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Assessment and optimization of green space for urban transformation in resources-based city – A case study of Lengshuijiang city, China

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ABSTRACT

Urbanization in China has changed gradually from production-oriented to consumption-oriented in recent years. Comfort and accessibility of green infrastructures effect the rate of urbanization and transformation. A well designed urban green space system is an essential part of the urbanization process. In this paper, the urban green space of Lengshuijiang city was assessed both qualitatively and quantitatively using data of field survey and high resolution remote sensing. In the study area, green space coverage was 37.14%, green space percentage was 33.45% and per capita park green space was 16.25 m^2. The high green space coverage suggested that there were ample potentials for further urban transformation. Within a 30 min service radius of existing green space, total service area was 204.49 ha, which accounted for 16.26% of the study area. A high proportion of the green space was made up of urban parks which were unevenly distributed across the study area. A green space optimization strategy, aimed at improving green space quality and accessibility, was proposed. After optimization, total service areas within the 30 min service radius will increase to 492 ha (39.12%), an increase of 22.86%. Our study demonstrated that combining qualitative and quantitative methods is an effective and reliable way for green space assessment and reliable and can be used for urban green space planning and management for small resource-based cities like Lengshuijiang in its process of urban transformation.

1. Introduction

As an important part of the urban ecosystem, urban green space provides multiple functions such as regulating microclimate, providing residents' recreation space, and purifying the atmospheric pollutant (Larson et al., 2016; Ngom et al., 2016). Further, urban green space plays an important role in solving many environmental problems, such as loss of biodiversity, water pollution, soil erosion, and rising temperatures associated with city heat-island (Lee and Maheswaran, 2011; Lovell and Taylor, 2013; Adinolfi et al., 2014). In addition, planning and construction of urban green space are not only the direct embodiment of city's soft power, but also the momentous symbol of urban civilization level (Swanwick et al., 2003; de la Barrera et al., 2016). Therefore, scientific planning and management of urban green space is essential for the benefit of urban development both ecologically and social – economically.

With the development of green space assessment and planning theory, urban green space assessment and optimization have attracted more attention recently (Jansson, 2013; Yao et al., 2014). Urban green space assessment is an important measure for ecological environment, and can provide the foundation for planning and optimization. In terms of quantitative analysis, each country has its own indicators to quantify urban green space. These indicators are used to measure the health of urban ecosystem associated with the process of urbanization (Rupprecht and Byrne, 2014; Santiago et al., 2014). The assessment of ecological service quality of urban green space is based on the landscape evaluation method, using landscape metrics, Analytic Hierarchy Process (AHP) and green space accessibility. The landscape metrics method is a powerful tool for landscape pattern analysis, nevertheless, it is unable to describe accurately all the ecological processes of urban green space (Kong et al., 2007). Suitability analysis based on AHP can effectively reflect the spatial difference of urban green space services quality, but the suitability layer weight is greatly influenced by individual judgments (Uy and Nakagoshi, 2008). Green space accessibility analysis can quantitatively reflect users' performance overcoming the difficulty, such as distance, time and cost to reach a service facility or activity place, which can be used to detect the potential service areas of urban green space more scientifically (Dony et al., 2015; Laatikainen

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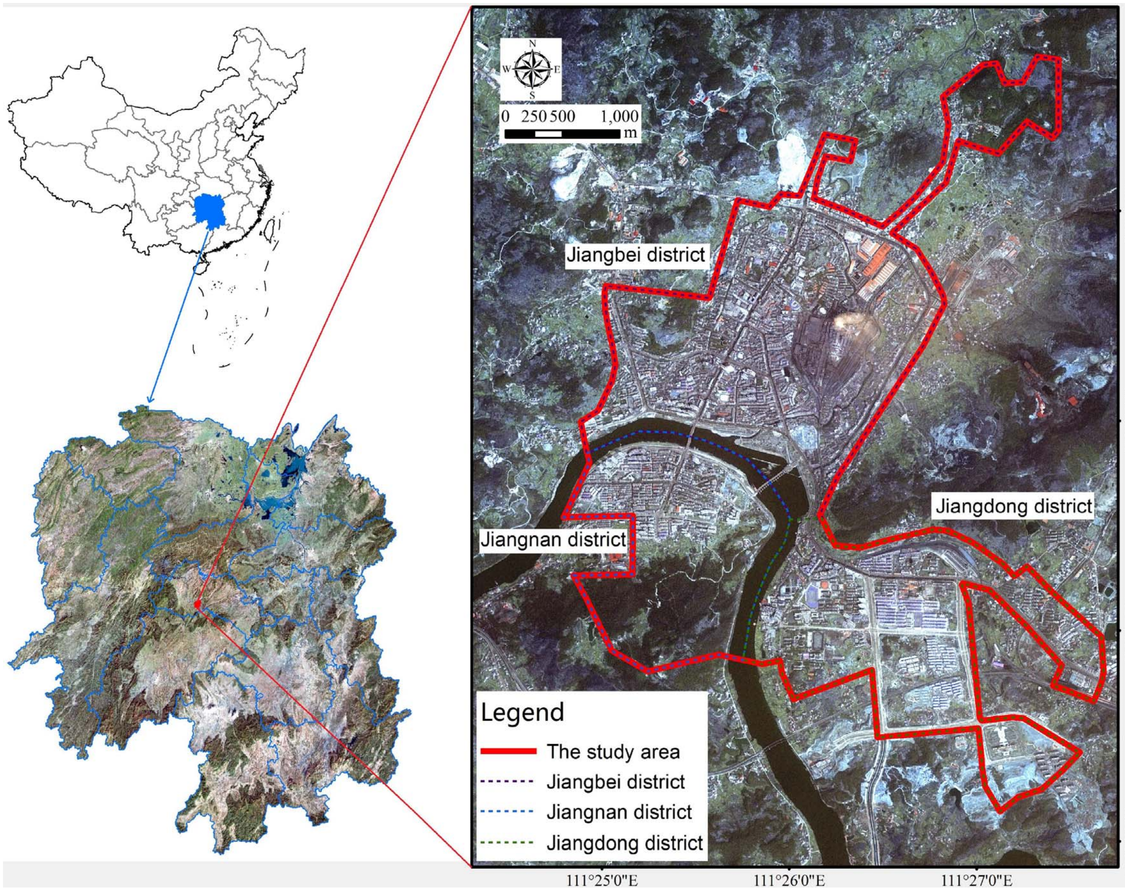


Fig. 1. The study area.

Table 1
Typology and definition of urban green space.
Source: Classification Standards of Urban Green Space CJJ/T85–2002.

