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# Spatial Pattern of Carbon Storage in the Drawdown Area of the Three Gorges Reservoir*

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**Abstract**: The spatial patterns of carbon storage were analyzed based on GIS and the natural environments in the drawdown area of the Three Gorges Reservoir (TGR). The results showed that carbon storage in the drawdown area was 514 862.3 tC and the area is gradually playing a role as a regional carbon sink. Carbon storage changes along the elevation grade, with 160 ~ 170 m above mean sea level having the largest carbon storage at 229 367.46 tC and other elevations following in the order: 160 ~ 170 m>150 ~ 160 m>170 ~ 175 m >145 ~ 150 m. Carbon storage was zero in areas with greater land slopes (>25°) due to water erosion and exposed bedrock leading to sparse growth of vegetation. In different slope zones, carbon storage was in the sequence: 5° ~ 15°>0° ~ 5°>15° ~ 25°. On the whole, due to the regulation and operation modes of TGR the drawdown zone had luxuriant vegetation in summer, which had uptake and accumulation of large carbon and had big carbon sequestration potential. Under these conditions, the distribution of carbon storage along the elevation grade and the slope grade in drawdown area of TGR are deeply affected by the soil, climate, human impacts and others.

**Key words**: carbon storage; spatial pattern; drawdown area; Three Gorges Reservoir

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The drawdown area of the Three Gorges Reservoir (hereinafter referred to as TGR) is an important part of the TGR ecosystem, performing the most active biogeochemical processes in the TGR[1]. Therefore the TGR drawdown area has become a topic of great interest in carbon cycle research. After impoundment of the TGR to a height of 156 m in 2006, the drawdown area has gradually developed, drawing the interest of many domestic and foreign scholars who have studied aspects such as floristics, biocoenosis structure and biodiversity [2-5]. Several studies have reported that the drawdown area is mainly covered with herbaceous plants during the exposed period in the summer, and features a high degree of cover and relatively few plant species [6-7].

Vegetation is a key biological factor in the process of ecological succession. During the vegetation succession process, carbon capture and storage constantly changes [8]. Currently, a considerable number of reports on the carbon cycle and low-carbon economic development in TGR have been published. Jia and others analyzed the characteristics of soil carbon under different vegetation covers in the TGR Area[9]. Wang and others examined the carbon storage of the forest ecosystem in the TGR Area [10]. Yuan and others conducted scientific exploration into carbon emissions from wetlands in the TGR drawdown area [1]. Yet no systematic study on vegetation carbon storage of the ecosystem in the TGR drawdown area has been reported. In this study we have therefore applied a joint research method of field survey results and literature review to evaluate

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vegetation carbon storage of the ecosystem in the TGR drawdown area, and its spatial distribution characteristics, in order to assess the potential of carbon pools in the TGR and provide a scientific basis for research and development of management strategies of the carbon sink of the TGR ecosystem.

# 1 Methods

## 1.1 Data source

With ArcGIS 9.0, 145 ~ 200 m contour lines were extracted from a 1 : 10 000 contour map of the TGR, and a 3D module was then applied to generate the DEM model. In this way, we obtained areas of different elevation grades of the drawdown area, which were used in further analysis to get the slope distribution. A hydrological analysis module was applied to calculate compositions of the drawdown area of the main tributaries in the TGR.

## 1.2 Carbon storage

Different vegetation types have differing carbon densities, and the carbon density of even the same vegetation type can vary in different regions. In this paper, the objective intention is to report research into the spatial pattern and horizontal distribution of carbon storage in the drawdown area of the TGR. To achieve this we refer to the findings of Wang and others in estimating the biomass in the drawdown area [11]. They found that at heights between 145 m and 150 m above mean sea level the average above-ground biomass was 0.39 $kg/m^2$; between 150 m and 160 m the value was 0.51 $kg/m^2$; between 160 m and 170 m the value was 0.79 $kg/m^2$; and between 170 m and 175 m the average above-ground biomass was 0.61 $kg/m^2$. Previous studies have demonstrated that during the exposed period the drawdown area is mainly covered by herbaceous plants. In accordance with a grassland ecosystem selected for comparison, the underground biomass can be calculated to be 4.42 times that of the above-ground biomass [12]. According to the practice of Fang and others. [13], we adopted 0.45 in converting herbaceous biomass (g) to carbon (gC). Due to the lack of vegetation biomass data for different slopes, the average above-ground biomass in the drawdown area of the TGR was adopted (the total biomass is 469 103.8/348.92 = 1 344.4 $t/km^2$).

