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Original Research Paper

# Evaluation of Environmental Purification Service for Urban Green Space in Nanjing

**Zhenshan Wang*, Shaoliang Zhang*†, Xuefei Wang** and Yongjun Yang***(***)**
*School of Environment Science and Spatial Informatics, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China
**College of Food Science and Technology, Nanjing Agricultural University, Nanjing, Jiangsu 210095, China
***Centre for Mined Land Rehabilitation, The University of Queensland, Queensland, Australia
†Corresponding author: Shaoliang Zhang

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## ABSTRACT

Urban environmental pollution intensifies with the acceleration of industrialization and urbanization. Urban green space plays an important role in improving the quality of urban environment. Statistical reports from 2002 to 2013 were analysed to estimate the environmental purification value of urban green space in Nanjing by using the production cost method and substituted expenses method. Results showed that the environmental purification value of urban green space from 2002 to 2013 increased from 0.212 billion to 0.354 billion RMB, showing an increase of 0.142 billion RMB and an annual average growth rate of 14% in the past 12 years. Carbon fixation and oxygen release of urban green space ecosystems are transferable in regional space; hence, these services can be performed by the natural ecosystems beyond the city. However, harmful gas absorption, dust detention and noise reduction of urban green space is not transferable in space and thus must be performed by the urban ecosystem. Therefore, aside from innovating technologies for pollution-reducing and pollution-controlling, increasing green space coverage, optimizing green plant distribution structure, and enhancing urban green space management must be executed to improve the urban ecological environment.

## INTRODUCTION

Urbanization and industrialization inevitably result in the production of wastewater, exhaust gas and waste residues. These wastes will not cause serious problems in the urban environment when produced within the tolerance of the urban ecosystem; otherwise, the urban ecosystem will be destroyed. Urban green space, an important component of urban ecosystems, plays an indispensable role in maintaining carbon-oxygen balance and improving the conditions of the urban environment. In addition to innovating technologies for pollution-reducing and pollution-controlling, strengthening the construction and increasing the ecological benefits of urban green space are important means to improve the urban environment, as well as effectively facilitate a sustainable urban development (Chiesura 2004).

The relationship between urban green space and urban thermal environment is currently a major research topic. For example, on the basis of the quantitative analysis of Landsat6 remote sensing data, surface temperature drops with the increase in the normalized differential vegetation index, as shown by studying the zone of rapid development in south Guang-zhou (Ke et al. 2010). This phenomenon is manifested in the differences in the mean surface temperature of various land use types. The mean surface temperature in decreasing order is as follows: industrial land > land for roads > commercial land > residential land > commonality construction land > other land > land for public facilities > green space > water area (Zhang et al. 2008), although the difference in surface temperature is not very obvious at night (Yan et al. 2015). Changes in green space area influence directly the range of urban heat island effect (Zhou et al. 2014). Using remote sensing and geographic information technologies, most urban green space plaques in the main urban area of Beijing can cool the surrounding buildings within approximately 100 meters. However, no significant correlation existed among the perimeter, area, and shape of green space plaque, as well as plant coverage and cooling amplitude of the surrounding buildings (Luan et al. 2014). Given that relieving the heat island effect is an effective measure to improve the urban ecological environment, urban green space plays an important role in improving the quality of life in the urban environment.

The ecosystem service value assessment, which is an effective method to measure the environmental benefit of urban green space, started from Costanza's quantitative evaluation of global ecosystem service value in 1997 and has become a major research topic in ecology, ecological economics, and other disciplines to date. The earliest ecosystem service value assessment in China was the economic value evaluation of the biodiversity of the Changbaishan Nature Reserve ecosystem in 1997. Existing evaluations mainly focus on forest and lake ecosystems. Some studies on the ecological benefits of urban green space, which mainly include carbon fixation and oxygen release, absorption of harmful gas, and noise reduction, among others, have been reported. The climate adjustment, cooling and entertainment functions of urban ecosystems in Europe were evaluated based on spatial data on urban-rural gradient (Larondelle et al. 2013). Studies have also found that reasonable landscaping in core cities will not always provide few ecological services (Heckert et al. 2012, Pearsall et al. 2014, Kim et al. 2015). Some researchers reported that urban areas covered with plants bring huge ecological benefits. Chinese researchers mainly evaluated the ecological benefits of urban green space, namely, Qingdao (Zhang et al. 2011), Nanchang (Hu & Fu 2011), and Linyi (Zhang et al. 2012), by using the evaluation method for the service value of other ecosystems (e.g., forest) but ignore the mechanism of the ecological benefits of urban green space.

