7th Intercontinental Geoinformation Days

igd.mersin.edu.tr

LULC change and CO_2 emissions in Shangai 2000-2020

Jianwen Zheng [1], Yishao Shi *[1], Katabarwa Murenzi Gilbert [1]

[1]Tongji University, College of Surveying and Geo-Informatics, Shanghai 200092, China

Keywords
Shanghai
Built-up
Land use change
Carbon emissions
Natural ecosystems

Abstract

The absorption and release of carbon dioxide by different types of land cover, with activities like deforestation or urbanization releasing CO^2, while afforestation or natural ecosystems act as carbon sinks, affecting the overall carbon balance in the atmosphere. This paper analyzes the spatial and temporal characteristics of land use and carbon emissions in Shanghai from 2000 to 2020 using the land use transfer matrix, the carbon emission estimation model, and the standardized error ellipse method. The results indicate that the total carbon emissions from land use in Shanghai have exhibited an upward trend from 2000 to 2020, with an average annual growth rate of 3.055%. The expansion of construction land has been identified as the main source of carbon emissions, while forests serve as the primary carbon sink. Spatial analysis reveals that areas with high-intensity carbon emissions are mainly concentrated in Pudong New Area, while regions with moderate carbon emissions are in Jiading and Minhang districts, gradually expanding towards the northeast. Based on these findings, it is recommended that carbon emission policies consider the characteristics of regional differences, control land use intensity appropriately, and guide low-carbon and efficient land utilization as the primary direction to achieve Shanghai's energy low-carbon transformation.

1. Introduction

With the severe global climate change situation, carbon reduction has become an important issue of common concern for countries worldwide. Land use change is one of the crucial factors influencing carbon emissions and carbon sequestration, indirectly affecting global climate change and regional ecological environments(Bryan et al., 2018; Jin et al., 2020). In response to climate change, China proposed the "dual carbon" goals in 2020(CAI et al., 2022). Emphasizing optimizing land use structure and improving green, low-carbon, and circular development in terms of carbon emissions reduction and carbon sinks. Therefore, conducting regional studies on carbon emissions from the land use perspective and analyzing the effects of different land use types within a region by constructing a scientifically sound accounting system for land use carbon emissions can contribute to formulating regional low-carbon spatial planning and carbon reduction decisions.

Many domestic scholars have analysed the spatial and temporal characteristics and trends of land use change and carbon emissions, carbon emission efficiency, and carbon reduction. (Pan et al., 2022; Wang et al., 2023; Xiao et al., 2022; Zhang et al., 2023; Zhu et al., 2022) Investigated the link between land use change and carbon emissions using a block approach at the national scale. Also, they explored the spatial correlation of carbon emissions at national and provincial levels by combining a model for assessing the hidden form of land use. Furthermore, they researched carbon emission efficiency, emission intensity, and spatial characteristics of different land use types at the provincial scale.

However, existing domestic literature mainly focuses on national macro-level, regional-level, and provincial-level analyses, with limited research on the relationship between land use and carbon emissions at the city level. Therefore, based on the land use changes in Shanghai from 2000 to 2020, this study investigates the spatiotemporal characteristics of carbon emissions among different regions, aiming to provide a more accurate and comprehensive scientific basis for urban planning and carbon reduction decision-making in Shanghai. Furthermore, it can be a reference and inspiration for carbon emission policy research in other cities and regions.

*Corresponding Authors

(hata2020@tongji.edu.cn) https://orcid.org/0009-0005-4789-275X
*(shiyishao@tongji.edu.cn)https://orcid.org/0000-0002-0048-6958
(zhengjianwen@tongji.edu.cn) https://orcid.org/0009-0009-3897-1025

Cite this study

Zheng, J., Shi, Y., & Gilbert, K. M. (2023). LULC change and CO_2 emissions in Shangai 2000-2020. Intercontinental Geoinformation Days (IGD), 7, 53-56, Peshawar, Pakistan

2. Method

2.1. Land use type transition matrix

The land use type transition matrix is a way to quantitatively express the inflow and outflow status of land use types in each parcel by creating a two-dimensional matrix. Its formula is as follows.

$$S_{ij} = \begin{vmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{vmatrix}$$

Note: S_{ij} represents the total area of land type changes in Shanghai from 2010 to 2020. Here, i and j represent different land classes, and n represents the number of land use types.