Main typology	Definition/Description	Main types of green space	
Urban park	To create green spaces for the recreation of the public urban population, including function of ecological, beautification, take precautions against natural calamities, etc.	Comprehensive park	City's parks, community park, etc.
		Community park	A small green space, garden in the community
		Theme park	Zoo, botanica1 garden, historical garden and park, etc.
		Greenbelt park	River and Canal Banks, Transport Corridors(road, rail, cycleways and walking routes)
Productive plantation area	To provide green space for urban nursery-grown planting, flowers and grasses, woodland for greening, etc.	Nursery stock, flowers, seed nursery, tree nursery and grass garden, etc.	
Protective green space	Green space used for urban environment protection, sanitation, safety and calamity prevention	Railway protective greenbelt	Green space in the both sides of railway used for health segregation, environment protection, etc.
		River protective greenbelt	Green space in the river and canal banks, but smaller and narrower than greenbelt parks.
Attached green space	The various types of land affiliated green space without the urban construction land	Residential green space	Green space in the residential land
		Urban road green space	Green space in the land for traffic, square of road, etc.
		Municipal green space	Green space in the municipal facilities lands, public facilities lands and land for special use, etc.
Other green space	Green space for quality of the city's, health and well-being of residents life, ecological environment and biological diversity protection	Forestland Shrubland Grassland	Green space in landscape and famous scenery, country parks, forest parks and nature reserves, woodland, natural preservation areas, wetland, wild zoo and botanical garden, landfill recovery land, etc.

et al., 2015). Quantity indicators such as park accessibility and landscape metrics have been used for urban green space optimization by a number of researchers (Lee and Hong, 2013; Moseley et al., 2013; Reyes et al., 2014). Their studies, however, focused mainly on large or medium-sized cities with adequate infrastructure. Few studies using the combined qualitative and quantitative method to assess urban green space.

In recent years, the urban development gradually changes from production-oriented to consumption-oriented (Yeh et al., 2015). Following the rapid urbanization, traditional industries with manufacturing as the core are gradually being replaced by the emerging creative, cultural and leisure industries (Aboy, 2012; Demirtas-Milz, 2013; Qian, 2015). In the process of urban transformation, a complete infrastructure can accelerate the urban development process, and a

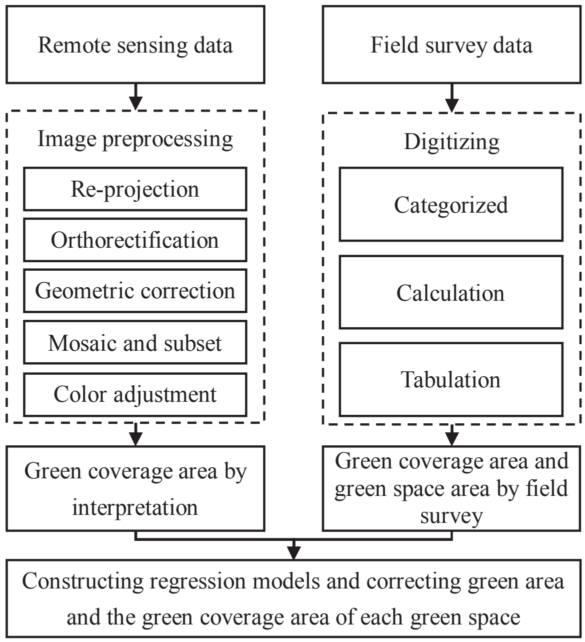


Fig. 2. Flow diagram of urban green space extracting and modifying.

detailed and sophisticated urban green space plans will become the brace or booster for urban development and transformation (Németh and Langhorst, 2014). In the urban structure system of the developing countries such as China, many small cities from different geographic regions possess the excellent development potential and prospect (Cameron et al., 2012; Kohn et al., 2012; Shaalan, 2013). In particular, resource-based cities (cities relying heavily on resource economy) are rich in natural resources, but facing problems of long-term sustainability of their economy in the process of urban transformation. The green space planning and construction in these cities are still at the initial stage and have ample space for further improvement (von Wirth et al., 2014). As the leaders in urbanization, large and medium-sized cities are in an advantageous position in terms of policy support, economic investment and practical research. The experience of green space planning and construction of these large cities is valuable for small cities in developing their green space system for the city (Ma, 2010; Li, 2012).

We chose Lengshuijiang city in China, a small city with a mineral resources based economy, as the site for our case study. We attempt to answer the following questions: (1) Does the city's total green space meet the requirements of social and ecological of urban transformation? If not, what need to be improved? (2) Could the ecological service capacity of urban park cover the entire study area? (3) How effective is the integrated quantitative and qualitative assessment method for green space assessment and optimization for small resource-based cities in its process of urban transformation?

2. Study area and data source

2.1. The study area

Lengshuijiang city locates in the central Hunan province, and at midstream of the Zijiang River. It lies between E 111°18′57″–111°36′40″ and N 27°30′49″–27°50′58″. The region belongs to the humid subtropical monsoon climate, has distinctive sceneries in different season, with abundant rainfall. The annual sunshine hours is about 1406.8 h, and frost-free period is around 269 d. Lengshuijiang city is rich in abundant water resources with a river (Zijiang River) and many streams. Annual total rainfall is around 1446.2 mm, and rainfall mainly occurs in June.

Our study area consisted of three urban districts, Jiangbei, Jiangnan and Jiangdong (Fig. 1). Total size of the area is 1258 ha. Jiangbei district is located north of the study area with Lengshuijiang Steel Plant as the core, Jiangnan district is located in the south of the study area with commercial and municipal lands as the core. Total population of the city was 137,537 (July 2014). Lengshuijiang city is rich in mineral resources with strong industrial foundation which makes the city an important raw material basis of Hunan Province, and ranks the top ten counties in economy status of Hunan province for eight successive years. As a result of pro-longed resource extraction, the environment of the city suffered severe, which hindered the urban sustainable development. Lengshuijiang city is one of 44 resource-exhausted (the mineral resources entering or nearing the end stage of the mining) cities and is in urgent need for urban transformation. The transformation program is supported by the central and provincial government both financially and politically.

2.2. Data sources

The remote sensing data mainly included Pleiades satellite images (taken in 9 April, 2014) and aerial images with the resolution of 0.5 m.

Table 2
Regressing models between interpretation results and measured areas.

Green space	Main types	Regressing model
Urban park		$y_1 = x - 7.3773$ ($R^2 = 0.9952$)
		$y_2 = 1.0111x - 7.2410$ ($R^2 = 0.9962$)
Productive plantation area		$y_2 \approx y_1 \approx x$
Protective green space		$y_1 = 0.00001x^2 + 0.8579x + 81.7430$ ($R^2 = 0.9998$)
		$y_2 \approx y_1$
Attached green space	Urban road green space (the raised flower bed)	$y_1 = 0.0004x^2 + 0.6263x + 16.6390$ ($R^2 = 0.8927$)
		$y_2 = 0.0004x^2 + 0.6229x + 33.7630$ ($R^2 = 0.9084$)
	Urban road green space (plant pit)	$y_1 = -0.00002x^2 + 0.0667x + 12.0110$ ($R^2 = 0.0781$)
		$y_2 = -0.0002x^2 + 1.2386x - 50.5240$ ($R^2 = 0.9554$)
	Residential green space	$y_1 = -0.00002x^2 + 0.9681x - 2.5983$ ($R^2 = 0.9896$)
		$y_2 = 0.00002x^2 + 0.9385x + 9.1452$ ($R^2 = 0.9991$)
	Municipal green space	$y_1 = 0.3999x + 31.7750$ ($R^2 = 0.7438$)
		$y_2 = 0.0001x^2 + 0.7607x + 4.8966$ ($R^2 = 0.9841$)
Other green space		$y_1 = -0.000004x^2 + 1.0132x - 2.1370$ ($R^2 = 0.9992$)
		$y_2 = -0.000003x^2 + 1.0123x - 1.5825$ ($R^2 = 0.9992$)

*x is the interpreting green coverage area, which is the vertical projected area of the vegetation canopy derived from remote sensing images. y_1 is the green space area based on the field survey, which is the land area occupied by the vegetation. y_2 is the green coverage area based on the field survey. R^2 is the coefficient of determination, which is the correlation coefficient squared.