An increasing number of studies on the urban green space layout have been conducted in the 21st century (Niemelä 2014). For instance, using geographical information systems and remote sensing technology, the variation law of urban green space gradient in Jinan was studied through walk forward analysis (Kong et al. 2006), and urban green space was reasonably distributed according to the variation law (Govindarajulu 2014). Therefore, buildings and green space must be reasonably arranged during urban planning to maintain sustainable urban development (Lofvenhaft et al. 2002).

The above mentioned studies focused on the relationship between urban green space and urban heat island effect, as well as on simple quantification of the ecological benefits of urban green space. However, few quantitative studies have investigated on the environmental purification mechanism of urban green space from the perspective of the quality of urban environment and its environmental purification capacity. Considering these shortcomings, the present research analysed the environmental purification mechanism of urban green space in Nanjing and quantitatively analysed the environmental purification service function of urban green space. This study also provided suggestions on green space construction to improve the quality of urban environment.

## MATERIALS AND METHODS

**Study area**: Nanjing (31°143'-32°373'N, 118°223'-119°143' E) is located in the southwest of Jiangsu province and in the downstream of the Yangtze River, connecting the Jianghuai plain in the north and the Yangtze River Delta in the east. Belonging to the subtropical monsoon climate, Nanjing has four distinct seasons, and the annual average temperature is 15.4°C. Nanjing receives adequate rainfall, that is, 117 rainy days every year with an annual precipitation of 1,200 mm. The rainy season lasts from the last 10 days of June to the first 10 days of July. The zonal soil of Nanjing is yellow brown, and the local vegetation ranges from broadleaved deciduous forest to a mingled forest of broadleaved deciduous forest and evergreen broadleaved forest. The built-up area in 2013 is 752.38 $km^2$.

**Data resources:** Statistical data from the China Urban Construction Statistical Yearbook (2002-2013), indicate that urban green space area in Nanjing from 2002 to 2013 increased continuously from 171.15 $km^2$ to 284.89 $km^2$. In addition, the green coverage ratio and greening rate of built-up area initially increased from 42.90% to 46.12% and from 39.02% to 41.71% respectively, and then eventually decreased from 46.12% to 44.06% and from 41.71% to 39.94% respectively, but the index values in 2013 remained higher than that in 2002. The green space area per capita also fluctuated around 50 $m^2$ (Table 1). Given the large population size and relatively small land area, urban development is imbalanced and the existing urban green space area is small; moreover, land scarcity in urban built-up areas reduced the land area appropriate for green space, resulting in the recent decrease in greening rate. Compared with the optimum urban green space area per capita (60 $m^2$) determined by the UN Ecological and Environmental Organization, China's urban green space construction standard is relatively low. But both urban green space area per capita (50.24 $m^2$) and a green coverage ratio (44.06 $m^2$) of built-up areas in Nanjing exceeded the national standard of the Ecological Garden City in 2013, indicating that Nanjing takes the lead in urban green space construction in China.

**Environmental purification mechanism:** Urban green space is an important component of urban ecosystem and can be divided into parkland, productive plantation area, green buffer, attached green space and other green space. The environmental purification mechanism of urban green space is mainly reflected in the following aspects. First, plants cannot only absorb $CO_2$ and release $O_2$ but can also absorb harmful gases (e.g., $SO_2$) and thus realize the goal of air cleaning. Second, forest canopy reduces wind speed, thereby keeping air particles in the forest and grounds. Moreover, a unique secretion on plant leaf surface can retain dusts. Third, plants can reflect and absorb sound waves. Sound waves are often absorbed, reflected, re-absorbed, and re-reflected after entering into urban green space ecosystems, such as in nearly

Table 1: Dynamic changes in urban green space in Nanjing from 2002 to 2013.

