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# A GIS-based Green Infrastructure Planning for Sustainable Urban Land Use and Spatial Development*

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**Abstract**

Green infrastructure has been a popular framework for smart development and conservation planning. If it is proactively planned, developed, and maintained in a systematical way, it also should be a better model for land use and spatial development in a city. By integrating a GIS-based ecological connectivity assessment with the patch-corridor-matrix model, this study provided a green infrastructure planning approach to guide the sustainable land use decision in the Longgang District of Shenzhen in China. The method has an effective performance in identifying the vital ecological areas and linkages prior to development in suburban areas, and also the key sites for protection and restoration in developed sites. It is hoped that based on this planned green infrastructure frame, the land resource units could be developed or protected when most needed and most suitable in the future.



*Keywords*:Green infrastructure; ecological connectivity; the patch-corridor-matrix model; sustainability; land resources.

## 1.Introduction

The concept of green infrastructure has been introduced to contrast with the term of "built infrastructure" including roads, sewers, hospitals, schools and other public facilities. It is defined as "the nation's natural life support system- an interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms,

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ranches and forests; wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life for communities and people" by the Green Infrastructure Work Group under the leadership of the Conservation Fund and the USDA Forest Service in the United States [1]. In China, green infrastructure is usually referred to the Green Space System, which composes of various environment-friendly land patches and corridors covered by the vegetation or the water in a city [2]. Taken together, green infrastructure is a holistic ecological network system, consisting of a set of natural vegetation, lakes and other areas with known or potential ecological value (namely hubs) connected by corridors or links. A whole green infrastructure network can be used to inform conservation-related land use decisions, if the two primary parts of hubs and links were proactively identified, planned and maintained before development [1, 3], especially in cities where urban growth has altered even reduced the quality and quantity of green spaces widely. Hence, green infrastructure planning should be the first step in urban land-use planning and design process [1].

In this paper, a GIS-based green infrastructure planning method coordinated with the ecological connectivity evaluation was applied into the future land conservation and development scheme. To better understand this approach, the Longgang District of Shenzhen City in China was chosen as the case area.

## 2.Materials and methods

### *2.1.The study area*

The Longgang District is located in the east of Shenzhen which，comprised of one special economic zone and two districts, is a city in the Guangdong province in the south of China (Fig.1). Longgang covers nearly an area of 84134 hm², and has a subtropical monsoon climate with the average annual temperature of 22.4℃, and precipitation of 1,948 mm. Owing to abundant natural mountains and wetlands, Longgang has become the most important part of ecosystem services in Shenzhen, and also one key hub of the green infrastructure of the Guangdong province in the up-scale. Last twenty years, with the rapid development of economy, the contradictory between the growing need for the industrial land and for the public green space and its benefits is increasingly appearing in the Longgang District.

### *2.2.Methodology and Data Preparation*

A series of land use maps is the foundation of green infrastructure planning. In this paper the land use change survey data of Shenzhen was used. The two key steps of this methodology are presented as Fig.2 shows.

- *The Whole Landscape Pattern Analysis with the Patch-Corridor-Matrix Model*: Based on the aggregate-with-outliers principle in landscape ecology, there is a "four top-priority ecological indispensables" pattern which is recognized as a robust way to fit elements together into a whole landscape planning [4]. The four key components in this pattern are a few large patches of natural vegetation, major stream or river corridors, connectivity with corridors and stepping stones between large patches, and heterogeneous bits of nature across the matrix. Based on the land use change survey map in the study area, we firstly analyzed the spectrum of the patch size of each land use type, then divided the landscape pattern into the eco-land matrix, the built-up and eco-land patches, and the traffic and river corridors by the statistical distribution of the land-use polygon sizes (see Table I). To identify where the connectivity between larger patches is the most suitable to compose links (Fig.2), here we adopted the following ECI method.