Table 3
Quantitative indicators of green space.

Indicator	Unit	Definition/Formula
Green space coverage	%	(Vertical projected area of the vegetation canopy in city/City area) × 100%
Green space percentage	%	(Land area of vegetation in city/City area) × 100%
Per capita park green space	m^2/person	Urban park area/Population
Compliance rate of residential green space	%	(The number of residential quarter with green space percentage > 25%/The number of residential quarter) × 100%
Compliance rate of protective green space	%	(Built area of protective green space/Planning area of protective green space) × 100%
Compliance rate of river greenbelt	%	(Length of river greenbelts with the width > 12 m/Total length of riverbank) × 100%

*Indicator definition and calculation method followed that of “Chinese Garden City Standard (GB/T50563 − 2010)” (http://www.yuanlin.com/rules/Html/Detail/2010-8/1361.html).

Table 4
Size and percentage of various types of green spaces of Lengshuijiang city, China.

Green space	Main types	Green coverage area (ha)	Green space area (ha)	Green space area percentage (%)	Urban green space occupying (%)
Urban park	Comprehensive park	164.35	163.91	38.95	–
	Community park	4.39	4.34	1.03	–
	Theme park	50.65	50.07	11.90	–
	Greenbelt park	5.36	5.29	1.26	–
	Sum	224.76	223.62	53.14	17.78
Productive plantation area		1.99	1.99	0.47	0.16
Protective green space	Railway protective greenbelt	8.06	8.06	1.92	–
	River protective greenbelt	27.63	27.63	6.57	–
	Sum	35.70	35.69	8.48	2.84
Attached green space	Residential green space	32.78	31.36	7.45	–
	Urban road green space	27.35	17.89	4.25	–
	Municipal green space	60.48	27.81	6.61	–
	Sum	120.61	77.05	18.31	6.12
Other green space	Forestland	8.05	7.67	1.82	–
	Shrubland	69.84	68.47	16.27	–
	Grassland	6.32	6.30	1.50	–
	Sum	84.20	82.44	19.59	6.55
Urban green space		467.26	420.80	100.00	33.45

We used the PC Spectral Sharpening to sharpen Pleiades satellite images (2 m pixel size for multispectral bands and 0.5 m pixel size for panchromatic band) by the ENVI 5.1 software for getting the very-high-resolution and matching the resolution of aerial images. After the preprocessing, the two datasets were used to extract green spaces in combination.

Auxiliary data provided by the Lengshuijiang Garden Bureau, and mainly contained Green Space Planning in Lengshuijiang City (2014–2030), Lengshuijiang City Administrative Area Map (2014), Lengshuijiang City Topographic Map (2014), Lengshuijiang City Land Use Map (2014), Lengshuijiang City Area/Population Description (2014) etc.

Field survey data included spatial distribution (longitude, latitude and layout) and measured area (the green space area and the green coverage area) of random samples for each green space. In addition, urban environment and green space services quality were collected from a questionnaire survey.

3. Method

3.1. Typology and definition of urban green space

There is no uniform classification for urban green space in the world at present, and the classification systems adopted by various countries have been continuously adjusted. We used the most widely used classification system in urban green space planning and management in China, CJJ/T 85–2002 (Table 1) to define the green space types and analyze the differences between different types.

The methodology of thematic information extraction in urban green space is illustrated in Fig. 2. Green patch was obtained by drawing on the remote sensing images after preprocessing. The interpreting green coverage area, the vertical projected area of the vegetation canopy obtained by interpretation (x in Table 2), is calculated in the ArcGIS software. The green space area (y_1 in Table 2) and the green coverage area (y_2 in Table 2) of random samples in each type of green space were measured by field survey. Regression models were established using these data (interpreting the green coverage area, the green space area and green coverage area of the field survey) (Table 2). According in the R^2 values of the regressions, the accuracy of our regression models was high with the exception of the regression model between the green space area and the interpreting green coverage area of urban road green space (plant pit), the R^2 of which was 0.0781. Finally, the interpreting green coverage area and those regression models were used to calculate the green space area and the green coverage area of each green space.

Six indicators (Table 3) were defined and calculated to assess the urban green space “quantity”. Green space coverage equals the vertical projected area of the vegetation canopy of total green space patches in the city divided by the city area, and is the economic and technical indicators of urban greening condition. While green space percentage equals the land area of total green space patches in the city divided by the city area, and was particularly important for urban green space planning and implementation among all the indicators.

3.2. Assessment of urban green space service

The urban green space “quality”, i.e., the service area of green infrastructure was assessed by the urban park accessibility analysis. The commonly used methods of accessibility analysis include buffer analysis, minimum proximity distance method, gravitation model method and network analysis method (Chang and Liao, 2011; Dai, 2011; Coutts et al., 2010). Among them, the network analysis based on urban road network and its capacity analysis, was most reliable to predict the actual available green space (Comber et al., 2008; Chen and Chang, 2015).

Network analysis is a model based method, the basic elements include the center, corridor and node (Gupta et al., 2016; Albert and Barabási, 2002; Teng et al., 2010). In the urban green space, the park entrances are regarded as the centers. As the skeleton of the network, roads are regarded as corridors and play important roles in resource migration in the network. No barriers are assumed to move along the road, and the impedance values are set as the lengths of each road. The intersection of corridors is the nodes, and people need to cost time to wait or response. In order to perform the network analysis and calculate the service areas, the road length and road capacity (walking speed) were used to quantify the access distances (Comber et al., 2008). The detailed network analysis process of urban park accessibility is as follows:

(1) Data preparation

The park entrance (point feature) and road (line feature) were

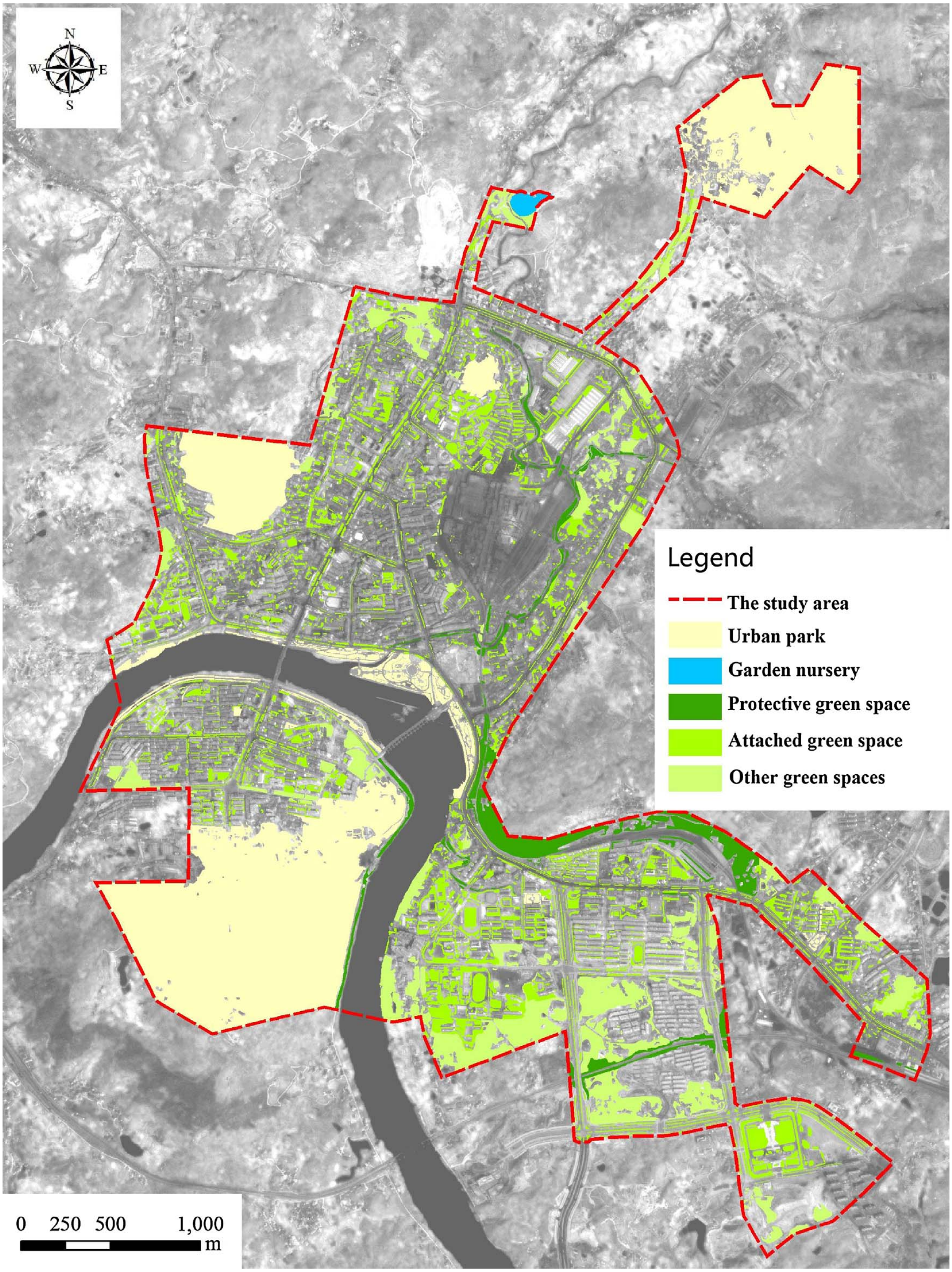


Fig. 3. Green space configuration of Lengshuijiang city, China.

created as two vector data, then converted to the topological network dataset by the ArcGIS software.

(2) Distances calculation

The study area was small with the relatively simple traffic structure, so the road capacity in this research was measured by walking. Walking speed was assumed at 1 m/s, which was used to calculate the access distances.

People prefer to live within 1000 m around the urban park, and the distance from the house to the green space was best controlled at 10–15 min walking time or about 500–1000 m (Kim and Kaplan, 2004; Chen and Chang, 2015). Chinese Ministry of Housing and Urban-Rural Development in 2012 also proposed urban residents travel to "see green within 300 m, see the park within 500 m". So, we based on the actual length of the road to calculate the access distance of each section from

Table 5
Comparison of quantitative indicators.

Indicator	Accounting value	Standard value	Difference
Green space coverage (%)	37.14	36	1.14
Green space percentage (%)	33.45	31	2.45
Per capita park green space (m^2/person)	16.26	7.5	8.76
Compliance rate of residential green space (%)	92.76	95	−2.24
Compliance rate of protective green space (%)	70.02	80	−9.98
Compliance rate of river greenbelt (%)	46.78	80	−33.22

* Standard value derived from "Chinese Garden City Selection Standard (GB/T50563-2010)".

the road to 5 min time interval for urban park. The corresponding park service radius is 0–5, 5–10, 10–15, 15–20, and 20–30 min, and the distance of the service is 0–300, 300–600, 600–900, 900–1200, and 1200–1800 m. The waiting time was usually 30 s, which was set as the impedance value at the road intersection.

(3) Evaluation of service area

Service area rate and service population rate were often used to analyze and estimate the accessibility of urban parks (Comber et al., 2008). Due to the small study area and population base, we used the service area rate only to quantify the green space accessibility. The service area map was obtained by network analysis, and the service area was modified by removing the water area. Finally, service area rate in each level was calculated.

4. Results and discussion

4.1. Quantitative characteristics of green space

Information of each urban green space (Table 4) and the green space spatial distribution (Fig. 3) were extracted from the remote sensing images and modified by the regressing models. The green coverage area (the vertical projected area of the vegetation canopy) was 467.26 ha, and the green space area (the land area of the vegetation) was 420.80 ha in the Lengshuijiang city. Green space coverage and green space percentage of the urban park were the highest among all kinds of green spaces. Green space percentage of each park varied markedly, comprehensive park had the highest (39.95%) and the community park had the least (1.03%). Green space percentage of theme park with beautiful scenes was around 11.90%, but community park and greenbelt park which were visited most frequently were less than 1.50%. Green space coverage and green space percentage of productive plantation area were similar, and were the least among all green spaces, only 0.47%. Total protective green space area was 35.69 ha, and railway protective greenbelt area was significantly higher than the river protective greenbelt area, which was relatively uneven for an industrial city. In addition, the area of attached green space was less, which hindered the economic development and urban transformation also.

The green space coverage and green space percentage were 37.14% and 33.45% respectively (Table 5). Per capita park green space indicated total area quantity of urban green space, was 16.25 m^2. The results indicated that Lengshuijiang city reached the Chinese standard for "Garden City". These results compared favorably with other industrial cities such as Birmingham and Stockholm, green space percentage of which was 11% and 39% a respectively (Fuller and Gaston, 2009). Besides, Lengshuijiang city has relatively high green space percentage in comparison with other metropolis such as Beijing (37.2%) and Shanghai (35.78%, sourced from China Urban Construction Statistics Yearbook in 2015). The high percentage of green space area of suggests that there is huge potential in improving the urban environment for urban transformation in the Lengshuijiang city.

There were 13 new residential quarters, of which green space percentage were more than 25% with the exception of "Bochang Garden" (Fig. 4a). There were marked differences in green space percentages between different residential quarters. Total planned protective green space area was 50.98 ha, and the compliance rate was 70.02% (Table 6, Fig. 4b). Of the various types of protective green space, river protective greenbelt of Lianxi River had the lowest compliance rate of 38.80%, Zijiang River had the highest compliance rate of 80% (Fig. 4c).