| Year | Green Coverage Ratio (%) | Green Space Ratio (%) | Green Space Area ($km^2$) | Green Space Area Per Capita ($m^2$) |
|---|---|---|---|---|
| 2002 | 42.90 | 39.02 | 171.15 | 52.97 |
| 2003 | 43.51 | 39.49 | 176.44 | 47.38 |
| 2004 | 44.46 | 40.48 | 196.03 | 49.65 |
| 2005 | 44.94 | 41.04 | 210.37 | 51.24 |
| 2006 | 45.49 | 41.30 | 237.45 | 55.05 |
| 2007 | 45.92 | 41.61 | 240.27 | 51.48 |
| 2008 | 46.12 | 41.71 | 246.95 | 51.65 |
| 2009 | 44.11 | 39.74 | 237.70 | 49.25 |
| 2010 | 44.38 | 40.02 | 247.58 | 51.06 |
| 2011 | 44.42 | 40.07 | 255.53 | 50.72 |
| 2012 | 44.02 | 39.74 | 259.63 | 48.32 |
| 2013 | 44.06 | 39.94 | 284.89 | 50.24 |

closed open forest, hedgerow or mixed system of trees, and bushes and grasses with complicated structure. The different growth directions and hierarchical growth of plant leaves also hinder sound waves from advancing, thereby significantly reducing noise.

**Methods:** This study evaluated the environmental purification services of urban green space in Nanjing, such as carbon fixation and oxygen release, absorption of harmful gases and dust detention, and noise reduction, in accordance with the environmental purification mechanism of urban green space, the evaluation index system of green space ecological service functions of other cities, and the evaluation standard of forest ecosystem service function issued by the State Forestry Bureau of China.

The main evaluation methods include the carbon tax approach, production cost, and substituted expenses. The carbon tax approach, which is one of the market value methods, calculates $CO_2$ absorption and $O_2$ release from dry matter yield during photosynthesis in urban green space according to the equation of photosynthesis: $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2\uparrow$. This approach then converts the ecological index into the economic index in accordance with the international $CO_2$ charging standard to calculate the economic values of $CO_2$ absorption by urban green space. The production cost method, which refers to green space cost method in this paper, takes the product of net plant carbon growth per unit of urban green space, afforestation cost, and the total area of urban green space as the value of one environmental purification service of urban green space. The substituted expenses method measures the value of the substitution by its market price and is mainly used to study environmental objects without the market price.

***Carbon fixation*:** The carbon tax approach and the green space cost method can be used to calculate the green space value in carbon fixation. The former is the market price method and the other is the production cost method. In this study, the carbon fixation of urban green space in Nanjing was calculated by the carbon tax approach, in which tax is collected according to the carbon content of the discharged $CO_2$. The tax rate in EU is 0.0103 EUR/kg, whereas that in Sweden is 0.15 $/kg, which is accepted by more countries. Some Chinese scholars have studied the tax rate of $CO_2$ discharge. The tax rate was modified as follows: $\beta_{ChinaRate} = (GDP_{ChinaPerCapita} / GDP_{SwedenPerCapita}) \times \beta_{SwedenRate}$ and then combined with the existing research results and the practical situations in China. Thus, the carbon tax rate adopted in this paper is 1.245 RMB/kg (Li et al. 2009).

$$Vc = S \times Qc \times Tc \quad ...(1)$$

Where, $Vc$ is the carbon fixation value of the urban green space (RMB/kg); $S$ is the urban green space area ($hm^2$); $Qc$ is the annual carbon fixation per unit of urban green space [$kg/(hm^2 \cdot a)$], in which the arithmetic mean [3738 $kg/(hm^2 \cdot a)$] of carbon fixation by the forest land and grassland in Beijing was taken as the control group (Song et al. 2009); and $Tc$ is the tax rate (RMB/kg), which is 1.245 RMB/kg according to the above analysis.

***Oxygen release*:** The oxygen released by green space can be calculated by the methods of green space cost and industrial oxygen production. Both methods estimate the oxygen production value of green space, according to the reproduction cost of other materials needed to produce the same amount of $O_2$. This study calculated the oxygen production value of urban green space in Nanjing by the industrial oxygen production method with the following formula:

$$Vo = S \times Qo \times Po \quad ...(2)$$

Where, $Vo$ is the oxygen release value of the urban green space (RMB/kg); $S$ is the urban green space area ($hm^2$); $Qo$ is the annual oxygen release per unit of urban green space [$kg/(hm^2 \cdot a)$], in which the arithmetic mean [10083 kg/