Based on the operational characteristics of the TGR with respect to scheduling changes in water-level, the drawdown area was divided into four elevation classes, namely, the lower part of 145 ~ 150 m, the middle lower part of 150 ~ 160 m, the middle upper part of 160 ~ 170 m and the upper part of 170 ~ 175 m. Carbon storage in each of these elevation classes was calculated. With reference to the official land utilization classes for different slopes, as well as the actual condition of the TGR, the drawdown area was also divided into four slope classes, namely, gentle slope (<5°), slope (5° ~ 15°), steep slope (15° ~ 25°) and very steep slope (>25°). Carbon storage in each slope class was similarly calculated.

# 2 Results and Analysis

## 2.1 The distribution of carbon storage in the drawdown area of TGR

In Tab. 1 it can be seen that the calculated carbon storage of the drawdown area of the TGR is 514 862.3 tC, of which that in Chongqing accounts for 451 930.3 tC, that in Hubei 62 932.1 tC, the Yangtze River part 2 074.32.2 tC, and that in tributaries 307 430.0 tC. The calculated carbon storage of the drawdown areas in the tributaries constitutes 59.71% of the total carbon storage, which is related in Tab.1 with the spatial location, elevation, slope, and human interference of the various TGR tributaries.

Tab. 1 The distribution of carbon storage in the drawdown area of TGR

| Zone | Drawdown area/$km^2$ | Above-ground carbon storage/tC | Below-ground carbon storage/tC | Total carbon storage /tC | Percent/% |
|---|---|---|---|---|---|
| Yangtze River | 140.58 | 38 271.6 | 169 160.6 | 207 432.2 | 40.29 |
| Tributary | 208.35 | 56 721.4 | 250 708.6 | 307 430.0 | 59.71 |
| Part of Chongqing | 306.28 | 83 382.0 | 368 548.3 | 451 930.3 | 87.78 |
| Part of Hubei Province | 42.65 | 11 611.1 | 51 321.0 | 62 932.1 | 12.22 |
| Total | 348.93 | 94 993.1 | 419 869.3 | 51 4862.3 | 100 |

### 2.2 The distribution of carbon storage along the elevation gradient in the drawdown area of TGR

Calculated carbon storage in the four elevation grades in the drawdown area of the TGR is presented in Tab. 2. The data reveal that carbon storage in the various elevation grades varies remarkably, although the changes in the above-ground parts, below-ground parts and total carbon are generally consistent and follow in the order 160 ~ 170 m > 150 ~ 160 m > 170 ~ 175 m > 145 ~ 150 m.

### 2.3 Distribution of carbon storage along the slope gradient in the drawdown area of the TGR

Carbon storage of four slope grades in the drawdown area of the TGR is presented in Tab. 3. As seen in Tab. 3, carbon storage of different slopes varies significantly but the variations of the above-ground part, underground part and total carbon are generally consistent and in the sequence 5° ~ 15° > 0° ~ 5° > 15° ~ 25°. Field investigation revealed that areas with slopes over 25° are mainly distributed in the canyon reaches of the Yangtze River and its tributaries. These river reaches are barely covered with vegetation and bedrock is generally exposed. Hence, above-ground and underground stored carbon in these areas is rare. In light of this, carbon storage in areas with slopes over 25° is defaulted as zero and not considered in the model.

Tab. 2 The distribution of carbon storage along the elevation gradient in the drawdown area of TGR

| Elevation/m | 145 ~ 150 | 150 ~ 160 | 160 ~ 170 | 170 ~ 175 | 145 ~ 175 |
|---|---|---|---|---|---|
| Area/$km^2$ | 55.83 | 108.93 | 119.03 | 65.13 | 348.92 |
| Above-ground carbon storage /tC | 9 799.92 | 24 999.44 | 42 318.72 | 17 875.44 | 94 993.52 |
| Below-ground carbon storage /tC | 43 315.65 | 110 497.50 | 187 048.74 | 79 009.45 | 419 871.34 |
| Total carbon storage/tC | 53 115.57 | 135 496.94 | 22 9367.46 | 96 884.88 | 514 864.85 |

Tab. 3 The distribution of carbon storage along the slope gradient in the drawdown area of TGR

| | Slope | | | | Total |
|---|---|---|---|---|---|
| | 0° ~ 5° | 5° ~ 15° | 15° ~ 25° | >25° | |
| Area/$km^2$ | 26.54 | 190.76 | 80.74 | 50.88 | 348.92 |
| Above-ground carbon storage/tC | 7 225.515 | 51 934.41 | 21 981.47 | 0 | 81 141.39 |
| Below-ground carbon storage/tC | 31 936.78 | 229 550.1 | 97 158.08 | 0 | 358 644.9 |
| Total carbon storage /tC | 39 162.29 | 281 484.5 | 119 139.5 | 0 | 439 786.3 |

