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Original Research Paper

Spatial Distribution Characteristics of Biomass and Carbon Storage in Forest Vegetation in Chongqing Based on RS and GIS

Qiannan Liu*(**), Zhiyun Ouyang*†, Ainong Li* and Weihua Xu*****
*Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu Sichuan, 610041, China
**University of Chinese Academy of Sciences, Beijing 100049, China
***Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
†Corresponding author: Zhiyun Ouyang

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ABSTRACT

Research on the spatial distribution characteristics of carbon storage in forest vegetation not only facilitates the study of carbon sink and ecological compensation of the forest ecosystem, but also provides basic data for recovering and reconstructing the forest ecosystem and increasing the carbon sink. In this study, remote sensing images of Landsat TM (August) in 2011 and a large amount of actual surveyed data of the sample plots were used as the main and supplementary data sources, respectively. Chongqing was selected as the study site to quantitatively estimate the biomass, carbon storage, and carbon density of forest vegetation based on the biomass-remote sensing (RS) geoscientific data regression model with the aid of RS and GIS techniques. With the spatial analysis function of ArcGIS, factors affecting the geographic distribution of biomass were investigated from a macroscopic perspective, and the geographical distribution pattern characteristics of biomass in the study area were quantitatively discussed. Results showed that the total aboveground biomass of Chongqing is 2.83×10^8 t, and that of the forest ecosystem is 1.39×10^8 t. Biomass was mainly distributed in northeast and southeast Chongqing, and the overall distribution pattern was high in the east and low in the west. Forest vegetation and biomass were mainly distributed in mid-high altitudes with steep slopes. Despite the results of this biomass and carbon storage study using RS in Chongqing, further research based on the carbon cycle is needed.

INTRODUCTION

As the main body of the terrestrial ecosystem, forests store 72% to 98% of the terrestrial ecosystem's organic carbon (Wang et al. 2001). The fixed carbon storage in forest vegetation accounts for 82.15% of the total carbon fixation of terrestrial vegetation (Sabine et al. 2004). A total of 85% of terrestrial biomass is concentrated on the forest vegetation (Fang et al. 2002), which shows higher productivity than other terrestrial ecosystems (Turneret et al. 1995). Thus, the biomass and productivity of the forest exert very important effects on global climate change and material cycling (Cramer et al. 1999, Field et al. 1999), maintain the regional ecological environment, and balance carbon distribution in the world (Liu et al. 2000, Dixon et al. 1999, Xu et al. 2012). The forest acts as the source, storehouse, and sink in the global circulation of carbon (Fu et al. 2005). Forest carbon storage is taken as the basic parameter that reflects the function of the forest ecosystem (Ge et al. 2013), and it is calculated by accurately estimating vegetation biomass (ICPC 2004, ICPC 2006). In addition to forest vegetation, the relationship between regional forest vegetation and global climate change is a hot spot in the research of ecology and environmental science (Zhang et al. 2010). Qualitative studies on biomass and carbon storage in the forest ecosystem in China have been conducted, but most of them focused on either the nationwide or local scale (Fang et al. 2001, Wang et al. 2004, Zhao & Zhou 2004). Research on carbon storage and carbon sink function of the middle scale or regional forest ecosystem is relatively weak (Wang et al. 2010), and studies on forest biomass, carbon storage, and carbon sink function in the southwestern forest region on the middle scale are lacking. Using Chongqing as the study area is particularly rare.

The forest vegetation in Chongqing and Sichuan is the main part of the southwestern forest region in China. Located on the east edge of the Qinghai-Tibet Plateau, which is considered the world's third pole, the study location is a sensitive response area to global climate change (Zhang et al. 1995). In addition, the forest vegetation is mostly distributed in the upper reaches of the Yangtze River, making it an important site for water resource conservation and protection while maintaining the ecological balance in the river (Huang et al. 2008). Chongqing became a municipality directly under the Central Government, and since the implementation of major forest projects, such as the Yangtze River grebe belt, green gills, and clear waters, the forest area has been increasing continuously, making the forest vegetation an important contributor to carbon sink and carbon balance. However, studies based on the biomass and carbon sink capacity of the forest vegetation are rare, and research on future carbon sink potential after conducting forest projects is lacking. The present study used a biomass-remote sensing (RS) geoscientific data multiple regression model to establish the RS biomass model of the forest vegetation, with Landsat TM in Chonqing (2011) as the main data source and a large amount of field survey and forest inventory data as the basis. Based on the biomass estimation of the forest vegetation and the ArcGIS spatial analysis module, the proposed model uses DEM data, land use situation, and carbon content of forest vegetation to quantitatively analyse the spatial distribution properties of forest vegetation biomass under different topographic features. The factors affecting the geographical distribution of biomass, as well as the geographical distribution characteristics of carbon storage in the study area, were also explored in a macroscopic perspective. The research results have important theoretical basis and practical significance in evaluating the carbon sink function of forest vegetation, calculating the green GDP (Gross Domestic Product), and establishing the ecological effect compensation mechanism of the forest carbon. This study also provides a scientific decision-making service and technical reference for the implementation of CDM (Clean Development Mechanism) afforestation and other relevant carbon sink projects in the regions of Chongqing in the future.

