Study on spatial distribution and carbon balance of major carbon sources and carbon sinks in Nanjing

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Abstract. In order to explore the current situation of carbon balance in Nanjing, with the above designated size industrial enterprises, 4993 residential communities and green areas as research objects, ArcGIS and ENVI software are used to spatially analyze the main carbon sources and carbon sinks in Nanjing. The calculation formulas of carbon sources and carbon sinks are used to calculate the carbon emissions and absorption of various districts in Nanjing, and compare the carbon balance of each district. The results show that: (1) the industrial and residential communities in Nanjing show the characteristics of agglomeration distribution; (2) the green land is mainly concentrated in the outskirts, which is mostly based on cultivated land; (3) the carbon balance coefficient of Nanjing city is 68, and all regions are in the carbon imbalance state, in which Qinhuai District is the most severe. Finally, from the planning point of view, suggestions for the construction of Nanjing City to improve the ecological environment of Nanjing and promote green sustainable development are proposed.

1. Introduction
In recent years, with the continuous development of urbanization, the consumption of fossil fuels in cities has increased sharply, resulting in a gradual increase in carbon dioxide content in the air, breaking the carbon balance of the ecosystem. At the same time, Yan Zhang et al [1] pointed out that 75% of global carbon dioxide emissions came from cities. Therefore, evaluating the urban carbon balance has an important role. Based on the spatial distribution of carbon emissions, carbon sinks and industrial and transportation data in Nanjing, this study measures the carbon emissions and carbon absorption of Nanjing, analyzes its carbon balance, and proposes corresponding planning proposals.

2. Spatial distribution characteristics of main carbon sources in Nanjing
Since the industrial revolution, industrial energy consumption has been the main source of carbon emissions in cities. In the process of rapid advancement of urbanization, due to the optimization and adjustment of industrial structure and the improvement of people's living standards, the proportion of carbon emissions in living is rising. At present, Chinese residents' energy consumption accounts for the proportion of terminal energy consumption, second only to the industrial sector, and its carbon emissions pose a more significant environmental threat [2]. Therefore, in this study, we select two aspects of industrial and residential life with carbon emissions ranking first and second.

2.1. Spatial distribution of residential areas
The nuclear density analysis map of residential areas in Nanjing directly shows the high-level distribution of communities in the downtown and the multi-core distribution of them in other areas. In
the Figure 1, different colors reflect the number of residential areas existed in different areas, and the darkest one indicates that the nuclear density value of the residential area is the highest, while the color white represents the lowest level. Except for the nuclear density value of the residential area in the central city, the value of the residential area from the downtown is decreasing continuously.

2.2. Spatial distribution of Industrial

The nuclear density analysis chart of industrial enterprises above designated size in Nanjing more intuitively shows that those industrial organizations are concentrated and developed along the Yangtze River. The number of central urban areas is small and scattered, and the distribution of other districts is large and concentrated, just as the Figure 2 shows. Except for Pudong District, Liuhe District and Qixia District, some of the main concentration centers of industrial enterprises above designated size in the Yangtze River system have large nuclear density values. Due to the development of industrial parks, there are a large number of industrial enterprises above the scale in the central area of Jiangning District.

![Figure 1. Nuclear density analysis of residential quarters in Nanjing.](image1)

![Figure 2. Nuclear density analysis of industrial enterprises above designated size in Nanjing.](image2)

3. Spatial distribution characteristics of carbon sinks in Nanjing

Carbon sink means carbon absorption. According to the carbon absorption capacity of various carbon sinks, it is mainly divided into green space and water carbon absorption. The researches on carbon sink at home and abroad mainly focus on urban green space. The land-use satellite imagery of Nanjing in 2017 is supervised classification through the ENVI software. In addition, the classification criteria is: LUCC (Land-Use and Land-Cover Change) classification system, which is divided into five categories: arable land, woodland, grassland, water area, rural construction land and unused land.

It can be seen from the spatial distribution map of the classification of green space in Nanjing that the green space in Nanjing mainly exists in the form of arable land, such as paddy fields and dry land, followed by woodland and grassland; the proportion of construction land in the main urban area is relatively high. The amount of various types of green space is small, which leads to a shortage of carbon sinks, while the Jiangning district, Liuhe district and Qixia district, are also distributed with more concentrated construction land. Whereas there are also a large number of green space in the
region. In addition, the area where the Yangtze River flows, the water area of Gaochun district and Lishui district is the largest. At the same time, it shows that the built-up area of Nanjing covers almost the entire area, and there are few unutilized land.

Figure 3. Spatial distribution of green space in Nanjing.

4. Carbon and oxygen balance analysis of each district

4.1. Measurement of carbon sinks

The same type of ecological land has different carbon sequestration capacity. Drawing on the research of other scholars, the calculation formula of urban internal carbon sink and the carbon emission coefficient of various types of ecological land were obtained [3], as the Table 1 shows.

The formula for calculating the carbon sink is as follows:

\[ C_f = A \times E_i \]  \hspace{1cm} (1)

Among them, \( C_f \) is the amount of carbon sink, \( A \) is the area of green land, \( E_i \) is the carbon absorption coefficient of each type of land.

| Land use types | woodland | arable land | grassland | Waters |
|----------------|----------|-------------|-----------|--------|
| Carbon fixation | 9.03     | 6.83        | 3.44      | 4.5    |

From the known green space carbon-sink factors and the area of various types of green spaces in different regions of Nanjing, the formula can calculate the carbon sinks (biomass, carbon fixation, oxygen release and standard ecological land) in various districts of Nanjing, as shown in the following figure:
Figure 4. The amount of carbon sinks in various districts of Nanjing.