## 3 Conclusion and Discussion

The unique regulation method of the TGR enables the extensive drawdown area to absorb and store carbon in the summer. Thus a large amount of stored carbon is found in this area. Studies show that the carbon stored in the drawdown area rises to about 514 862.3 tC, of which the above-ground part accounts for 94 993.1 tC and the underground part accounts for 419 869.3 tC. The drawdown area occupies 60 % of the total TGR area but contributes only 18 % of forest carbon storage from the aspect of elevation and 15 % from the aspect of slope [10]. This indicates that the drawdown area has notable potential for carbon storage, based on its capacity for $CO_2$ absorption and the resultant accumulation of biological material by vegetative growth during the exposed period in the summer, thanks to the operation strategy of the TGR, namely, "clear water impounding and muddy flow releasing".

Many studies have demonstrated that the vegetation distribution and amount in the drawdown area are directly related to various influencing factors, such as soil environments, climates, agrotypes, moisture status, nutrient status and human interference before and after impoundment [14]. Due to the features of TGR operation, exposure of different parts of the drawdown area happens in different seasons and periods. Specifically, differences can be found in the inundating time and extent of the drawdown area at different elevations. The same is true of timing of vegetative growth, development, and impoundment of biocoenoses, which jointly leads to the varying carbon storage of the above-ground parts of plants (as shown in Tab. 2) [15-16]. Wang and others [11] pointed out that vegetation biomass in the TGR can be described by a parabolic curve. In the middle of the drawdown area, the biomass was the highest, forming the largest amount of carbon capture and storage [11]. Distribution patterns and features of above-ground and underground carbon storage in the drawdown area change considerably. Regions with elevations between 160 m and 170 m in the middle of the drawdown area have the highest storage rates. Compared with this grade, the grades below it have longer impoundment times and less growth. Biomass in the 160 ~ 170 m zone is thus more than in the two lower grades combined. This can be understood as follows. Firstly, areas at lower elevations are subjected to more severe fluctuations of water level that lead to the flushing away of organic matter into rivers, leading to reduced underground carbon storage and restricted carbon sequestration capability. Secondly, due to the longer impoundment time, and therefore shorter exposure period and growing season, herbaceous plants dominate the area during the year, leading to limited biomass and lower carbon storage [5,17]. Compared with the upper part lying between 170 m and 175 m, the area lying between 160 m and 170 m is gradually developing into new wetlands, which are mainly covered by wetland plants. The uppermost parts of the drawdown area (170 ~ 175 m) are more similar to the terrestrial environment, which has less biomass live weight and carbon storage per unit area than wetland ecosystems, according to various studies [18].

Slope directly influences the size and morphology of the exposed lands in the drawdown area, and also determines the scale of soil erosion and sedimentation, geological disasters, bank stability, water status, nutrient status, seed banks and other variables [19-20]. Therefore, slopes influence ecological characteristics of vegetation in the drawdown area, such as plant species, biocoenosis structure and spatial distribution. As a result both the above-ground and underground biomass in the drawdown area is affected, leading to varying carbon storage in different slope zones. According to findings from field surveys, after the exposure of the drawdown area vegetation is mainly and extensively distributed in gentle slope areas of 5° to 15°. In field surveys conducted before impoundment it was found that much of the area consisted of paddy fields and dry lands. In many places traditional clay dikes had been constructed to form small wetland pond systems, which held large biomass and high potentials for carbon storage [21].

Although in this study we have estimated vegetative carbon storage and its spatial distribution in the drawdown area of the TGR, our findings inevitably have certain limitations and errors. Regarding the total amount of carbon storage of different elevation grades and slopes there is an error of about ±0.1 million tC, which can be attributed to the lack of available specific vegetation biomass data for different slopes, for which we compensated by adopting the average biomass in the drawdown area. Another limitation is the default zero value for soil-covered reservoir banks having slopes above 25°. These areas account for about 1/7 of the total drawdown area, and present considerable potential in the natural recovery process of the vegetation in the drawdown area. The data applied to the model did not include the identification of specific vegetation types but adopted the vegetation area data of the entire drawdown area. The calculation of carbon storage was therefore conducted with reference to the average biomass in the TGR, thus presenting a source of error.

Further studies will highlight characteristics of vegetation responses to fluctuation of the water table at different elevations and slopes, so as to permit more detailed analysis. In this way, more precise management strategies of the carbon sink in the drawdown area having higher operability can be developed.

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