RESEARCH AREA AND RESEARCH METHOD

Introduction of the research area: Chongqing City (E: 105°17'-110°11'; N: 28°10'-32°13') is bordered by Hubei Province and Hunan Province to the east, Guizhou Province to the south, and Sichuan Province to the west and north. Its northeast is bordered to Shan'anxi Province. It is an economic center in the upper Yangtze River, an important industrial town in the southwest, a hub of land and water transportation, and an important ecological barrier of the Yangtze River basin. It covers an area of 82400 km^2, with mountains accounting for 75.8% and hills for 18.2% of the total city area. This area experiences the humid tropical monsoon climate of central Asia with the same period of rain and heat. Temperature is high and precipitation is abundant, but the distribution is uneven in different seasons. In summer, the subtropical high pressure and topographic influence cause high temperature and severe drought. The main vegetation in the city includes coniferous forest, broad-leaved forest, bamboo forest, shrubs, and meadows. Soil erosion frequently occurs because of numerous mountains, high slopes, and uneven distribution of rainfall in different seasons (Zhang et al. 2004).

Remote sensing data processing: This study is based on 1:50000 topographic map geographical data. The remote sensing software ENVI 4.8 adopts the quadratic polynomial and adjacent interpolation method to complete the geometric correction of Landsat TM remote sensing data shadow in 2011 and control the correction error within 1 pixel. The projection way is the UTM (Zone48N), and the coordinate system is WGS84. FLASSH module of the software was used to complete the atmospheric correction of remote sensing image and eliminate the influence of atmospheric scattering on the image radiation distortion. Terrain correction of the remote sensing image based on DEM was completed to eliminate the influence of mountain shadow on the forest vegetation and conduct mask cutting processing on the image according to the administrative boundary of the study area.

The overall land classification systems, characteristics of Landsat TM data, and actual land use situation in the study area complete the field sampling survey on the test area. After obtaining a large amount of field-surveyed samples, the multi-step classification method was conducted to complete the classification processing of the remote sensing images by the classification model established in ERDAS IMAGE 9.3. Land use in Chongqing is classified into seven grades, namely, forest, shrub, grassland, wetland, farmland, town, and bare land. The study adopts random sampling to complete the precision verification of the classification result. The Kappa coefficient is 0.893, which is higher than the minimum allowed discriminant precision requirement of 0.7. In addition, the Kappa coefficient completes the correction and topology processing of the final classification results based on ArcGIS 9.3 to generate the thematic map of land use distribution.

The Model module of ERDAS IMAGE 9.3 was used to complete the quantitative extraction of ratio vegetation index (RVI), normalized difference vegetation index (NDVI), atmospheric resistance vegetation index (ARVI), modified soil atmosphere resistance vegetation index (MSAVI), and enhanced vegetation index (EVI). The luminance component (KT1), green component (KT2), and humidity component (KT3) based on Tasseled Cap transformation, as well as three principal component variables of PCA1, PCA2, and PCA3 based on principal component analysis (PCA), were also obtained.

Quadrat design: The plant community was surveyed using traditional methods. The survey period was from August to October 2011. Given that the aboveground biomass data

Table 1: Correlation coefficients between aboveground forest biomass and model factors.

Parameter	Pearson Correlation Coefficient	Parameter	Pearson Correlation Coefficient
TM1	-0.105	KT1	0.335*
TM2	-0.212	KT2	-0.497**
TM3	0.091	KT3	-0.227
TM4	0.337*	PCA1	0.318*
TM5	0.248	PCA2	0.464**
TM7	0.213	PCA3	0.067

Note: a: two-tailed test; **represents 0.01 significance level, and *represents 0.05 significance level. The number of samples is 110.

Table 2: Correlation coefficients between aboveground forest biomass and vegetation indexes.

Parameter	ARVI	EVI	MSAVI	NDVI	RVI
Pearson Correlation Coefficient	0.323	-0.337	0.847**	0.558**	0.524**
Significance Level	0.546	0.574	0.000	0.002	0.022
Number of Samples	110	110	110	110	110

Note: a: two-tailed test; **represents 0.01 significance level.

were from the field sample survey, the representative quadrats selected in the study were coniferous forest, mixed forest, and broad-leaved forest, resulting in a total of 158 forest vegetation quadrats. Considering that the spatial resolution of Landsat TM shadow was 30 m, the quadrats were uniformly set to 30 m × 30 m. A handheld GPS was used to record the central coordinates of the quadrats to match the geographic information system database with the remote sensing data (Wang et al. 2008). Each tree of the tree layer plants was investigated by recording tree species, height, DBH, and crown diameter. The areas of shrubs and grass were set to 4 m^2 (2 m × 2 m) and 1 m^2 (1 m × 1 m), respectively. The shrub species, height, coverage, and number of plants (bundles) were recorded for shrubs, and the species, height, and coverage were recorded for herbs. In addition, the degree of interference on the quadrats and details of plant death were recorded.