There were marked variations in size between urban green spaces of different categories. Area of urban park was high, while protective green space and attached green space were much lower for urban transformation in resources-based city. In addition, the spatial

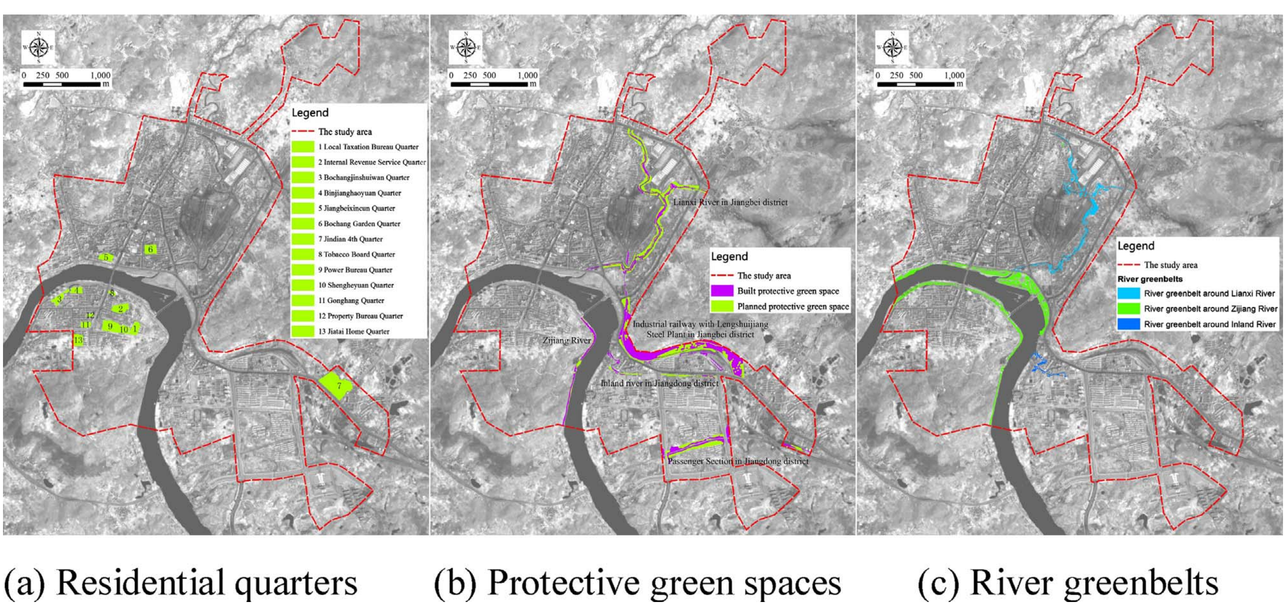


Fig. 4. Distribution maps of residential quarters, protective green spaces and river greenbelts.

Table 6
Area and compliance rate of protective green space of Lengshuijiang city, China.

Protective green space	Location	Planning green space area (ha)	Built green space area (ha)	Compliance rate (%)
Railway protective greenbelt	Passenger Section in Jiangdong district.	8.22	4.63	56.30
	Industrial railway with Lengshuijiang Steel Plant in Jiangbei district	25.26	23.01	91.07
River protective greenbelt	Lianxi River in Jiangbei district	12.35	4.79	38.80
	Inland river in Jiangdong district	1.68	0.77	45.84
	Zijiang River	3.46	2.50	72.14
Total area		50.98	35.69	70.02

Table 7
Comparison of urban parks of Lengshuijiang city, China, before and after green space optimization.

Park name	Current situation		Optimization		Measures
	Green space area (ha)	Park entrance	Green space area (ha)	Park entrance	
Hongriling park	26.46	1	26.46	1	Change the entrance location
Binjiang park	8.35	5	8.35	8	Increase entrance
Qingshan park	129.11	1	129.11	2	Increase entrance
Lengshuijiang steelwork people's livelihood park	3.56	1	3.56	1	None
Guihua garden	0.16	1	0.16	1	None
Buxidachengjie garden	0.16	1	0.16	1	None
Jinzhushan mining garden	0.46	1	0.46	1	None
Boyuedong park	50.07	1	51.01	2	Increase area and entrance
Zijiangbinhe park	5.24	4	5.24	8	Increase entrance
Street greenbelt park	0.05	0	3.57	4	Increase area and entrance
Lengshuijiang botanic garden			13.03	4	Build according to planning
Huimeipanshan park			1.98	2	Build according to planning
Dalingshang park			1.79	2	Build according to planning
Lianxibinhe park			12.33	4	Build according to planning
Sum	223.62	16	257.21	41	–

distribution of green space showed a significant difference. Jiangnan district and Jiangdong district with lower population density and less developed industry, had relatively more green space than Jiangbei district.

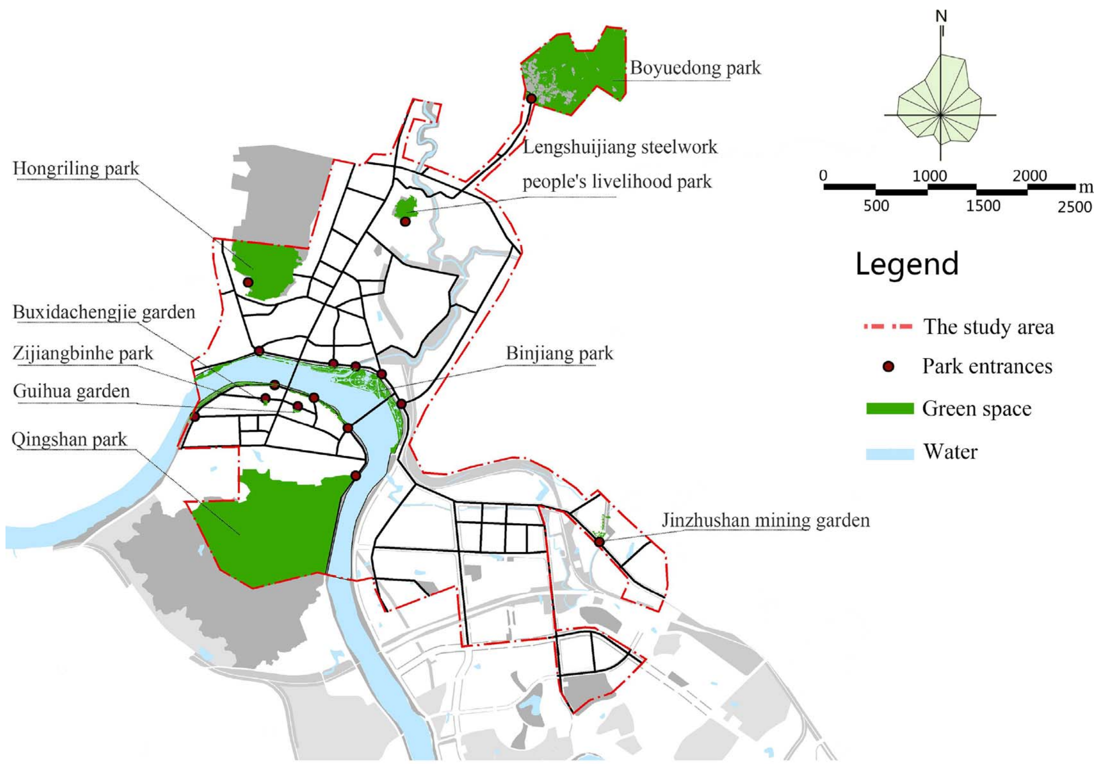
4.2. Qualitative characteristics of green space

The area of comprehensive parks (Hongriling Park, Binjiang Park and Qingshan Park) were larger aside from Bingjing Park. The area was 8.35 ha with 5 entrances, with high visiting frequency from nearby residents (Table 7). The Hongriling Park and Qingshan Park were built on the natural mountain, with less entrances. The former was located in north and the latter was located in the south of the city, and both were far away from residents. Boyuedong Park in the north of Jiangbei district was a theme park with beautiful scene and large recreational area, but accessibility to the park was constrained by the lack of sufficient transport. Moreover, community parks and greenbelt parks which had high service efficiency, were few and insufficient. These results suggested that the uneven distribution of urban parks affected their accessibility by comparing with other transforming cities.

