosystems in other provinces (Wang *et al*. 2010; Huang *et al*. 2007; Ma *et al*. 2013) and is close to the average of Chinese forest ecosystems. High levels of vegetation carbon density are mainly due to the formation of developed vegetation ecosystems with a mild climate, abundant precipitation and sufficient solar resources. In conclusion, despite its barren soil layer, the soil carbon density of karst areas can still reach the average level of national terrestrial ecosystems, while the vegetation carbon intensity is far higher than the average of forest ecosystems in most provinces, demonstrating the great potential of carbon sequestration and the need for rocky desertification control in Guizhou karst canyon areas.

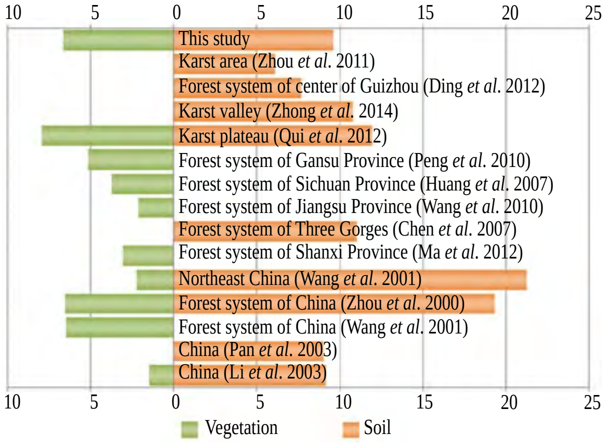

Fig. 8 Comparison of the carbon density of karst canyon areas in Guizhou to other areas (kg m^{-2}).

4.4 The uncertainty of carbon storage evaluation based on land use

Unique geologic structure characteristic make carbon cycles in these karst areas follow special patterns. Although combining LUCC and ecosystem carbon density is a traditional method yielding accurate results, there are uncertainties that need to be considered. First, this study assumes the carbon density of nine kinds of land use is stable, whereas carbon density changed weakly during different periods and this may have some impacts on the evaluation of carbon storage. Second, soil carbon density changes slower than land use change, and the recovery ability of different kinds of soils is different; this study did not consider this factor and this may mean we overestimated carbon storage.

5 Conclusions

From 1988 to 2009 the carbon storage and average carbon intensity decreased initially and then increased. Vegetation ecosystems including grasslands, shrub lands, plantation and natural forests contribute to the majority of carbon storage, and their expansion is the main reason for the increase in carbon storage. On the contrary, human use lands and difficult-to-use lands have lower capabilities for carbon sequestration. Consequently, increases in difficult-to-use areas leads to the reduction of carbon storage.

Population expansion, economic growth and government policies are critical factors that affect carbon storage. Specifically, from 1988 to 1999, expansion of population and lands for construction, cultivation and deforestation led to land degradation and contributed to the drastic reduction in carbon storage in the study area. However, the implementation of the Green for Grain policy in 2002 and ecological immigration facilitated restoration ecology, resulting in significant increases in carbon storage in Qinglong karst areas.

Based on current results for carbon storage in Qinglong karst canyon areas, we estimated the actual, reachable maximum and ideal maximum values of carbon storage and carbon intensities in Guizhou karst canyon areas. Interestingly, the actual carbon density is much higher than the average of terrestrial ecosystems in China, and the ideal maximum average carbon density is 3.19 times higher than the average national level. Thus, Guizhou karst canyon areas have great potential for carbon sequestration, and their ecological restoration is necessary for increasing carbon storage across terrestrial ecosystems in China.

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References

Bai Y C, Xia J G, Wang C Q, *et al*. 2009. Land use transition in Dongpo District, Meishan City in China based on a tendentious model for analyzing spatial transition of land use types. *Resources Science,* 31(10): 1793-1799. (in Chinese)

Batjes N H. 1996. Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science,* 47: 151-163.

Bockheim J G, Wilson S C, Leide J W. 1990. Soil development in the beardmore glacier region, Antarctica. *Soil Science,* 147: 144-157.