Biomass estimation: The forest biomass was estimated using the biomass and volume regression equation established by Fang Jingyun, and the combination of the calculation parameter of 21 dominant tree species and the basic parameters of major tree species in the study area. Based on relevant literature, the product of the coverage and height of shrubs and herbs were used the independent variables of the predictive model. The biomass regression model was used to obtain the biomass in the herb and shrub levels per unit to obtain the biomass of the whole quadrat (Liu et al. 2000).

A total of 110 forest vegetation samples were randomly selected, and correlation analysis was conducted with the data of different bands of the corresponding TM image (Band 1, 2, 3, 4, 5, 7), vegetation index data (ARVI, RVI, NDVI, EVI and MSAVI), Tasseled Cap transformation data (KT1, KT2 and KT3) and PCA data (PCA1, PCA2 and PCA3). Based on the obtained correlation coefficients (Table 1), the factors with significant correlation between the remote sensing geological data and sample biomass were selected to establish the multiple linear regression model using the remote sensing model method and the stepwise regression method. The biomass in the study area was estimated based on ERDAS IMAGE 9.3 model. In addition, 48 more samples were used for biomass precision evaluation. Five commonly used vegetation indices were selected and used as the dependent variables with SPSS 17.0 software for correlation analysis with the biomass data of the corresponding aboveground survey points. About 70% of the sample data was selected randomly to construct the biomass model, and about 30% of the sample data was used to examine the precision of the model. Finally, 110 sample points were determined for model establishment and 48 were used for verification. The regression results of various vegetation indices are given in Table 2.

Model construction: According to the analysis result, the index MSAVI with the highest correlation was selected to construct the experience model. The experience model includes linear and index function, logarithmic, power, hyperbolic, and polynomial functions. Increasing the parameters of the model or raising the order of polynomials may violate the biological law. Thus, the best regression equation was selected according to the simplest model, maximum correlation coefficient, smallest standard error, and F test optimum to obtain the remote sensing estimation model of the aboveground biomass of the forest in Chongqing (Fig. 1).

Carbon storage calculation: According to the biomass spatial distribution in the main forest vegetation of Chongqing and the biomass-carbon conversion coefficient, 0.5 was selected as the biomass-carbon conversion coefficient for calculation (Olson et al. 1983). Thus, the biomass multiplied by 0.5 is the researched carbon storage. However, the carbon storage used in this study did not include that in the dead wood and soil layer but mainly covered that in the forest vegetation, shrub layer, and herb layer.

Extraction of the topographic feature factor: Based on the spatial analysis module in ArcGIS, this study superposed the biomass and topographic feature factors of the study area to quantitatively analyse the spatial distribution characteristics of biomass in three directions of elevation, slope, and aspect. The elevation is graded at intervals of 100 m. The slope is graded at equal intervals of 5°, and the aspect is graded at equal intervals of 45°. The aspect is divided into sunny slope (135°-225°), shady slope (315°-45°), half-sunny slope (90°-135° and 225°-270°), and half-shady slope (45°-90° and 270°-315°). The due north is 0°, and the due south is 180°.

RESULT S AND ANALYSIS

Biomass estimation and spatial distribution: Qualitative inversion of the multiple linear regression model of the forest vegetation biomass showed that the total aboveground biomass in Chongqing was 2.83×10^8 t, with an average biomass per unit area of 34.22 t/hm^2. Of the average biomass per unit area, the total biomass of the forest ecosystem was 1.39×10^8 t, accounting for 49.12% of the total, followed by shrub, grassland, and farmland ecosystems. In addition, the average biomass per unit area in the forest ecosystem reached 45.59 t/hm^2, which was much higher than the total average biomass per unit. As shown in Figs. 2 and 3, the distribution pattern of biomass of the vegetation in the study area was high in the east and low in the west. The biomass in northeast and southeast Chongqing was evidently higher than that in central and west Chongqing. The figure in southeast Chongqing was the highest, with an average biomass per unit area of 222.29 t/hm^2, and lowest in central Chongqing with only 17.11 t/hm^2. Northeast and southeast Chongqing are the advantageous distribution areas for studying regional biomass, because the altitude is relatively high and the slope is steep. The natural geographical conditions limit the human development activities to a certain extent. In addition, given the small population, the forest vegetation is less interfered by human activities. As a result, a large number of natural forest vegetation can preserve primeval conditions. The forest vegetation comprised dark coniferous forests at the top community with *Picea asperata* and *Picea jezoensis*