From the diagram, GaoChun district, Jiangning district, Lishui district, Pukou district and Luhe district due to its own large land area, the green space is bigger, correspondingly their various ecological factors is more outstanding, especially in Jiangning district, Lishui district, Luhe district, the three areas’ carbon sequestration are more than 5000000 tons per year. However, the downtown areas (Jianye district, Qinhuai district, Xuanwu district, Gulou district) arise the situation about shortage of carbon sink. In addition, the carbon sink in Qixia district is medium, and the results confirm the previous conclusion about the spatial distribution of carbon sink.

4.2. Calculation of carbon emission

4.2.1. Calculation of residential carbon emissions. Jiangning district, Gulou district, Pukou district and Qinhuai district have a large amount of living carbon emissions, which are all more than 30,000 tons, accounting for 53.00% of the whole living carbon emissions of Nanjing residential area, of which Jiangning district has the largest figure, reaching 45,048 tons. The living carbon emission of Lishui district and Gaochun district is relatively small, both less than 10000 tons, and Gaochun district is the least, only 4578 tons.

4.2.2. Calculation of industrial carbon emissions. Jiangning district, Qixia district and Luhe district have bigger figure for industrial carbon emissions, and they are all above 30 million tons, of which Jiangning district has the largest figure, reaching 66,065,065 tons, accounting for 30.08% of the total industrial carbon emissions in Nanjing in 2017. The amount of industrial carbon emissions in Xuanwu district and Jianye district are relatively small and the total carbon emissions in Jianye district is the least, only 159,521 tons.

4.3. Comparative analysis of carbon balance in each region

By consulting literature, the formula for calculating the carbon balance coefficient [3] is as follows:

$$B = \frac{C_E}{C_F}$$

(2)

Where, $B$ is the carbon balance coefficient, $C_E$ is the annual carbon dioxide emission, and $C_F$ is the annual fixed amount of carbon dioxide. When B is less than or equal to 1, it indicates that the carbon dioxide emission is less than the amount of carbon dioxide absorption, which can be completely absorbed by ecological land and is conducive to the sustainable development of the region. On the contrary, these carbon emissions cannot be completely absorbed.

From the calculation results, as the Table 2 shows, the carbon emission scale of Nanjing is 221600618 tons, the carbon absorption scale is 3261325 tons, and the carbon balance coefficient is 68, so the carbon imbalance is very apparent. From the perspective of each district, the carbon balance
coefficient of Qinhuai district, Gulou district, Qixia district and Yuhuatai district are all over 100, with a serious carbon imbalance. The carbon balance coefficient of Qinhuai district even reaches 1564, seriously affecting the sustainable development of the ecosystem. On the other hand, as a result, Jianye district and Xuanwu district with more green spaces and industrial energy is less for using, therefore the carbon balance coefficient is small and the carbon imbalance in the region is not too serious.

| Name           | Total carbon emissions/ton | Total carbon absorption/ton | carbon balance coefficient |
|----------------|-----------------------------|-----------------------------|---------------------------|
| Qinhuai district | 3419890                     | 2187                        | 1564                      |
| Gulou district  | 3377826                     | 4488                        | 753                       |
| Qixia district  | 41645762                    | 139671                      | 298                       |
| Yuhuatai district | 3992364                    | 38882                       | 103                       |
| Jiangning district | 66612113                  | 791725                      | 84                        |
| Pukou district  | 29367818                    | 469712                      | 63                        |
| Gaochun district | 18375936                   | 409088                      | 45                        |
| Luhe district   | 30525532                    | 753113                      | 41                        |
| Lishui district | 23717870                    | 607528                      | 39                        |
| Xuanwu district | 382850                      | 27800                       | 14                        |
| Jianye district | 182657                      | 17131                       | 11                        |
| Nanjing         | 221600618                   | 3261325                     | 68                        |

5. Conclusions and suggestions
Because the traffic and other carbon source of Nanjing are not taken into account, the total carbon emission in 2017 is smaller than the actual. The practical carbon balance coefficients are larger than the calculated ones, and carbon imbalance phenomenon is more obvious. Moreover, following suggestions are proposed:

(1) Reasonable layout of carbon-emission controlling area and carbon sink functional area to achieve regional carbon balance. When planning in the scale of the whole city, it is emphasized that the dense industrial and residential areas should be divided into carbon emission control areas to strengthen the control of regional high carbon emission. The cultivated land and urban green land are defined as functional areas of carbon sink to strengthen the ecological effect of regional carbon sink. Control areas and functional areas should be evenly distributed to achieve a dynamic balance between regional carbon emission and absorption.

(2) Make the requirements of "green line" of the city clearer and attach importance to the functional repair of carbon sink system. According to the planning requests of urban ecological control line, the carbon sinks such as forest and urban green space should be taken as the key objects of carbon sink function restoration. What’s more, the woodland area should be appropriately improved to pay attention to the improvement of the carbon sink carrying capacity of urban green space, as to optimize the carbon sink system structure.

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References
[1] Yan, Z., Qiong, W., Fath, B.D. (2018) Review of spatial analysis of urban carbon metabolism. J. Ecological Modelling, 371.
[2] Yang, L., Hao, J., Ai, D., Lei, S., Shuang, W. (2011) Adjustment of Land Use Structure Based on
Regional Carbon Balance: A Case Study in Quzhou County, Hebei Province. J. Resources Science, 33(12):2293-2301.

[3] Zeng, X. (2015) Study on the Ecological Land Use Demand of Jitai Corridor Based on Carbon and Oxygen Balance Analysis. J. Jiangxi Building Materials, 24:65-67.