GREEN INFRASTRUCTURE PLANNING FOR THE WELL-BEING OF HUMAN AND WILDLIFE IN XUCHANG, CHINA

by

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(Under the Direction of Jon Calabria)

ABSTRACT

Natural ecosystems in China are being displaced by rapid urbanization. Green spaces and semi-natural areas provide essential ecosystem services that serve needs of both humans and wildlife. Interconnected networks of green spaces conserve ecosystem functions and services, such as wildlife habitat, air filtering, microclimate regulation, and recreational and cultural services. This thesis examines how to improve urban green spaces in Xuchang, China by using suitability analysis and promoting elements of green infrastructure at a variety of scales. Lastly, site designs illustrate the possibilities to apply green infrastructure approaches to Xuchang.

INDEX WORDS: Green Infrastructure, Ecosystem Services, Urban Green Space, Urban Parks, Greenway, Suitability Analysis, GIS-Weighted Overlay, Analytical Hierarchy Process, Prioritization

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CHAPTER 1

INTRODUCTION

The overarching goal of this thesis is to suggest strategies supporting urban green infrastructure planning in Xuchang, Henan Province, China. The thesis reviews recent green infrastructure theoretical approaches, case studies, existing conditions and issues associated with linking urban green space in Xuchang, China. The design portion of the thesis provides a suitability analysis and a comprehensive plan that offers design suggestions to prioritize retrofitting green infrastructure projects in the urban area of Xuchang for the well-being of both humans and wildlife.

1.1 Problem Statement

The report by the "Commission on the Measurement of Economic Performance and Social Progress" (The Stiglits-Sen-Fitoussi Report) identified eight essential dimensions that define human well-being. They include: material living standards, health, education, personal activities including work, political voice and governance, social connections and relationships, environment, and insecurity of an economic as well as physical nature. In this paper, the focus of human well-being is on the health, personal activities, social connections and relationships, environment and insecurity of physical nature.

Wildlife conservation aims at protecting, enhancing and managing enhancement wildlife populations in their habitats (Herborn 2014). Based on this, the definition of well-being of wildlife in this paper is a stable or increasing biodiversity in urban environment.

Urban green spaces can exist as semi-natural areas (Jim and Chen, 2003) and are valued for recreation venues and offer wildlife habitats that are essential to healthy environments. Cities are dependent on the global and regional ecosystems beyond city boundaries, but also benefit from internal urban ecosystems like street trees, lawns, parks, urban forests, cultivated land, wetlands and lakes (Bolund and Hunhammar 1999). These systems generate a range of ecosystem services, such as air filtering, micro-climate regulation, rainwater drainage, recreational and cultural services, and providing wildlife habitat (Alcamo and Bennett 2003).

In China, natural ecosystems are being lost due to increased development, urbanization, and land use intensification. The urban built-up area[1] in China has nearly doubled from 21,525 km^2 in 1999 to 40,058km^2 in 2010 (Ge 2012). Land use change alters the structure of ecosystems, leading to the fragmentation of landscapes. Disruption influences the processes, functions and services of ecosystems, thus affecting the living environment of both people and wildlife (Bolund and Hunhammar 1999). As urban areas expand in China, and natural ecosystems continue to disappear, the remaining semi-natural areas within cities become more important, providing ecosystem services that humans and wildlife depend on (Crane and Kinzig, 2005).

Surprisingly, urban green coverage rate in Chinese cities' built-up areas increased from 21.8 % to 35.2% over the last two decades due to encouragement and support from

[1]Developed areas with basic public utilities and services within cities' administrative boundary.

the national and local governments (Zhao et al. 2013). However, the higher green coverage rate is largely the result of compulsory policy control on urban green space. These policies control mainly on quantitative indicators and often ignore qualitative ones. The health of urban ecosystems cannot be guaranteed by existing regulations and policies, and many urban green spaces exist in poor and "unusable" condition, serving mainly to create a better "city perception" (Jim and Chen 2003).