2.2. Carbon emission estimation model

Carbon emissions from land use are composed of direct and indirect carbon emissions. Since the carbon emissions of cultivated land, garden land, forest land, grassland, water area and unused land remain stable for a long time, the direct carbon emission coefficient method is adopted to calculate their carbon emissions, and the calculation formula is as follows:

$$E_p = \sum_{i=1}^{n} e_i = \sum_{i=1}^{n} S_i \cdot \delta_i$$

Note: E_p represents the total carbon emissions; e_i represents the carbon emissions of each land use type; S_i represents the area of each land use type; δ_i represents the carbon emission coefficient of each land use type. Based on existing research, the carbon emission (absorption) coefficients for cultivated land, forest land, grassland, water areas, and unused land are 0.442, -0.644, -0.021, -0.298, and -0.005 tons per hectare ($t \cdot hm^{-2}$), respectively.

The carbon emission of construction land mainly comes from the energy consumed by human activities on impervious water areas. Since the construction land area cannot express the real carbon emissions well, the indirect carbon emission coefficient method is used to estimate the carbon emissions of construction land by calculating the consumption of various energy sources. The energy consumption data of each district in Shanghai is indirectly measured by the ratio of the district's GDP to the city's GDP. The types of energy involved in this study are shown in Table 2, and the calculation formula is as follows.

$$E_p = \sum_{i=1}^{n} a_i * b_i * c_i$$

Note: E_p represents the total carbon emissions from construction land; represents the consumption of various energy sources; represents the standard coal conversion coefficient for each energy source; represents the carbon emission coefficient for each energy source. The standard coal conversion coefficients and carbon emission coefficients for various energy sources can be found in Table 1.

Table 1. Standard coal conversion coefficient and carbon emission coefficient of energy

Energy Type	Raw Coal	Coke	Crude Oil	Gasoline
Standard Coal Conversion Coefficient(tce/t)	0.7143	0.9714	1.4286	1.4714
Carbon Emission Coefficient (tC/tce)	0.7559	0.855	0.5857	0.5538
Kerosene	Diesel	Fuel Oil	Natura l Gas	Electricity
1.4714	1.4571	1.4286	1.33	0.1229
0.5714	0.5921	0.6185	0.4483	0.733

2.3. Ellipse analysis of standard errors

By using the Standard Deviation Ellipse Analysis feature in ArcGIS Pro 3.0.1 software, an analysis was conducted on the spatial distribution of carbon emissions in different regions of Shanghai. The major and minor axes of the ellipse represent the shape variation of carbon emission distribution, while the area indicates the concentration or dispersion of carbon emissions. The centroid coordinates represent the trajectory of the center of gravity of carbon emissions.

3. Results

According to Fig. 1 (a) and (b), it can be observed that the area of cultivated land in Shanghai has the highest proportion, averaging around 50%. The area of construction land and water bodies follows it. From 2000 to 2020, the most significant changes in Shanghai's land area were observed in cultivated land and construction land. The cultivated land area declined from 2000 to 2015, while the construction land area exhibited a continuous upward trend.

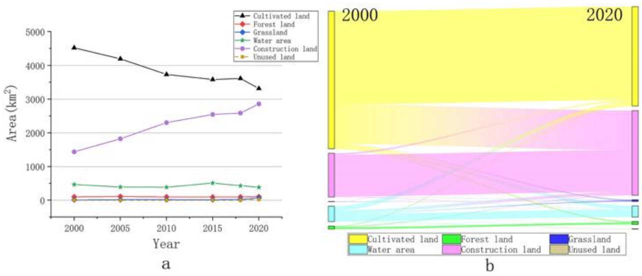

Figure 1. (a) Change of land use type area; (b) Land use transfer map

Between 2000 and 2020, the construction land area increased by 1419 km², with the highest growth rate of 98%. On the other hand, the area of cultivated land decreased by 1200 km², representing the highest decline rate of 26%. The areas of the remaining land types showed relatively stable changes.