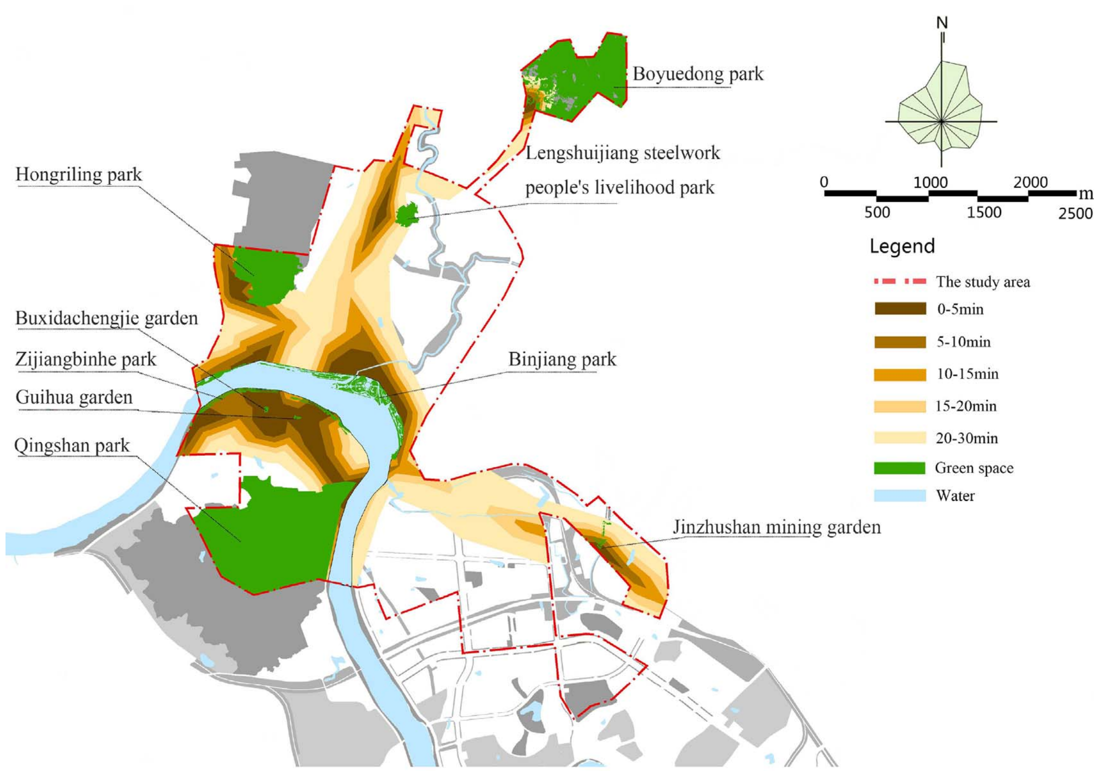
The vector data of park entrance and road were established (Fig. 5a), and the lengths of each road were calculated by ArcGIS software. Then the isochronous line map corresponding urban park accessibility was generated using the location-allocation model (Fig. 5b). The service area of 0–30 min was about 204.49 ha, accounting for 16.26% of the study area (Table 8). The service area of 20–30 min was about 113.99 ha; ranked the first and followed by 0–5 min and 5–10 min. So, most of the residents lived more than 20 min away from any urban park.

The region of service radius of 0–10 min mainly distributed around the greenbelt parks on the banks of Zijiang River, which may be affected by the connectivity and the number of entrances for the Bningjiang Park and Zijiangbinghe Park. Hongriling Park and Qingshan Park had not played the corresponding comprehensive park service, i.e., the service area were very small, because these two parks were near to the city's edge or there were insufficient number of entrances to the park. Although the area was large, Boyuedong Park’s service is very poor because it was far away from residential quarters and had only one access-way. In the Jiangbei district, there was a belt-area with service radius of 0–10 min running vertically from north to south with limited access to green space. While it was located along the major urban trunk road, there was a lack green space infrastructure within the area. A blind area with service radius of > 30 min appeared between the Lengshuijiang Steel Plant and the urban east ring road due to the lack of park and protective green space. Jiangdong district was a new development with less green space within the 0–10 min service radius.

The questionnaire survey revealed that there were not enough number of urban parks for daily recreational activities. These results were contrary to our findings of relatively high per capita green space area. Uneven distribution of urban parks and poor accessibility to them were the main cause of the difference. According to the urban park accessibility analysis and referring to other green spaces such as East Lake Scenic Area of Wuhan, we conclude that if the park occupied larger area but had few entrances, the service function will be insufficient. Moreover, the road infrastructure may also affect the park's service. Park service capacity and park area were not positively linear correlated, which was the common and important problem in urban green space planning for helping urban transformation and environmental protection (Zhou and Kim, 2013). Although our results demonstrated that the service of urban park was poor in Lengshuijiang city, it could be improved by increasing the number of park entrance and road by reference from other industrial cities such as Birmingham, Chongqing and Wuhan.



(a) Roads and park entrances



(b) Service areas

Fig. 5. Green space accessibility of Lengshuijiang, China, estimated by network analysis.

4.3. Optimization of green space

4.3.1. Increasing the size and improving the environment of green space

Our quantitative analysis revealed that the rate of different types of green space was out of balance. So we proposed the optimization strategy of "increasing the size and improving the quality of green space", i.e., increasing the area of protective green space, waterfront greenbelt park and productive plantation area to improve the aesthetic and ecological quality of the green space system.

Lianxi River flows from the mountainous area north of the city, runs

Table 8
Comparison of service areas of urban green space of Lengshuijiang city, China, before and after green space optimization.