Chen L Z, Xie B Y, Xiao W F, *et al*. 2007. Organic carbon storage in soil under the major forest vegetation types in the three gorges reservoir area. *Resource and Environment in the Yangtze Basin,* 16(5): 640-643. (in Chinese)

Chuai X W, Huang X J, Zheng Z Q, *et al*. 2011. Land use change and its influence on carbon storage of terrestrial ecosystems in Jiangsu Province. *Resources Science,* 33(10): 1932-1939. (in Chinese)

Ding F J, Pan Z S, Zhou F J, *et al*. 2012. Organic carbon contents and vertical distribution characteristics of the soil in three forest types of the Karst regions in central Guizhou Province. *Journal of Soil and Water Conservation,* 26(1): 161-169. (in Chinese)

Fan F D, Wang K L, Xiong Y, *et al*.2011.Assessment and spatial distribution of water and soil loss in karst regions, southwest China. *Acta Ecologica Sinica*, 31(21): 6353-6362. (in Chinese)

Fang J Y, Chen A P. 2001. Dynamic forest biomass carbon pools in China and their significance. *Acta Botanica Sinica*, 43(9): 967-973. (in Chinese)

Guo K, Liu C C, Dong M. 2011. Ecological adaptation of plants and control of rocky-desertification on karst region of Southwest China. *Chinese Journal of Plant Ecology,* 35 (10): 991-999. (in Chinese)

Huang C D, Zhang J, Yang W Q, *et al*. 2007. Spatial temporal variation of carbon storage in forest in Sichuan Province. *Chinese Journal of Applied Ecology,* 18(12): 2687-2692. (in Chinese)

Jiao J G, Wu J X, Li H X, *et al*. 2007. Soil quality in relation to land use/ cover in landscape at a village level in hilly regions south China. *Acta Pedologica Sinica,* 44(2): 204-211. (in Chinese)

Kozlowski T T. 1986. Soil aeration and growth of forest trees. *Scandinavian Journal of Forest Research*, 1: 113-123.

Li K R, Wang S Q, Cao M K. 2003. Vegetation and soil carbon storage in China. *Science in China* (*Series D*), 47(1): 72-80.

Liu J Y, Liu M L, Zhuang D F, *et al*. 2002. China's recent analysis of the spatial pattern of land use change. *Science in China* (*Series D*), 32(12): 1031-1040.

Liu J Y, Wang S X, Chen J M, *et al*. 2004. Storages of soil organic carbon and nitrogen and land use changes in China: 1990-2000. *Acta Geographica Sinica*, 59(4): 483-496. (in Chinese)

Liu J Y, Zhang Z X, Zhuang D F, *et al*. 2003a. A study on the spatial-temporal dynamic changes of land usage and driving forces analyses of China in the 1990s. *Geographical Research,* 22(1): 1-12. (in Chinese)

Liu K, Ouyang Z Y, Wang X K, *et al*. 2003b. Eco-environmental sensitivity and its spatial distribution in Gansu Province. *Acta Ecologica Sinica,* 23(12): 2711-2718. (in Chinese)

Luo D H, Xia J, Yuan J W, *et al*. 2010. Root biomass of karst vegetation in a mountainous area of southwestern China. *Chinese Journal of Plant Ecology,* 34(5): 611-618. (in Chinese)

Ma Q, Liu K, Zhang H. 2012. Carbon storage by forest vegetation and its spatial distribution in Shanxi. *Resources Science,* 34(9): 1781-1789. (in Chinese)

Pan G X, Li L Q, Zhang X H, *et al*. 2003. Soil organic carbon storage of China and the sequestration dynamics in agricultural lands. *Advance in Earth Sciences,* 18(4): 609-618.

Peng H H, Jiang H M, Zhao C Y. 2010. Carbon storage of forest and its spatial distribution in Gansu Province. *Journal of Arid Land Resources and Environment,* 24(7): 154-158. (in Chinese)

Peng W X, Wang K L, Song T Q, *et al*. 2008. Controlling and restoration models of complex degradation of vulnerable karst ecosystem. *Acta Ecologica Sinica,* 28(2): 811-820. (in Chinese)

Qiu H S, Su Y R, Chen X B, *et al*. 2012.Characteristics of the distributions Journal of soil organic carbon and main components in a typical catchment in the karst plateau. *Agro-Environment Science,* 31(10): 1956-1964. (in Chinese)

Ramita M, Inakwu O A O, Robert G P J. 2010. Analysis of twenty years of categorical land transitions in the Lower Hunter of New South Wales, Australia. *Agriculture, Ecosystems and Environment,* 135: 336-346.

Remezon N P. 1959. Method studying the biological cycles of elements in forest. *Soviet Soil Sei*, 1: 59-67.

Rennie P J. 1955. The uptake of nutrients by nature forest growth. *Plant Soil,* 7: 49-95.