Table 2: Environmental purification service value of urban green space in Nanjing from 2002 to 2013. Unit: $\times 10^6$ RMB

| Year | Carbon fixation | Oxygen release | $SO_2$ absorption | $NO_x$ absorption | Dust detention | Noise reduction | Total value |
|---|---|---|---|---|---|---|---|
| 2002 | 79.65 | 68.72 | 4.55 | 10.41 | 0.11 | 49.30 | 212.74 |
| 2003 | 82.11 | 70.84 | 4.69 | 10.73 | 0.11 | 50.82 | 219.31 |
| 2004 | 91.23 | 78.71 | 5.21 | 11.92 | 0.13 | 56.46 | 243.66 |
| 2005 | 97.90 | 84.47 | 5.59 | 12.79 | 0.14 | 60.59 | 261.49 |
| 2006 | 110.50 | 95.34 | 6.31 | 14.44 | 0.15 | 68.39 | 295.15 |
| 2007 | 111.82 | 96.47 | 6.39 | 14.61 | 0.16 | 69.21 | 298.65 |
| 2008 | 114.93 | 99.16 | 6.57 | 15.01 | 0.16 | 71.13 | 306.96 |
| 2009 | 110.62 | 95.44 | 6.32 | 14.45 | 0.15 | 68.47 | 295.46 |
| 2010 | 115.22 | 99.41 | 6.58 | 15.05 | 0.16 | 71.31 | 307.74 |
| 2011 | 118.92 | 102.60 | 6.80 | 15.54 | 0.17 | 73.60 | 317.62 |
| 2012 | 120.82 | 104.24 | 6.90 | 15.79 | 0.17 | 74.78 | 322.71 |
| 2013 | 132.58 | 114.39 | 7.58 | 17.32 | 0.18 | 82.06 | 354.11 |

$(hm^2 \cdot a)]$ of oxygen release by the forest land and grass land in Beijing was taken as the control group (Song et al., 2009); and *Po* is the price of industrial oxygen (RMB/kg), which is 0.4 RMB/kg according to the recent wholesale price of industrial oxygen in China (Xiao et al. 2004).

***$SO_2$ absorption***: According to the substituted expenses method, the urban green space value of $SO_2$ absorption was calculated from the industrial management cost of $SO_2$ using the following formula:

$$Vs = S \times Qs \times Fs \qquad ...(3)$$

Where, $Vs$ is the $SO_2$ absorption value of the urban green space (RMB/kg); $S$ is the urban green space area ($hm^2$); $Qs$ is the annual $SO_2$ absorption per unit of green space [kg/$(hm^2 \cdot a)$], in which the $SO_2$ absorption per unit of temperate broadleaved deciduous forest [88.65 kg/$(hm^2 \cdot a)$] is adopted (Peng et al. 2005); and $Fs$ is the industrial management cost of $SO_2$ (RMB/kg), that is, 3 RMB/kg (Peng et al. 2005).

***$NO_X$ absorption***: The $NO_X$ absorption was calculated in accordance with the current management expenses for denitrification in tail gas by using the substituted expenses method as follows:

$$V_N = S \times Q_N \times F_N \qquad ...(4)$$

Where, $Vn$ is the $NO_X$ absorption value of the urban green space (RMB/kg); $S$ is the urban green space area ($hm^2$); $Q_N$ is the annual $NO_X$ absorption per unit of green space [kg/$(hm^2 \cdot a)$], in which the $NO_X$ absorption per unit of broadleaved deciduous forest [380 kg/$(hm^2 \cdot a)$] is adopted (Zhang et al., 2012); and $F_N$ is the management cost of $NO_X$ (RMB/kg), which is 16 RMB/kg according to the current management expenses for denitrification in tail gas (Zhang et al. 2012).