According to Fig. 2 (a) and (b), the total carbon emissions in Shanghai have shown an increasing trend from 2000 to 2020. The carbon emissions have grown from 53.08 million tons in 2000 to 85.46 million tons in 2020, with an annual increase of 1.61 million tons. The growth trend can be divided into two phases: a rapid growth phase (2000-2010) with an increase of 64% and a slower phase (2010-2020) with a slightly reduced growth rate (the growth rate in 2020 was affected by the COVID-19 but still showed an overall increasing trend). From the perspective of the urban area (Hongkou, Huangpu, Jing'an, Putuo, Xuhui, Yangpu, Changning districts) and the suburban area (Minhang, Pudong New Area, Jiading, Jinshan, Qingpu, Songjiang districts), the carbon emissions in the urban area increased from 8.02 million tons in 2000 to 28.93 million tons in 2020, with an annual average increase of 1.05 million tons. On the other hand, the carbon emissions in the suburban area increased from 45.23 million tons in 2000 to 56.44 million tons in 2020, with an annual average increase of 0.57 million tons. From 2000 to 2020, the growth rate of carbon emissions in the urban area was higher than that in the suburban area. Still, the total carbon emissions in the suburban area have consistently exceeded those in the urban area.

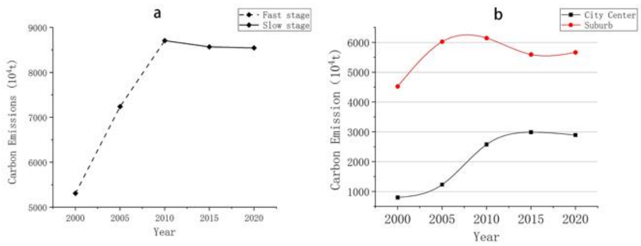

Figure 2. (a) Total carbon emissions of Shanghai; (b) Carbon emissions of urban and suburban areas of Shanghai

From 2000 to 2020, the total area of land use transfer in Shanghai was 1,850 km^2, accounting for 28% of the total land area of Shanghai. Generally, the land types that experienced more transfer out were arable land and water areas, with 1,466.866 km^2 and 268.119 km^2, respectively. The land type that experienced the most transfer was construction land, with an area of 1,422.017 km^2. The proportions of transfer in and out for forest land, grassland, and unused land were relatively low.

To visually demonstrate the spatial evolution of carbon emissions from land use in Shanghai from 2000 to 2020, this study standardized the data. It divided carbon emissions into four levels: slight, mild, moderate, and severe. As shown in Fig. 3, there are significant spatial differences in carbon emissions from land use in different periods in Shanghai. From 2000 to 2020, the heavy carbon emission zone expanded from the outer areas towards the inner areas.

Shanghai's severe carbon emission zone is mainly concentrated in the Pudong New Area. Pudong New Area, the special economic zone of Shanghai, is a highly active economic center. The region accommodates several industrial parks and bases that cater to diverse industries, including manufacturing, high-tech, and finance. However, it also houses energy-intensive and high-emission process industries. As a result, carbon emissions have rapidly increased from 23.77 million tons in 2000 to 29.5 million tons in 2020, and the emissions have remained consistently high.