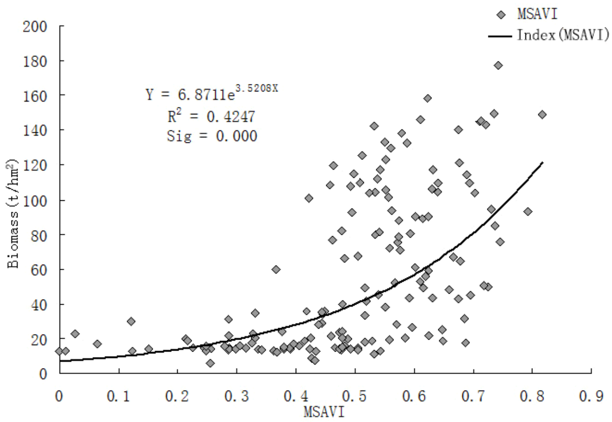

Fig. 1: Relationship between biomass and MSAVI index.

as the primary species. The natural ecosystem is completely protected with high biomass, implying that the bulk of the biomass of the forest vegetation in Chongqing is in the natural forests. Thus, the natural forest plays an important role in the carbon sink function of the forest vegetation in the southwest forest region. With a relatively flat landscape and large population, central and west Chongqing are the main agricultural and industrial production bases where the economy is rapidly developed and transportation is convenient. In the pursuit of economic interest, other forest areas are destroyed, except for the natural ecosystems in the mountain reserves. As a result, the human disturbance landscape replaces the primitive natural landscape and the biomass of the forest vegetation is reduced. Therefore, the majority of primeval forest vegetation ecosystems are distributed at the high mountains and mountain edges where there are less human activities and high biomass.

After completing the statistics of the forest biomass in different districts and counties in the study area, the spatial distribution characteristics were analysed using ArcGIS spatial analysis tool. Overall, the forest biomass was high in the south and low in the north. The highest forest biomass was found in Youyang county, followed by Shizhu, Fengjie, and Wuxi with biomass of 9.58×10^6, 8.34×10^6, 8.27×10^6, and 7.78×10^6 t, respectively. The forest biomass density was also highest in Youyang at 56.8502 t/hm^2. These results may be attributed to the large areas of fir, spruce, oak, broad-leaf, and other primeval natural forests in this region with high forest density and less human activities. The forest biomass and forest biomass density were lowest in Rongchang county at 0.37×10^6 and 0.37×10^6 t, respectively. For the areas with high forest biomass, continuous efforts should be made to seal off the mountain for forest cultivation, protection of the natural forests, remediation of cultivated land to forests, further enhancement of forest quality, and increase in carbon

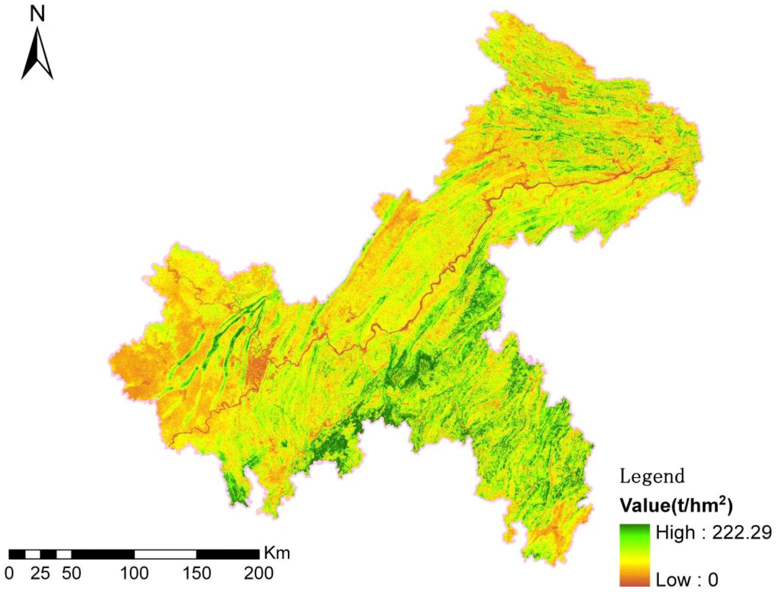

Fig. 2: The spatial distribution of the general aboveground biomass in Chongqing city.