Time (min)	Current situation		Optimization		Increased area	
	ha	%	ha	%	ha	%
0–5	61.57	4.89	181.86	14.46	120.29	9.56
5–10	5.96	0.47	45.67	3.63	39.71	3.16
10–15	13.15	1.05	88.01	7.00	74.86	5.95
15–20	9.82	0.78	90.19	7.17	80.37	6.39
20–30	113.99	9.06	86.38	6.87	−27.61	−2.19
0–30	204.49	16.26	492.11	39.12	287.62	22.86

across the Jiangbei district, and enters the Zijiang River near Bingjiang Park. Due to the space constraints, the river bank of Lianxi River had a smaller area with complex land-use types. The revetment (a sloping structure used in erosion control and fortifications) were mainly the traditional hard stone masonry, so there was notably height difference between water and road. Although this revetment structure was beneficial for urban flood control and drainage, it represented a barrier for residents to access the river. More importantly, it had a severe negative influence on the self-purification capacity of the river (Fig. 6). Compared with other big cities in China like Beijing, Shanghai or Guangzhou, small cities such as Lengshuijiang has a small area proportion of the ecological land (green space, water, etc.), it is difficult to build a large-scale integrated park like a large city. Under this situation, the scientific planning and utilization of the river greenbelts (greenbelt park and river protective greenbelt) could improve the landscape and ecological quality, and solve the problems of protective green space and neighborhood park shortage in industrial cities.

To solve the above problems, we proposed the ecological revetment reconstruction program to increase the width and area of river greenbelts (Fig. 7). The detailed reconstruction measures of the ecological revetment around Lianxi River were as follows: (1) In the areas where the slope was steep water-flow velocity was high, the traditional revetment (the hard stone masonry) should be replaced by the shore gabion step revetment. (2) In the other areas, the traditional revetment should be replaced by the natural revetment, and waterfront greenbelt park should be considered in the green space planning. Both revetments could provide an ecologically integrated ecotone for the bank area of Lianxi River. In the river bank of west Lianxi River, the width of river protective greenbelt should be more than 5 m for walking, cycling and other recreational needs. And the plant configuration on this water-land ecotone should be “tree & herb”, “shrub & herb” and other simple structures to keep the openness of green space. While in the river bank of east Lianxi River with a small amount of construction but larger green space, waterfront greenbelt park could be planned and the green space distribution should be improved to form an available amusement space. In addition, a railway protective greenbelt should be planned to isolate the pollutants from the Lengshuijiang Steel Plant (Yellow area in Fig. 7). As Lengshuijiang Steel Plant was located in the Jiangbei district with many residential quarters, the width of railway protective greenbelt should be flexible to accommodate with the surrounding land use types. In areas where the available space was below the minimum required width, multiple layers of plants such as “tree & shrub & herb” should be attempted. Species with high capacity to absorb and resist pollutants should be selected.

The field survey on the railway protective greenbelt showed that the natural environment was better and some protective green space was built on the natural forest land. For example, there were two natural forests on the north side of Lengshuijiang Passenger Section in Jiangdong district. Therefore, the ecological service should be improved for this protective green space. According to the specific natural environment of each section, the width of railway protective greenbelt should be at 20 m minimum to ensure the provision of adequate ecological services. At the same time, the plant configuration of railway protective greenbelt should be focused on the landscape effect and

Fig. 6. Current situation of river greenbelts around Lianxi River, Lengshuijiang, China.

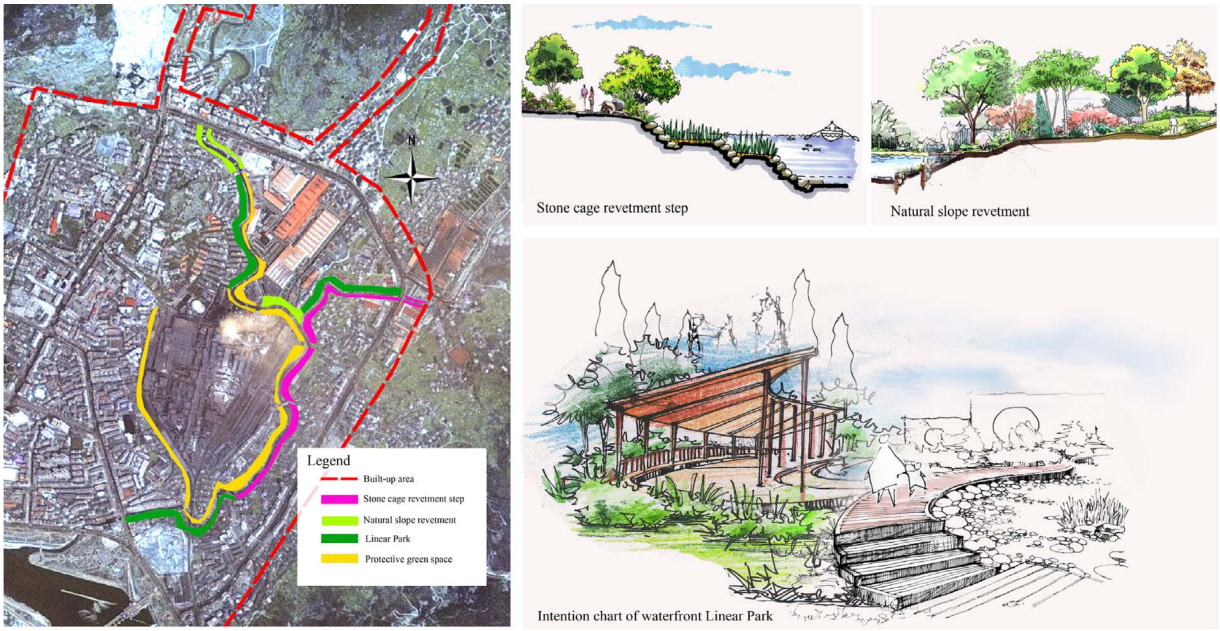


Fig. 7. River greenbelts planning and designing around Lianxi River of Lengshuijiang, China. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)

include fragrant plants and color leaf trees to bring better visual and olfactory experience for visitors (Lee and Maheswaran, 2011).

4.3.2. Increasing center and corridor

Although the area of urban park was relatively large, the service efficiency of urban park was very low. So we proposed the optimization strategy of "increasing center and corridor" for urban park, i.e., increasing the number of park entrance and enhancing the connectivity of greenway network by referring to the greenway planning in large or medium-sized cities.