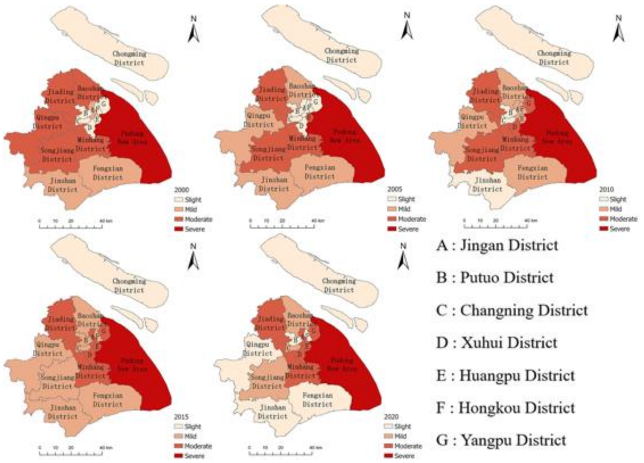

Figure 3. Spatial change of carbon emissions from land use in Shanghai from 2000 to 2020

The moderate carbon emission zone is mainly concentrated in Jiading District and Minhang District. In 2000, the carbon emissions in these districts accounted for 15% of the total emissions in Shanghai. In 2020, Jiading District and Minhang District had a total carbon emission of 11.29 million tons, accounting for 13.2% of the city's total. From 2000 to 2020, Songjiang District and Baoshan District transitioned from the moderate zone to the mild zone, and Qingpu District transitioned from the moderate zone to the mild zone and then to the slight zone. Jing'an District, Xuhui District, Huangpu District, and Yangpu District shifted from slight to moderate zones. As core commercial and bustling areas of the city, Jing'an District, Xuhui District, Huangpu District, and Yangpu District experience a significant population influx and transportation activities. They are also home to many energy-consuming industries, such as commerce, finance, and services, contributing to the increase in carbon emissions.

The mild and slight carbon emission zones are mainly concentrated in Putuo District, Baoshan District, Jinshan District, Fengxian District, and Chongming District. In 2000, the total carbon emissions in the slight zone were 7.56 million tons, accounting for 14.2% of the city's total. In 2020, the total carbon emissions in the slight zone were 13.52 million tons, accounting for 15% of the city's total. Chongming District, known for its ecological island tourism, has consistently remained in the slight zone. These areas have abundant forest land and superior ecological environments, reducing carbon emissions.

From the perspective of spatial differentiation characteristics in Fig. 4, carbon emissions in Shanghai are generally dominated by a northwest-southeast direction, and the spatial distribution range tends to contract from the outer areas to the inner areas. Looking at the distribution center, from 2000 to 2010, the spatial distribution center of carbon emissions in the city shifted from the internal center of Pudong New Area to the northwest boundary of Pudong New Area, with a displacement of 16 km. From 2010 to 2020, the distribution center moved 2.8 km northward to Huangpu District, then shifted 1.2 km southeast, and finally returned to the southwest boundary of Pudong New Area.

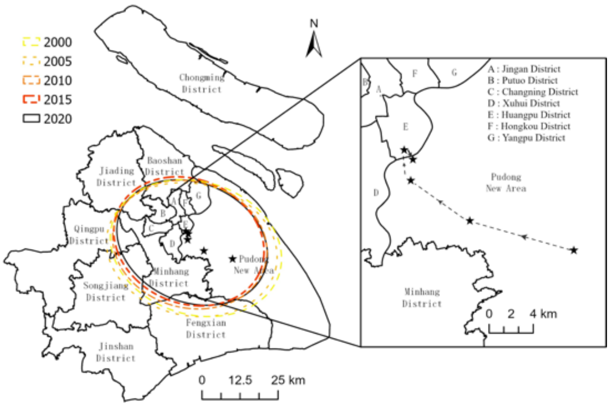

Figure 4. Ellipse of the standard deviation of total carbon emission in Shanghai from 2000 to 2020

Regarding the differentiation shape, the ratio of the minor axis to the major axis of the standard error ellipse of carbon emissions spatial distribution in the city showed a decreasing trend followed by an increasing trend from 2000 to 2020. The city's carbon emissions distribution was generally flattened, gradually developing along the major axis (northwest-southeast direction) while relatively slowing down along the minor axis (northeast-southwest direction). From the direction of divergence, the azimuth of the quasi-differential ellipse of the spatial distribution of carbon emissions in the city has been decreasing from 107.11° in 2000 to 105.55° in 2010, indicating that the influence of the southeast-oriented region of Shanghai on the spatial pattern of carbon emissions in the city has strengthened. The azimuth has increased by 7.85° from 2010 to 2020, indicating that the northwest region on the province's spatial pattern of carbon emissions.