The case study city, Xuchang, is administratively a medium sized city located in the Huaihai Plain of China. It is a historic city founded in 100BC, Zhou Dynasty. Existing indicator values of urban green space in Xuchang, such as green coverage rate and green area per capita meet the regulations and the requirements for “National Garden City.” Even so, environmental challenges there are very severe, including such as issues as landscape fragmentation, lack of wildlife habitat, and a geographically uneven distribution of parks. Just as many cities have done, Xuchang has emphasized beautification and size over ecological or recreational functions. Luckily, the city government of Xuchang always values its cultural and natural resources and has been very supportive of urban green space projects. The current Comprehensive Overall Plan of Xuchang (2005-2020) is about to be replaced by a new one (2015-2030). There is an opportunity for the study of green infrastructure initiatives in Xuchang to contribute to the new Comprehensive Overall Plan (2015-2030), and for new urban green space construction projects to improve the city’s ecosystem services, thus providing a better and healthier living environment for both humans and wildlife.

1.2 Current Research

Traditional Chinese people planned their cities based on natural environments. The forms and locations of cities were designed to borrow and speak to the surrounding mountains and rivers. In ancient capital cities, royal gardens were usually built between the city and mountains. Private gardens were designed next to rivers, canals, flood control facilities and water supply facilities. These gardens, street trees, rivers and lakes formed urban ecosystem networks and provided recreational, aesthetic and ecological functions for urban dwellers (Rong 2012), which can be considered as the traditional Chinese approaches of urban green infrastructure planning.

In European, the concept of green infrastructure refers to the network of green routes and hubs that preserves biodiversity (Murphy 2009). The term of Green Infrastructure originated as an effort in United States in the mid-1990s to upgrade urban green space systems as a coherent planning entity, to achieve healthier urban ecosystems and better ecosystem services (Benedict and McMahon 2002). It was defined as an interconnected network of green spaces that conserves natural ecosystem values and functions, and provides associated benefits to humans, such as micro-climate regulation, recreational functions and visual enjoyment (Benedict and McMahon 2002).

In this paper, green infrastructure refers to the interconnected network of green spaces, water and other natural features within urban areas that consists of hubs and linkages, which can provide a variety of ecosystem services for humans while preserves biodiversity.. It is based on Benedict and MacMahon's (2002) definition of green infrastructure, as well as related to traditional Chinese approaches.

Several recent major approaches worldwide concerning green infrastructure (GI) include: the study of services that humans derive from urban ecosystems (ecosystem services); the study of the relationship between spatial composition of landscapes and wildlife well-being--landscape ecology principles; the approach of linear connections forming green infrastructure networks—greenway; green infrastructure techniques—green street, rain garden, green roof, and vertical greening (Benedict and McMahon 2002).

In the last decade, much emphasis was placed on the functions provided by ecosystems and determining methods for evaluating specific benefits people derive from ecosystem processes and functions (Daily and Matson 2008). Ecosystem services are defined as "benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al. 1997)." Ecosystem services are classified as provisioning services, regulating services, cultural services and supporting services (Capistrano 2005). Early studies on ecosystem services focused primarily on "natural" ecosystems. However, the importance of human-dominated landscapes in urbanized areas is now being recognized (Lovell and Johnston 2009). Bolund and Hunhammar (1999) propose the following services as most important for ecosystems in urban areas; air filtering, microclimate regulation, noise reduction, stormwater drainage, sewage treatment, recreational and cultural services. Jim and Chen (Jim and Chen 2009) studied ecosystem services and methods to evaluate urban forests in China, and conducted several projects measuring the influence city comprehensive overall plans can have over land use and ground cover. Such projects include Panyu (Integrated Urban Land-Use Planning Based on Improving Ecosystem Service: Panyu Case, in a Typical Developed Area of China 2011), Dujiangyan (Ge 2012), and Xingguo (Hualin, Jinzheng, and Jing 2012).