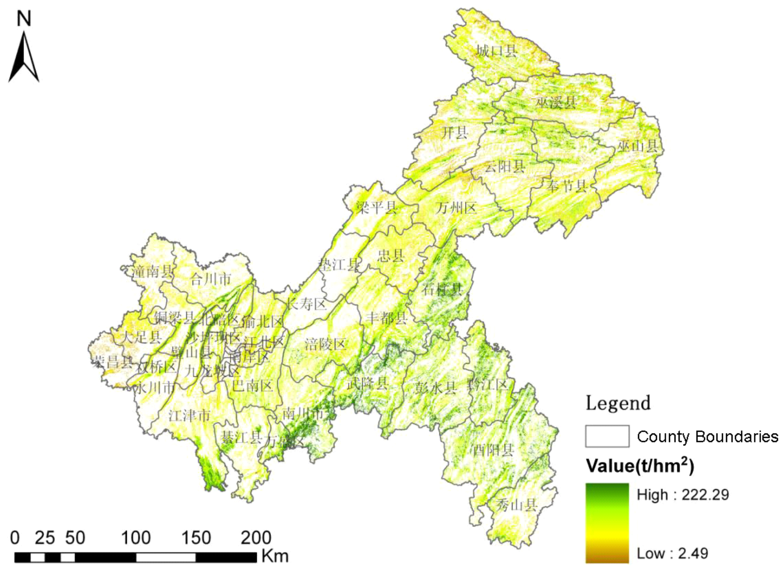

Fig. 3: The spatial distribution of the forest biomass in Chongqing city.

fixation capacity. To improve existing forest biomass, it is necessary to enlarge the area of artificial forest, gradually increase its carbon storage capacity, promote its role in the carbon sink function in Chongqing, and strengthen the service function of the forest ecosystem based on increasing overall aboveground biomass in the study area. Therefore, the artificial landscape will be a potential carbon pool for Chongqing.

Carbon storage estimation and its spatial distribution: From the estimation of the carbon storage with the biomass-carbon conversion coefficient, the total carbon storage in the forest ecosystem in Chongqing was 6.29×10^7 t, with an average carbon storage per unit area of 22.01 t/hm^2. The carbon storage in coniferous forest was the highest, accounting for 75% of the total in Chongqing, and it was much higher than that in broadleaved tree species. However, the carbon storage in spruce-fir forest occupied the dominant position in the whole ecosystem. Based on the geographical distribution of carbon storage in the study area (Fig. 4), Jinyun Mountain in Beibei district, Simian Mountain in Jiangjin district, Jinfo Mountain in Nanchuan district, Wuyi Mountain in Fuling district, and Daba Mountain in northeast Chongqing were the main distribution zones of completely preserved and perfectly structured forest vegetation resources. The carbon storage in Simian Mountain in Jiangjin district was low, but its distribution was relatively concentrated. The carbon storage in Daba Mountain in northeast Chongqing was scattered, but the carbon storage density was high, which may be closely related to the long-term forest protection in the area. In addition, the complex terrain, various vegetation types, and changing climate in Chongqing are also important factors affecting the spatial distribution characteristics of carbon storage. The forest carbon sink distribution in different districts and counties of Chongqing is geographically uneven. The carbon sink capacity of the districts and counties in the west is generally much lower than that in the northeast and southeast of Chongqing. Thus, future ecological forest reconstructions in Chongqing should be based on the carbon storage distribution characteristics combined with the natural forest resource protection projects, reversion of cultivated land to forests or pastures, and other forest ecosystem recovery projects. Efforts should be made to realize forest ecosystem management in different regions, coordinate the forest carbon sink distribution, strengthen the cultivation and management of coniferous forests with large carbon storage, and increase the planting area of broadleaved tree species and

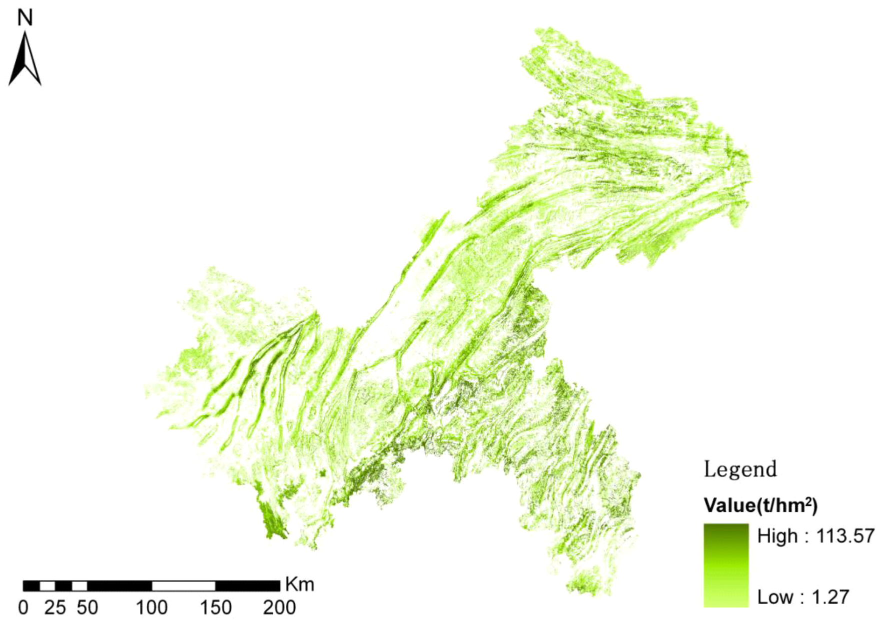

Fig. 4: The spatial distribution of carbon storage by forests in Chongqing city.

artificial forests. Priority should be placed on developing the forest carbon sink in west Chongqing by increasing the carbon sink function of the forest vegetation in the study area and integrating it with the forest carbon sink development in northeast and southeast Chongqing. References and basic data for carbon storage research and forest ecosystem management in the southwestern forest region are available.