TABLE I The patch-corridor-matrix elements of the landscape pattern in the longgang district

| Code | Land use types | Land use sub-types | The total area ($hm^2$) | The perception of patch numbers in the patch size spectrum (%) [a] | | | Landscape pattern types |
|---|---|---|---|---|---|---|---|
| | | | | I | II | III | |
| T1 | Agro-lands | Croplands | 1834.15 | 0.58 | 2.82 | 4.50 | Patches |
| | | Groves | 10869.06 | 22.81 | 19.26 | 11.65 | The matrix, patches |
| | | Prairies | 2.99 | 0.00 | 0.00 | 0.02 | Patches |
| | | Forests | 37492.07 | 50.29 | 19.36 | 11.04 | The matrix, patches |
| | | Other agro-lands | 2413.69 | 2.34 | 1.95 | 10.57 | Patches |
| T2 | Transportation lands | Railways, highways and urban roads | 3707.69 | 9.36 | 5.16 | 5.95 | Corridors |
| T3 | Low density built-up lands | Public facilities, municipal utilities and specially-designed lands | 3162.82 | 1.17 | 4.09 | 9.59 | Patches |
| T4 | High density built-up lands | Commercial, industrial and residential lands | 20346.09 | 7.61 | 40.46 | 38.37 | Patches |
| T5 | Water reservoirs | -- | 2162.71 | 5.26 | 3.50 | 1.72 | Patches |
| T6 | Unused lands | Wetlands and other unused lands | 1602.12 | 0.58 | 2.14 | 5.00 | Patches |
| | | Rivers | 541.44 | 0.00 | 1.26 | 1.59 | Corridors |
| T7 | -- | -- | 84134.83 | 100 | 100 | 100 | -- |

[a] Since the patch size is the dominant principle of identifying the matrix in a landscape [4], the patch size spectrum of each land use type was divided into three types. They were the type I, II and III, respectively presenting the set of patches with the area larger than 50 $hm^2$, 10 $hm^2$-50 $hm^2$, and smaller than 10$hm^2$.

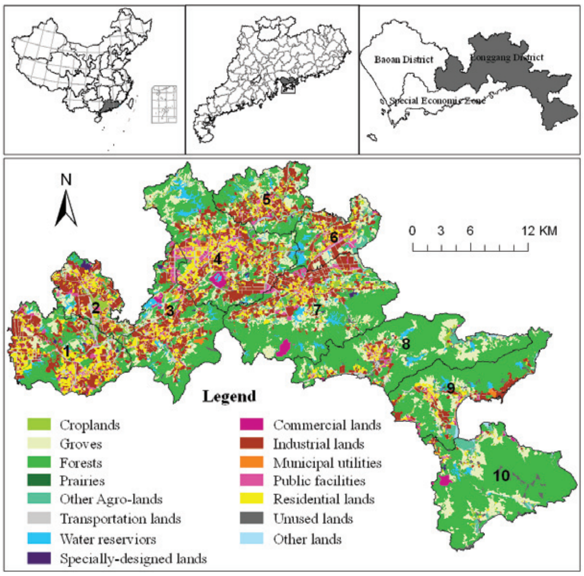


Fig. 1 The study area. Here, the numbers indicate sub-districts in the Longgang of Shenzhen: 1, Bujing; 2, Pinghu; 3, Henggang; 4, Longgang; 5, Pingdi; 6, Kenzhi; 7, Pingshan; 8, Kuicong; 9, Dapeng; 10, Nan'ao.