Tan Q J, Song T Q, Peng W X, *et al*. 2014. Carbon pattern of different ecosystems in canyon karst region in southwestern of China. *Acta Ecologica Sinica,* 34(19): 5579-5588. (in Chinese)

Tang F K, Cui M, Zhou J X, *et al*. 2014. Difference analysis of soil organic carbon pool in different forestlands returned from farmlands in karst gorge area. *Science of Soil and Water Conservation*, 12(4): 1-7. (in Chinese)

Tian D L, Wang X K, Fang X, *et al*. 2011. Carbon storage and spatial distribution in different vegetation restoration patterns in karst area, Guizhou Province. *Scientia Silvae Sinicae,* 47(9): 7-14. (in Chinese)

Wang L, Ding J J, Ji Y H, *et al*. 2010. The dynamic carbon storage and economic value assessment of forest in Jiangsu Province. *Journal of Nanjing Forestry University (Natural Science Edition),* 34(2): 1-5. (in Chinese)

Wang S J, Lu H M, Zhou Y C, *et al*. 2007. Spatial Variability of soil organic carbon and representative soil sampling method in Maolan karst virgin forest. *Acta Pedologica Sinica,* 44(3): 475-483. (in Chinese)

Wang S Q, Zhou C H, Luo C W. 1999. Studying carbon storage spatial distribution of terrestrial natural vegetation in China. *Process in Geography,* 18(5): 238-244. (in Chinese)

Wang S X, Zhou C H. 1999. Estimating soil carbon reservior of terrestrial ecosystem in China. *Geographical Research,* 18(4): 349-355. (in Chinese)

Wang S X, Zhou C H, Liu J Y, *et al*. 2001a. Simulation analyses of terrestrial carbon cycle balance model in northeast China. *Acta Geographica Sinica*, 56(4): 391-400. (in Chinese)

Wang X K, Feng Z W, Ouyang Z Y. 2001b. Vegetation carbon storage and density of forest ecosystems in China. *Chinese Journal of Applied Ecology,* 2(1): 13-16. (in Chinese)

Yang Y L, Wang J L, Yang B F. 2008. Eco-sensitivity assessment of land in Yunnan Province. *Acta Ecologica Sinica,* 28(5): 2253-2260. (in Chinese)

Zhang M Y, Wang K L, Liu H Y, *et al*. 2013. Spatio-temporal variation of vegetation carbon storage and density in karst areas of Northwest Guangxi based on remote sensing image. *Chinese Journal of Eco-Agriculture,* 21(12): 1545-1553. (in Chinese)

Zhong Y X, Zhou Y C, Li Z J. 2014. Rearch on the carbon storage and potential carbon sequestration of vegetation in the trough valley of a karst area, Yinjiang. *Earth and Environment,* 42(1): 82-89. (in Chinese)

Zhou W L, Xiong K N, Long J, *et al*. 2011. Organic carbon density features and regional variation of the topsoil in karst demonstration areas of rocky desertification integrated rehabilitation. *Chinese Journal of Soil Science,* 42(5): 1131-1137. (in Chinese)

Zhou Y R, Yu Z L, Zhao S D. 2000. Carbon storage and budget of major Chinese forest types. *Acta Phytoecologica Sinica,* 24(5), 518-522. (in Chinese)

典型喀斯特峡谷区碳储量空间分配格局、演变过程及其贡献率

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摘 要：采用样方法和土地利用转移矩阵，以贵州省西南部的晴隆县为研究区域，研究了典型喀斯特峡谷区不同土地利用类型在1988、1999和2009年的碳储量空间格局和演变过程，并由此估算了贵州省喀斯特峡谷区的碳储量及贡献率。结果表明：晴隆县喀斯特区域的碳储量和平均碳密度呈先减少后增加的趋势。由晴隆县不同情况下的碳储量比例关系，估算出贵州省喀斯特峡谷区碳储量的实际值为42.55 Tg。同时，研究结果表明人类活动对碳储量的空间格局和演变有很大的影响。此外，估算的贵州省喀斯特峡谷区生态系统的平均碳密度远高于中国陆地生态系统的平均值，土壤平均碳密度则接近全国陆地生态系统平均值，但其植被平均碳密度却远高于全国陆地生态系统平均值，与全国森林系统的植被平均碳密度持平。这说明喀斯特峡谷区具有极大的固碳潜力，对其进行石漠化防治，是极其必要的。

关键词：碳储量；演变过程；峡谷型喀斯特；空间格局