Analysis of the topographical factors affecting the spatial distribution of biomass: Chongqing is dominated by mountainous areas. Given that the forest vegetation is mostly distributed in the mountainous area, the terrain factors play an important role in the rearrangement of environmental factors, such as rainfall and temperature. In addition to the influence of the Qinghai-Tibet plateau uplift and human interference (Liu et al. 2006), the forest vegetation biomass in the study area shows certain particularity and complexity in topographical features.

Fig. 5 shows that the biomass in the study area increased with the altitude, peaked at 500-1000 m, and gradually decreased. In the low altitude area, the flat terrain and fertile soil are suitable for industrial and agricultural production activities, giving rise to a large human population. Driven by economic interests, the population increase disturbs the native vegetation in the area. As a result, the zonal evergreen broad-leaved forest is destroyed, and the primary forest either evolves into secondary forest vegetation or is replaced by artificial forestswith minimal biomass (Huang et al. 2009). These tendencies show that human interference is an important factor affecting the biomass pattern in this area to a certain extent. In mid-high altitude areas, soil condition, moisture, heat, and other site conditions are suitable for the growth of forest vegetation, so the natural subalpine coniferous forest with high biomass is mainly distributed here (Huang et al. 2009). In addition, the low population density and terrain conditions limit the intensity of human interference, leading to the high biomass. In the high altitude areas, the poor moisture and heat conditions limit the growth of some forest vegetation, so low and sparse shrubs are distributed in these regions with low biomass. The natural conditions are an important factor affecting the biomass in these areas.

The biomass evidently increases with the slope. When the slope is between 0° and 10°, the soil layer is relatively thick, transportation is convenient, the population density is great, and the human interference activities are frequent. After dark coniferous forests are destroyed, farmland, residential areas, and destroyed woodlands occupy most of the lands in the region. Oak broad-leaved forest is the secondary forest representative community with average biomass. When the slope is between 10° and 35°, the biomass rises gradually with it. The peak appears when the slope is between 20° and 25° and then gradually decreases. In this region, the opportunity and degree of human interference on the forest vegetation are small, so large areas of natural fir forest and spruce forest are distributed here. The forest vegetation grows for a long time period with large biomass, making it the major forest carbon pool of Chongqing. Despite the increasing slope (35°) and diminishing human activities, the temperature, rainfall, and soil moisture are low and the site conditions are poor, thereby restricting the growth of the forest vegetation to a certain extent and leading to the low productivity and biomass of the forest.

The biomass changes in a curve in the slope aspect. The biomass on the shady and half-shady slope is significantly higher than that on the sunny and half-sunny slope. The shady slope receives less solar radiation, so evaporation is low and soil moisture conditions are good, which are suit-