- *Ecological Connectivity Assessment by the ECI Method*: Ecological connectivity refers to the functional aspects of the actual connection between the different ecosystem units; from energy to information and matter, i.e. nutrient cycles, pollen dispersion and movements of flora or fauna populations [5]. In this study, an ECI (Ecological Connectivity Index) method developed by Marulli and Mallarach [6] was used to evaluate the eco-lands' ecological connectivity in the District of Longgang. It was calculated as follows,

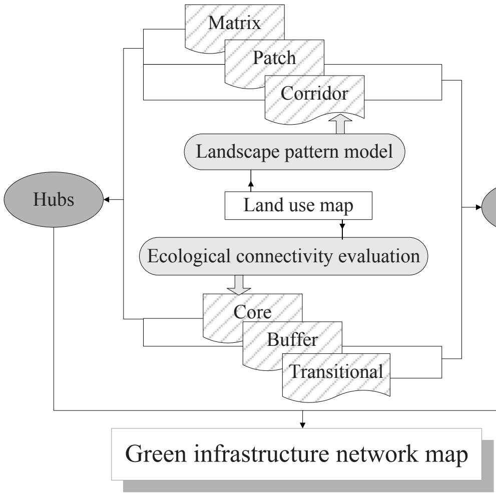


Fig. 2 The green infrastructure planning steps

$$\mathrm{ECI} = 10\text{-}9\left[\ln\left(1 + x_i - x_{min}\right)/\ln\left(1 + x_{max} - x_{min}\right)\right]. \tag{1}$$

where ECI is the ecological connectivity index, $x_i$ is the ecological cost-distance value in a pixel, and $x_{\min}$, $x_{\max}$ are respectively the minimum and maximum ecological cost-distance value in a given area.

The calculation of the ecological cost-distance value ($x_i$) is the first step of ecological connectivity assessment, which can be calculated based on the cost-distance model in GIS [6]. Besides the diverse eco-land units as sources (Fig.1), it also needed an impedance surface from artificial land units, which was calculated by the following equation,

$$\mathrm{X}_i = Y_i / Y_{max} . \tag{2}$$

here, $\mathrm{Y}_i$ and $\mathrm{Y}_{max}$ are defined respectively as the value of the Barrier Effect in a pixel and its maximum value on a given area [6]. And they are gained from the barrier effect value set ($\mathrm{Y}_s$) calculated as follows,

$$\mathrm{Y_S} = \sum_{s=1}^{s=n} Y_s = \sum_{s=1}^{s=n} \left[b_s - ks_1 \ln\left(ks_2 d_s + 1\right)\right]. \tag{3}$$

here, $\mathrm{Y_S}$ is the barrier effect value surface of the artificial land types $s$, $n$ is the numbers of artificial land types ($n$=1-3). $b_s$ is the barrier weights of three types (see Table II), $d_s$ is the cost-distance obtained by Cost Distance Module in GIS based on the origin surface database for each barrier type (see Table II) and the resistance surface database from the potential impact matrix (see Table III). $ks_1$ and $ks_2$ is the constants for logarithmic decreasing function [6].

It is showed that the ECI value in Longgang ranges from one to ten (Fig.3), and there are a higher ecological connectivity both in the south-east and the north, however lower in the west and the centre.

TABLE II The Artificial Barrier Types And Their Weights and Constants

| Code | Types | $b_s$ [b] | $k_{s1}$ [b] | $k_{s2}$ [b] |
|---|---|---|---|---|
| B1 | Low density built-up lands | 20 | 11.1 | 0.253 |
| B2 | High density built-up lands | 50 | 27.75 | 0.102 |
| B3 | Railways, highways and other main traffic roads | 100 | 55.52 | 0.051 |

[b] According to the relativity of the artificial barrier effect, the weight of different barriers and the constants resulted from the related literatures [6-7].

TABLE III The Impact Coefficient of The Barriers on The Different Land Units

| Code | Types | Affection distance [c] | Affection value [c] |
|---|---|---|---|
| A1 | Forests | 1000m | 0.10 |
| A2 | Agricultural lands and other lands | 750m | 0.13 |
| A3 | Wetlands and water reservoirs | 500m | 0.20 |
| A4 | Artificial barrier lands | 250m | 0.40 |
| A5 | Rivers | 1m | 100 |

[c] According to the effect difference of the land types from the artificial barrier, the affection distance and the affection value to different land types resulted from the existing literatures [6-9].