4. Discussion

The research results indicate that the annual average growth rate of carbon emissions from land use in Shanghai from 2000 to 2020 was 3.055%, indicating a relatively fast growth rate. Carbon sources showed an increasing trend, while carbon sinks exhibited only slight fluctuations. The composition of carbon sources was dominated by construction land, while the composition of carbon sinks was dominated by forest land. Regarding the spatial differentiation of carbon emissions from 2000 to 2020, the heavy carbon emission areas were mainly concentrated in Pudong New Area, while the moderate carbon emission areas were concentrated in Jiading and Minhang districts, showing an expansion from the outer areas to the inner areas trend. Regions with carbon emissions above the moderate level accounted for a significant proportion. The center of carbon emissions gradually moved in the northeast direction. The spatial distribution of carbon emissions showed a shrinking trend from the outer to the inner areas. The influence of the northwestern region on the total carbon emissions in the city strengthened over time.

5. Conclusion

In summary, the pattern of carbon emissions from land use in Shanghai is not optimistic. The municipal government needs to optimize further and adjust the land use structure, formulate practical low-carbon emission reduction policies in line with the actual situation of Shanghai, and realize the low-carbon and efficient, sustainable use of regional land resources. To promote the sustainable development of land use and guide the development and utilization of land use in the direction of low-carbon intensification, it is recommended that the region carry out the regulation of low-carbon land use. In urban areas, low-carbon land use and compound utilization can be realized by increasing urban greening, promoting sustainable transportation, optimizing building energy efficiency, developing low-carbon industries, strengthening land planning control and promoting circular economy development; suburban areas carry out industrial structure adjustment, develop new energy by taking advantage of their geographical conditions and technology, gradually eliminate backward industries with high energy consumption, heavy pollution and low production capacity, and strictly control land use types to construction land, and reduce the conversion of land use types with low emission intensity.

References

Bryan, B. A., Gao, L., Ye, Y., Sun, X., Connor, J. D., Crossman, N. D., Stafford-Smith, M., Wu, J., He, C., & Yu, D. (2018). China's response to a national land-system sustainability emergency. *Nature*, *559*(7713), 193–204.

Caı, R., Zhu, H., Li, W., Xiao, Y., & Liu, Z. (2022). Development path of energy science and technology under "dual carbon" goals: Perspective of multi-energy system integration. *Bulletin of Chinese Academy of Sciences (Chinese Version)*, *37*(4), 502–510.

Jin, G., Guo, B., & Deng, X. (2020). Is there a decoupling relationship between CO2 emission reduction and poverty alleviation in China? *Technological Forecasting and Social Change*, *151*, 119856.

Pan, L., Yu, J., & Lin, L. (2022). The temporal and spatial pattern evolution of land-use carbon emissions in China coastal regions and its response to green economic development. *Frontiers in Environmental Science*, *10*, 1018372.

Wang, H., He, Y., Shi, W., Zeng, W., & He, Y. (2023). Spatiotemporal spillover effect and efficiency of carbon emissions from land use in China. *Environment, Development and Sustainability*, 1–39.

Xiao, P., Zhang, Y., Qian, P., Lu, M., Yu, Z., Xu, J., Zhao, C., & Qian, H. (2022). Spatiotemporal Characteristics, Decoupling Effect and Driving Factors of Carbon Emission from Cultivated Land Utilization in Hubei Province. *International Journal of Environmental Research and Public Health*, *19*(15), 9326.

Zhang, X., Zhang, J., & Yang, C. (2023). Spatio-Temporal Evolution of Agricultural Carbon Emissions in China, 2000–2020. *Sustainability*, *15*(4), 3347.

Zhu, L., Xing, H., & Hou, D. (2022). Analysis of carbon emissions from land cover change from 2000 to 2020 in Shandong Province, China. *Scientific Reports*, *12*(1), 8021.