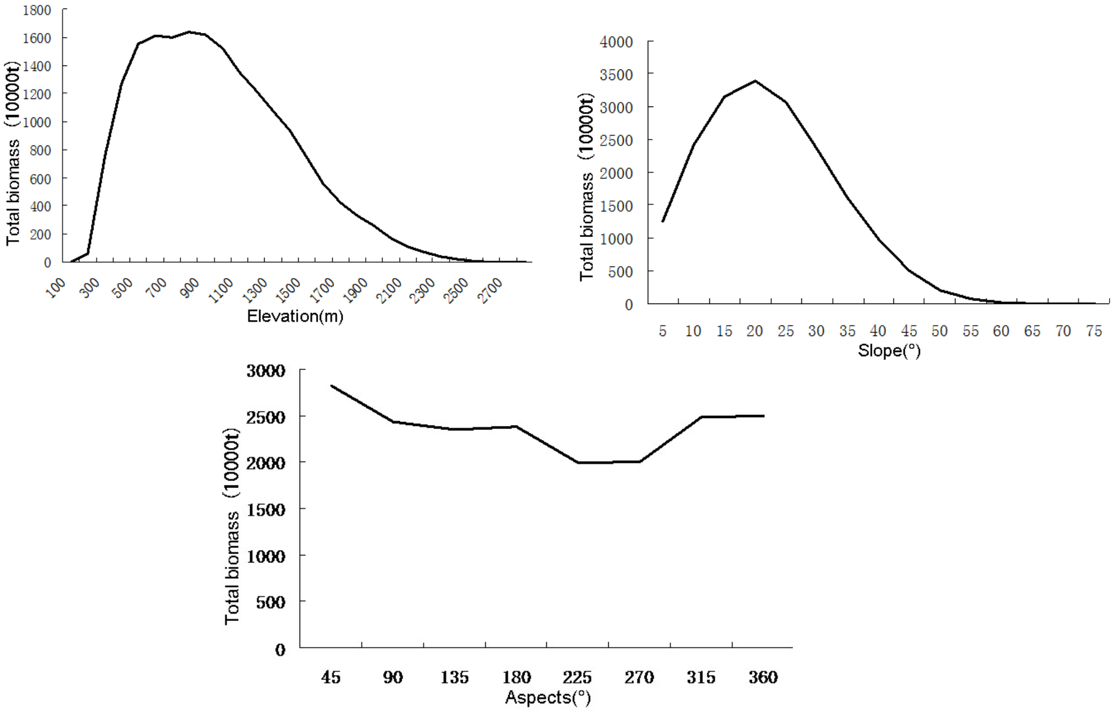

Fig. 5: The spatial distribution of the general aboveground biomass in terrain factor of Chongqing city.

able for forming dense fir and spruce trees. In the sunny slope, shrubs, *Pinus tabulaeformis*, birch, poplar, and other secondary forest species are distributed. These species mostly comprise the dark coniferous forests, which are formed through natural or artificial updating after destruction (Lan et al. 2004). Thus, the biomass on the shady and half-shady slopes is easier to accumulate than that on the sunny and half-sunny slopes.

Overall, the forest vegetation and biomass in Chongqing are intensely distributed in the areas at mid-high altitude and on the steep slopes, but these areas are typical environmentally fragile zones (Huang et al. 2009). Once the forest vegetation is destroyed, ecological recovery is difficult. Thus, efforts should be made to minimize human interference, intensify the protection of the forest vegetation, and promote the succession from secondary forest with low biomass to spruce-fir top community with high biomass, thereby improving the carbon sink function of the forest vegetation in Chongqing.

CONCLUSION

With the Landsat TM remote sensing image in 2011 as the main data source and a large amount of actual surveyed data as the basis, this study used the biomass-remote sensing geoscientific data regression model to estimate the aboveground biomass of the forest in Chongqing via RS and GIS technologies. Quantitative analysis of the spatial distribution properties of biomass of the forest vegetation under different topographic features was conducted to explore the factors affecting the geographical distribution of biomass and the geographic distribution characteristics of carbon storage in the study area from a macroscopic perspective. The main research results are as follows.

1. The total aboveground biomass in Chongqing is 2.83×10^8 t, with an average biomass per unit area of 34.22 t/hm^2. The total biomass of the forest ecosystem is 1.39×10^8 t, accounting for 49.12% of the total, followed by shrub, grassland, and farmland ecosystems. The biomass in the study area is highly distributed in the east and low in the west, mainly in northeast and southeast Chongqing.
2. The aboveground biomass of the forest in the study area evidently increases with the altitude and peaks at 500-1000 m, decreasing gradually as the altitude continues to increase. The biomass significantly increases with the slope. The peak appears when the slope is between 20° and 25° and then decreases gradually. The biomass on the shady and half-shady slopes is higher than that on the sunny and half-sunny slopes. The areas at mid-high altitudes and on steep slopes are the main distribution

areas of the forest vegetation, as well as the distribution zones of biomass.

3. The total carbon storage in the forest ecosystem in Chongqing in 2011 was 6.29×10^7 t, with an average carbon storage per unit area of 22.01 t/hm^2. The geographical distribution of the forest carbon sink in different districts and counties of Chongqing is uneven with a relatively extreme overall trend. The carbon sink capacities of the districts and counties in west Chongqing is generally much lower than those in northeast and southeast Chongqing.

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REFERENCES

Cramer, W. and Kicklighter, D. W. et al. 1999. Comparing global models of terrestrial net primary productivity(NPP):overview and key results. Global Change Biology, 5: 1-15.

Dixon, R. K., Solomon, A. M., Brown, S., Houghton, R. A. et al. 1994. Carbon pools and flux of global forest ecosystems. Science, 263(5144): 185-190.

Fang Jingyun and Chen Anping 2001. Dynamic forest biomass carbon pools in China and their significance. Journal of Plant Ecology, 43(9): 967-973.

Fang Jingyun, Chen Anping, Zhao Shuqing, et al. 2002. Forest biomass estimation in China: supplementary notese on report published in Science (2001,291:2320-2322) by Fang et al. Journal of Plant Ecology, 26(2): 243-249.

Fang Jingyun, Liu Guohua and Xu Songling 1996. Biomass and net production of forest vegetations in Chin. Journal of Ecology, 16(5): 497-508.