## 3.Green infrastructure planning results

### *3.1.Ecological connectivity pattern analysis*

According to the guideline of a nature reserve's establishment pattern in the Regulations of the People's Republic of China on Nature Reserves, the ecological connectivity pattern of the study area were divided into four types based on the ECI value by natural breaks classification method in GIS: the core, the buffer, the transitional zone and the no or low connectivity area (Fig.4). Here, the sites with the ECI value larger than 5.36 belong to in the core area, where the development and construction are forbidden except the scientific research activities; this zone covers about the area of 6272 $hm^2$. The areas with the ECI value ranging from 4.09 to 5.36 are designated as the buffer zone with the area of 22095$hm^2$, where only the scientific research and education or visit activities are allowed, e.g. rare and native wild botanic garden and country parks may be established. And outside the above protection areas, the area covering 37864 $hm^2$ is designated as the transitional zone with the ECI value ranging from 2.69 to 4.09, where the environment-friendly facilities and other construction activities are allowed, such as scenic spots, amusement parks and other public open spaces. Besides the above three protection oriented regions, other lands with the ECI value less than 2.69 belong to the no-connectivity and low-connectivity areas, where the matter, energy, and information among ecosystem sites hardly communicate due to the dispersed and small eco-land patches.

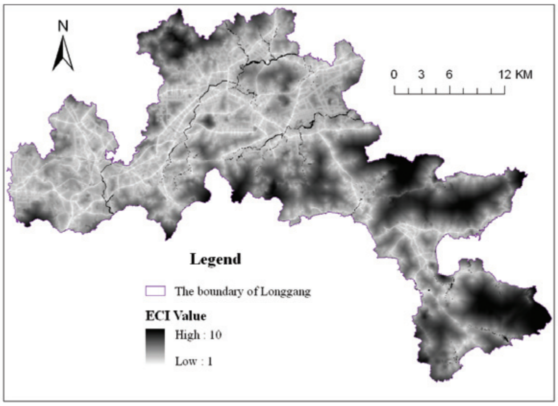


Fig. 3 The ecological connectivity index distribution map in the Longgang

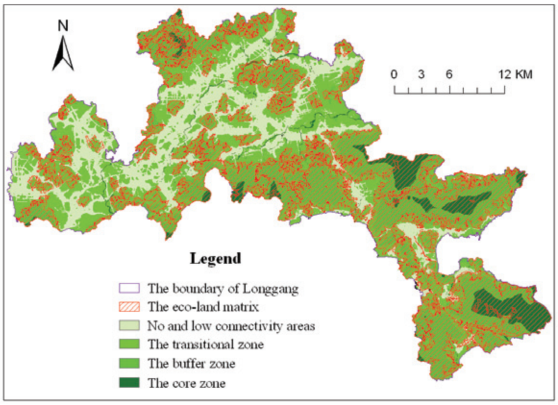


Fig. 4 The ecological connectivity pattern map and the green infrastructure hubs made of the eco-land matrix units inside the core and buffer zone

### *3.2.Green infrastructure planning by the patch-corridor-matrix model based on ecological connectivity pattern*

It is commonly accepted that green infrastructure is a network system and consists of hubs connected by corridors or links [1, 3]. Then a green infrastructure planning in a given area may be realized through identifying the components of hubs and links.