The ability of ecosystems to provide ecosystem services depends on a healthy ecosystem and biodiversity (Daily and Matson 2008). Landscape ecology studies relationships between spatial composition of landscapes and biodiversity. Ecologists around the world have been studying the interactions between humans and ecological processes in anthropogenic landscapes (Lovell and Johnston 2009). Dramstad, Olson and Forman summarized essential principles of landscape ecology, emphasizing that they can be easily applied to land-use planning and landscape design as well (Dramstad, Olson et al. 1996). Some studies have shown how these principles could also be applied to urban green and open space planning. Flores (1998) proposed "ecological content, context, dynamics, heterogeneity and hierarchies" as ecological principles for the development of a green space system for the New York City area. Leitao and Ahern (2002) proposed a common framework that applies similar ecological knowledge to both landscape and urban planning. In China, Jim and Chen (Jim and Chen 2003) applied landscape ecological principles to the green space planning of Nanjing City. Similarly, a comprehensive concept plan of urban green space in Beijing based on landscape ecological principles was also proposed (Feng et al. 2005).

Greenway planning began during 1980s and 1990s and has resulted in thousands of completed greenway plans and projects in the USA and Europe. Modern greenways and ecological networks are designed to incorporate "biodiversity conservation, storm water management, recreation, and visual quality" (Hellmund and Smith 2006). Greenway planners employ methods and features used in landscape ecology, such as corridors, patches, matrix, and connectivity, and incorporate such landscape architecture principles as pedestrian and bicycle circulation into greenway plans. The major types of greenways include those along urban streams and canals and greenways following traffic corridors. The greenway movement in Asia is experiencing explosive growth, especially in China, Japan, and Singapore (Fábos and Ryan 2006). The functions of greenways are usually protective and productive, with designers often overlooking recreational functions like cycling or hiking. Urban problems such as uniformly planted trees, limited-use development, the lack of science-based planning, and network inaccessibility can all be addressed by applying a strategic, modern greenway approach to urban green infrastructure planning (Yu, Li, and Li 2006).

Other successful green infrastructure elements and techniques, smaller in scale than greenways, are also being studied and designed around the world. Green streets are planted using street-side planters or swales that capture stormwater runoff, allowing it to infiltrate the ground as soil and vegetation filter pollutants. Green alleys are implemented to achieve a suite of ecosystem services and public health goals using long-neglected back alleys. Green roofs and green walls are being constructed to help mitigate heat island effects and absorb a limited amount of rainfall. These methods can all be adopted to benefit urban green space in Chinese cities.

1.3 Research Questions

This thesis seeks to answer the following question: How can green infrastructure theory design methods be applied in Xuchang to help the city achieve a sustainable and healthy living environment for both human residents and wildlife? This thesis also seeks to answer the following sub-questions:

- What is the existing amount of urban green space in Xuchang?
- How can suitability analysis address green infrastructure planning in Xuchang?

1.4 Research Structure

To answer thesis question and sub-questions, Chapter Two provides an overview of urban green space conditions in Chinese cities. Cities with similar existing conditions in urban built-up area, population density and green surface coverage are designated as study cities. Chapter Three provides an inventory of the existing urban development conditions and urban green space conditions of Xuchang, and identifies several main issues to be solved. Chapter Four studies green infrastructure theoretical approaches that can enlighten green infrastructure planning and design for Xuchang. Chapter Five explores three precedent urban green space planning projects applying green infrastructure theoretical approaches as design examples for Xuchang. Chapter Six is the design chapter where methods and strategies about how to improve urban green spaces in Xuchang are proposed based on previous chapters.