***Dust detention***: Dust detention was calculated using the substituted expenses method in accordance with the expenses for industrial dust reduction as follows:

$$V_D = S \times Q_D \times F_D \qquad ...(5)$$

where $V_D$ is the dust detention value of urban green space (RMB/kg), $S$ is the urban green space area ($hm^2$), and $Q_D$ is the annual dust detention per unit of green space [kg/$(hm^2 \cdot a)$]. Different green plants exhibit significantly different dust detention capacities. Hangzhou reported that the dust detention in sweetgum (megaphanerophyte), *Euonymus japonicas* L.f. *aureo-marginatus* Rehd. (suffruticosa plant), and *Ophiopogon japonicas* (herbaceous plant) are 0.5534, 1.7451, and 0.8195 g/$m^2$, respectively. In the current study, the mean dust detention of trees, brushes, and grasses [1.04g/$(m^2 \cdot a)$, which is 3800 kg/$(hm^2 \cdot a)$] was employed (Jiang et al., 2011). $F_D$ is the cost of industrial cutting dust (RMB/kg), that is, 0.17 RMB/kg (Xu et al. 2014).

***Noise reduction***: At present, the afforestation cost method is widely used to calculate the noise reduction value of urban green space. The noise reduction value is determined to be 15% of the afforestation cost, and it was calculated as follows:

$$V_{N'} = S \times F \times C \times 15\% \qquad ...(6)$$

Where, $V_{N'}$ is the noise reduction value of the urban green space (RMB/kg); $S$ is the urban green space area ($hm^2$); $F$ is the average reforestation cost (RMB/$m^3$), that is, 240.03 RMB/$m^3$ (Zhang et al. 2011); and $C$ is the timber reserves per unit area of mature forest ($m^3/hm^2$), that is, 80 $m^3/hm^2$ (Zhang et al. 2011).

## RESULTS ANALYSIS AND DISCUSSION

**Results analysis:** The environmental purification service value of the urban green space ecosystem in Nanjing from

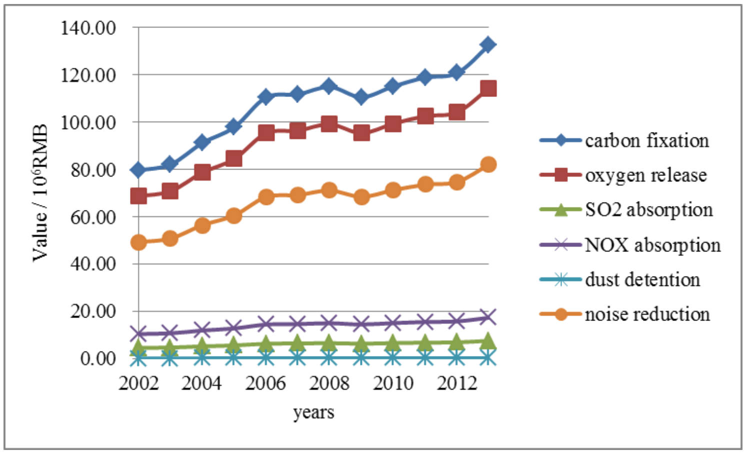


Fig. 1: Ecological service values of urban green space in Nanjing from 2002 to 2013.

2002 to 2013 was calculated using the above equations. Table 2 reveals that the environmental conditioning service value of the urban green space in Nanjing increased by 0.142 billion RMB from 2002 to 2013, showing a growth of 66% and an annual growth rate of 14%. Moreover, carbon fixation, oxygen release, and noise reduction account for a large proportion in the environmental purification value of the urban green space ecosystem in Nanjing, leaving a small proportion for harmful gas absorption and dust detention (Fig. 1). For instance, the proportions of carbon fixation, oxygen release, and noise reduction in the total value of urban green space ecosystem in Nanjing in 2013 were 37.44%, 32.30%, and 23.17%, respectively, whereas those of $SO_2$ absorption, $NO_x$ absorption, and dust detention were 2.14%, 4.89% and 0.05%, correspondingly.

**Discussion:** Most indexing systems and public data used to evaluate the environmental purification service function of urban green space are based on the Evaluation Norms of Forest Ecosystem Service Function and other published references. However, these indexing systems and public data, evaluated only the main environmental purification services of urban green space. In addition to these services, urban green space performs other functions, such as water conservation, soil maintenance, landscape aesthetics, and biodiversity protection. All these functions were disregarded in the present research, resulting in a lower calculated total value than the actual value. Moreover, no unified standard approach has been developed to calculate the ecosystem service value of urban green space. The same city may select different indexes, and the same indexes may employ various calculation methods, resulting in varying results. For example, the vegetation type (trees, brushes, and grasses), green biomass of leaf area, vegetation canopy, and leaf surface characteristics all influence the ecological benefits of urban green space. Additionally, given that the net primary productivity and the capacity for harmful gas absorption and dust detention of forest, brushes, and grassland vary, the carbon fixation and oxygen release of different vegetation types (trees, brushes, grasses) must be calculated according to their net primary productivity. More accurate values for harmful gas absorption, dust detention and noise reduction are obtained using different indexes. However, this approach was not implemented in the current study because the existing statistical data did not divide the urban green space accordingly. Despite the shortcomings, this study has objectively determined the ecological benefits of the urban green space. A simple, quantitative ecological service function value evaluation method was employed to estimate the environmental purification capacity of urban green space. This method can completely elaborate the importance of environmental purification service rendered by the urban green space ecosystem in Nanjing, although these values cannot be monetized.