Field, C. B. and Randerson, J. T. et al. 1995. Global net primary production: combing ecology and remote sensing. Remote Sensing of Environment. 51(1): 74-88.

Fu, B. J., Niu, D. and Zhao, S. D. 2005. Study on global change and terrestrial ecosystems: history and prospect. Advances in Earth Science, 20(5): 556-560.

Ge, Liwen, Pan Gang, Ren Dezhi, et al. 2013. Carbon storage and density in the Forest and its distribution in Linzhi area of Tibet. Chinese Journal of Applied Ecology, 24(2): 319-325.

Huang Congde, Zhang Jian, Yang Wanqing, et al. 2008. Study on carbon storage dynamics in forest vegetation in Sichuan and Chongqing. Journal of Ecology, 28(3): 966-975.

Huang Congde, Zhang Jian, Yang Wanqing, et al. 2009. The spatial distribution characteristics of the carbon storage in forest vegetations in Sichuan. Journal of Ecology, 29(9): 5115-5121.

IPCC. 2004. Good Practice Guidance for Land Use, Land-Use Change and Forestry [EB /OL].(2004-05-01) [2010-12-01]. http: //www. Ipcc-nggip. iges. or. jp /public/gpglulucf/gpgluluc.f.html.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventory [EB/OL].(2006-12-15)[2010-12-01].http: //www. Ipcc-nggip. iges.or.Jp/public/2006gl/index.html

Lan Zhenjiang, Cai Hongxia and Zeng Tao, et al. 2004. Biomass distribution of the major plant communities in Jiuzhaigao Valley, Sichuan. Chinese Journal of Applied and Environmental Biology, 10(3): 299-306.

Liu, Guohua, Fu Bojie and Fang Jingyun 2002. Carbon dynamics of Chinese forests and its contribution to global carbon balance. Journal of Ecology, 20(5): 733-740.

Liu, Guohua, Fu Bojie and Fang Jingyun 2000. Carbon dynamics of Chinese forests and its contribution to global carbon balance. Journal of Ecology, 20(5): 7333-7401.

Liu, Jiyuan and Yue Tianxiang 2006. Comprehensive evaluation of the ecosystem in west China. Beijing: Meteorological Press.

Olson, J. S., Watts, J. A. and Allison, L. J. 1983. Carbon in Live vegetation of Major World Ecosystems. Report ORNL-58620, OakRidge National Laboratory, Oak Ridge, Tenn, 15-25.

Sabine, C.L., Heimann, M., Artaxo, P. et al. Current status and past trends of the global carbon cycle/ / Field C B, Raupach MR, MacKenzie SH, eds. The Global Carbon Cycle: Integrating Humans, Climate and the Natural World.

Turner, D.P., Koerper, G.J. and Harmon, M.E. et al. 1995. A carbon budget for forests of the conterminous United States. Ecological Applications, 5: 421-436.

Wang Xiaoke, Feng Zongwei and Ouyang Zhiyun, 2001. Vegetation carbon storage and density of forest ecosystems in China. Chinese Journal of Applied Ecology, 12(1): 13-16.

Wang Shujun, Guan Dongsheng and Ni, Xia 2008. The temporal-spatial evolution and heterogeneity of forest carbon in Guangzhou. Journal of Environmental Sciences, 28(4): 778-785.

Wang Ming, Li Guicai and Zhong Guoqing, et al. 2010. Regional-scale analysis of the estimation method of carbon storage in the forest ecosystem. Forest Resource Management, 2: 107-112.

Xu Shaojun, Zeng Bo, Su Xiaolei, et al. 2012. Spatial distribution of vegetation in Tianmu Mountain Nature Reserve based on RS and GIS data. Journal of Ecology, 32 (7): 2174-2184.

Zhao Ming and Zhou Guangsheng 2004. Vegetation carbon storage in the Chinese forest ecosystem and the influential factors. Chinese Geographical Science, 24(1): 50-54.

Zhang Ping 2009. Carbon Storage of Forests in Beijing. Beijing: Doctoral Dissertation of Beijing Forestry University.

Zhang Jianguo, Fan Jianrong, et al. 2004. Spatiotemporal distribution characteristics of rainfall erosivity in Chongqing. Research of Soil and Water Conservation, (01): 56-59.

Zhang Liang, Lin Wenhuan, Wang Zheng, et al. 2010. The spatial distribution pattern of the carbon storage in the forest vegetation in Guangdong. Ecology and Environmental Sciences, 19(6): 1295-1299.

Zhang Xinshi and Zhang Dian'an 1995. China's setting and research on the global changing sample zone. Quaternary Sciences, (1): 43-52.

Zhou Yurong, Yu, Zhenliang and Zhao Shidong 2000. Carbon storage and budget of major forest ecosystems in China. Journal of Plant Ecology, 24(5): 518-522.