- *Hubs of Green Infrastructures*: In the Longgang District, the forests and groves constitute the eco-land matrix due to their large total area and patch size (see Table I). These matrix units with the patches larger than 50hm$^2$ are mostly within the core and the buffer zone of the ecological connectivity pattern (Fig.4). Therefore it implies these eco-land matrix units compose the hubs of green infrastructure, which cover the area of 43887.94 hm$^2$, and in the future, they would be the strictly-protected areas in Longgang.
- *Corridors and Stepping Stones of Green Infrastructures*: Rivers and the eco-lands around them are increasingly pressed and fragmented by the development in Longgang contributing to their amenity of living. According to the existing literatures [9-10], the river corridors may help increasing the species, ecosystem and landscape biodiversity and other ecological benefits, if the extent of a river with its two-side buffers is longer than 1200m. Fig.5 shows within the river buffers of 1200m, there are ample eco-land patches, but they are barely connected. Hence the river buffers and their inner eco-land patches larger than 5hm$^2$ are brought into the potential links of green infrastructure in Longgang, and the river corridors and stepping stones would be the future restored and reconstructed areas. This kind of link covers about the area of 3026.70hm$^2$.
- *The Eco-land Patches of Green Infrastructures*: Besides the hubs and the corridors, the ecological patches are required to sustain the connectivity of the hubs and corridors. So the forests, groves, croplands, prairies and water patches within the transitional zone may play an important role in the whole green infrastructure network. Here, considering the harmony of protection and development, the patches ranging from 5 hm$^2$ to 50 hm$^2$ outside the river buffer are put into the green infrastructure network, covering about the area of 2478.98 hm$^2$ (Fig.6). Taken together, the above planed green infrastructure covers the area of 49393.61 hm$^2$, and nearly 59% of the total area of Longgang.

## 4.Conclusion and discussion

The paper provides a method integrating the green infrastructure into the land use planning process in a given area. The case study of Longgang District of Shenzhen in China showed based on the “aggregate-with-outliers” principle and the analysis of the size spectrum of land units, the land use pattern was distinguished in a GIS, including the eco-land matrix made of forests and groves, the river and transportation corridors, and the eco-land and built-up patches. However what parts should be brought into the green infrastructure protection planning or not is still unclear. Hereby the GIS-based Ecological Connectivity Index method developed by Marulli and Mallarach was used to evaluate the functional connectivity among the land units, by which the ecological connectivity pattern was identified and divided into the core, the buffer, the transitional zone and the no or low connectivity areas. Then through overlaying the results of the Patch-Corridor-Matrix pattern and the core-buffer-transition zone in the Longgang District, the hubs and links of the green infrastructure network were demonstrated and planned. Nevertheless, in this study the spectrum analysis of the eco-land patch size was based on the practice experiences due to the lack of the minimum eco-land functional unit knowledge, which should be farther strengthened in the future research.

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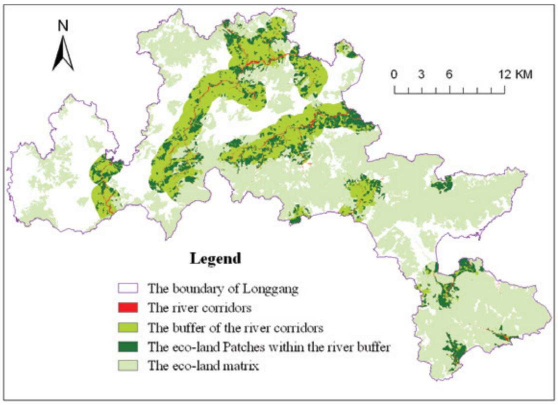


Fig. 5 The potential links of green infrastructure in Longgang

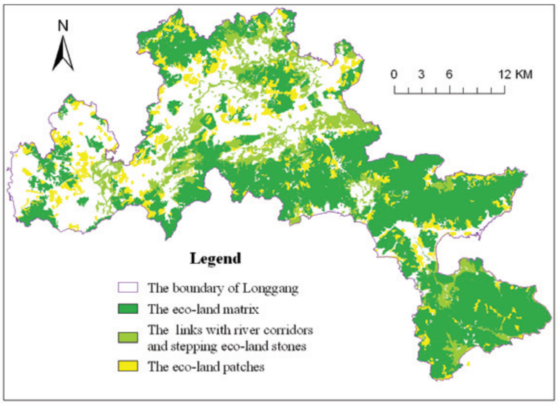


Fig. 6 Green infrastructure planning map resulting from the patch-corridor-matrix model integrated into the ecological connectivity pattern

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