According to a report issued on April 30, 2015, among the PM2.5 sources in Nanjing, the industries, vehicle exhaust, raised dust and other pollution sources account for 46.4%, 24.6%, 14.1% and 14.9%, respectively. Moreover, the "three wastes" (waste gas, wastewater, industrial residue) produced from industries are the main sources of environmental pollution in Nanjing. In addition to environmental protection, the control of urban environmental pollution based on ecological service functions of urban green space effectively mitigates environmental degradation. Carbon fixation and oxygen release of urban green space ecosystem are transferable in regional space; thus, these services may be performed by the natural ecosystems beyond the city. However, harmful gas absorption, dust detention and noise reduction of urban green space are not transferable in space.

Although these services account for a small proportion in the total service value of urban green space ecosystems, these services are very important and indispensable; thus, urban development and management must rely on strengthening the ecological construction of urban green space.

## CONCLUSIONS

On the basis of the analysis of the dynamic variations of urban green space area in Nanjing, we estimated the carbon fixation and oxygen release, $SO_2$ absorption, $NO_x$ absorption, dust detention and noise reduction of the urban green space in Nanjing. The results showed that with the acceleration of urbanization and the expansion of urban green space, the environmental conditioning service value of urban green space in Nanjing increased by 0.142 billion RMB from 2002 to 2013, showing an annual growth rate of 14%; these services are arranged in decreasing service values as follows: carbon fixation > oxygen release > noise reduction > $NO_x$ absorption > $SO_2$ absorption > dust detention.

To improve the quality of urban environment, the environmental purification service value of the urban green space may be increased through the following measures:

**Optimize urban green space structure:** In green construction, the species and site should match, and reasonable distribution of forest types and tree species must be carefully considered. A stereochemical structure comprising an organic combination of trees, brushes, and grasses must be constructed, and the green quantity per unit of green space area must be increased. Research indicated that a plant community composed of trees, brushes and grasses renders ecological benefits that are 4-5 times higher than those of public lawns (Zhou 2003), thereby significantly improving the service function of urban green space ecosystem. Given that harmful gas absorption and dust detention of urban green space ecosystem are not transferable in space, arboreal forest green space with highly efficient harmful gas absorption, dust detention and noise reduction shall be developed first. A tree green space can absorb 5-10 times more $SO_2$ than a green space without trees; moreover, the dust detention per hectare of mixed forest is approximately 79.6 tons, which is 36 times higher than that of grassland (only 2.2 tons); the short and simple grassland hardly exhibits any sound absorption, whereas forest green space with dense branches and leaves and hierarchical canopies can significantly reduce noise. For example, one 10 m (width) × 2-5 m (height) forest greenbelt can reduce 8-10 db of noise (Zhou, 2003).

**Enhance urban green space management:** Personnel must be assigned for green space protection and management, who will perform administrative functions, including formulating green space protection and other supplementary measures, improving the preventive measures against damages caused by pests and diseases, strengthening environmental awareness of the public, and propagandizing environmental protection. Simultaneously, large suburb forests and natural conservation area shall be developed in suburbs to optimize the overall functions of urban green space, cope with urban climate changes effectively, and meet the increasing ecological service demands to urban green space caused by the improvement of life quality of urban residents.

**Realize coordinated development in intensive land use and ecological use of land in cities:** The coupling of the changes in global climate and urban land use will be an enormous challenge in the maintenance of urban ecosystem services. Hence, further studies on the intensive land use and the ecological use of land in urban areas are necessary. To improve the urban green space ecosystem services, urban green space in a limited land area must be carefully planned while maintaining the urban construction land index.

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