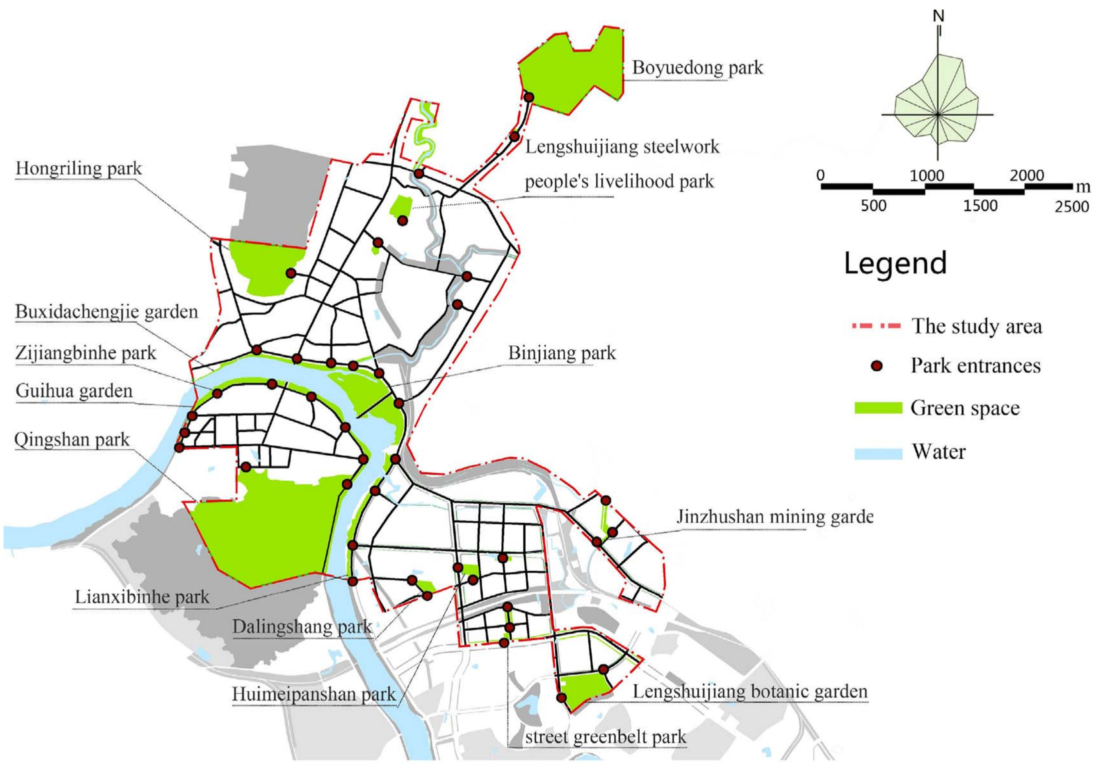
According to the distribution of residents in the Lengshuijiang city, the detailed measures for increasing the park entrance were as follows: (1) increasing the east and south entrances of Hongriling Park near the residential quarters as soon as possible, enhancing the network connectivity by replacing some constructions to greenway during the Jiangbei district reconstruction. (2) increasing the number of park entrances near the north of Qingshan Park to improving the service area (Fig. 8a). After optimization, the number of park entrances increased from 16 to 41 (Table 7), and the service area of 0–30 min almost covered the entire Lengshuijiang city (Fig. 8b). The service area of 0–30 min was about 492.11 ha, accounting for 39.12% of the study area (Table 8). The service area of 0–5 min was about 181.86 ha, accounting for 14.46% of the study area, an increase of 120.29 ha.

Lengshuijiang was a small city rich in mineral resources, with small green patches green space. To enhance the service area of 0–10 min of the city, small green patches should be linked to form larger green space, and the area and number of community parks and gardens should be increased coupled with vertical afforestation. As walking and cycling were popular in small cities, a proportion of the roads should be designed as pedestrian only (Zhai and Baran, 2016) to improve accessibility to urban park by local residents.

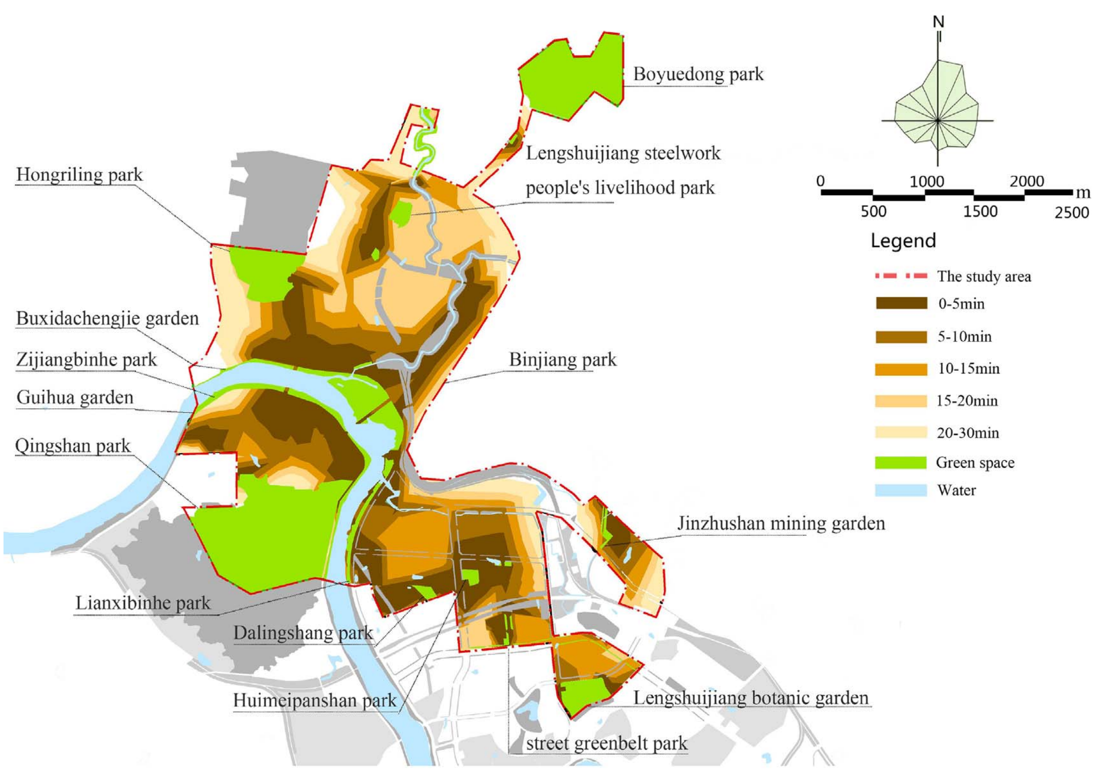
5. Conclusion

In this study, we used remote sensing technology to analyze the urban green space composition and urban park accessibility of Lengshuijiang city. Our results showed that green space coverage was 37.14%, green space percentage was 33.45%, and per capita park green space was 16.25 m^2. Compared with other cities after the urban transformation, the green space area of Lengshuijiang city was relatively large and there was ample potential in improving the urban environment for urban transformation. Green spaces were not uniformly distributed across the city. Much of the green space was made up of recreational parks and there was generally a lack of protective green space. The service quality of urban parks was lowered by traffic problems. Based on the above analysis, the optimization measures of "increasing the size and improving the environment quality" and "increasing center and corridor" were proposed. In order to regulate the area of each green space, the optimization measures should be taken in the revetment of Lianxi River to improve the landscape and ecological quality. Moreover, increase the number of park entrances and construction of greenway corridors could improve the urban park service. After optimization, the service area of 0–30 min almost covered the entire Lengshuijiang city, and the service area of 0–5 min increased notably.

For small resource – based cities, scientific planning and optimization of urban green space would intuitively improve the urban ecological environment and enhance the city value, which could help urban transformation for these cities. Based on the study of urban green space optimization strategy in the Lengshuijiang city, this paper demonstrated that (1) Regulating types and scales of urban green spaces can be used to meet demand for human life and urban transformation when the total area is large but all kinds of green spaces are unevenly distributed. (2) Increasing the number of park entrances and improving network connectivity between green spaces can improve the green space service quality. (3) The method employed in the present study for green space assessment and optimization is reliable and can be used for urban green space planning and management in its process of urban transformation.



(a) Roads and park entrances



(b) Service areas

Fig. 8. Green space accessibility of Lengshuijiang, China, after optimization by network analysis.

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