1.5 Research Limitations

This thesis is an exploration of possible enhancements to guide the Green Space System Planning section in the Comprehensive Overall Plan of Xuchang (2014-2030) and prioritize future urban green space projects in Xuchang. The plan is not intended to be a complete Green Space System Plan, nor does it strive to produce the detailed landscape design or construction documents. However, it provides a trajectory for planning purposes and suggests a site based design concept for an area of Xuchang.

The planning methodology, strategies and design solutions compiled for Xuchang may be applied to other cities with similar density and current conditions, which are identified in Chapter 2. However, they may not be suitable for all Chinese cities, due to varying factors such as local economy and policy, and differences from city to city in physical conditions such as density, landscape type, or ecoregion.

The research focus of the thesis is the urban built-up area of Xuchang within the outer ring road, which is defined as the main development area in the Comprehensive Overall Plan of Xuchang (2015-2030).

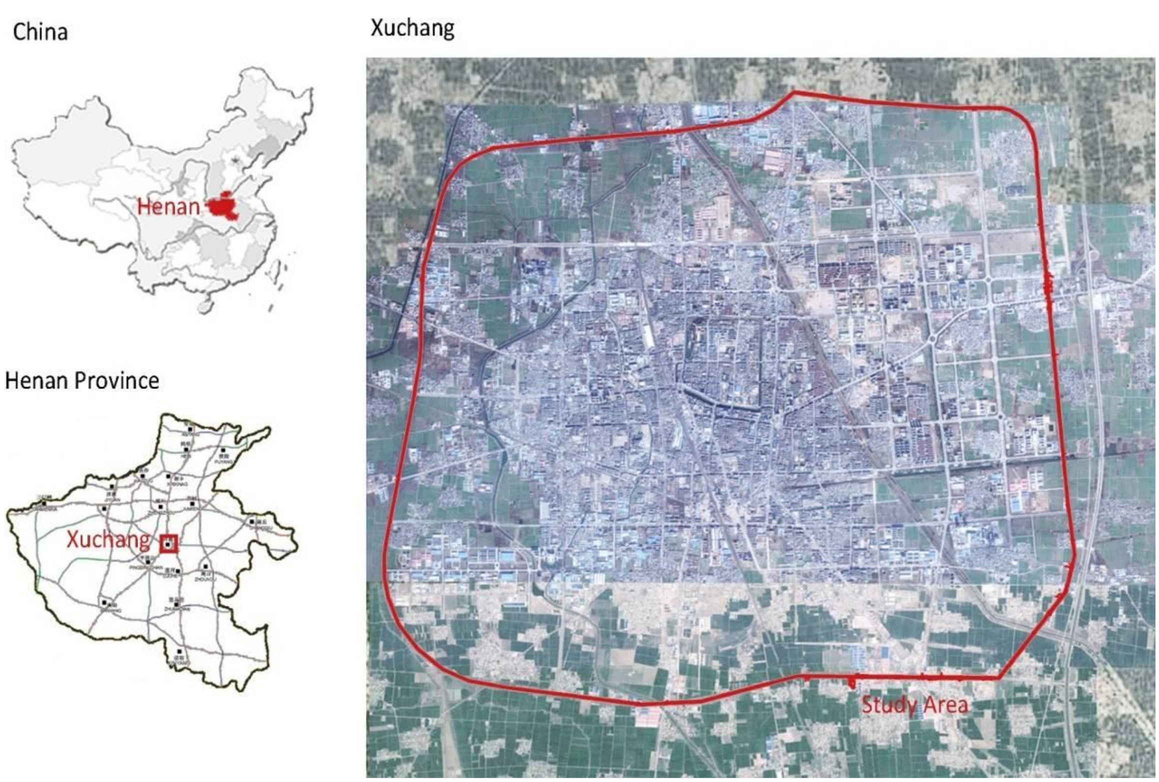

Figure 1-1 Study area boundary (red line) map created by author

CHAPTER 2

URBAN GREEN SPACE IN CHINA

This Chapter provides an overview of urban green space conditions in Chinese cities, including historic context, recent trends, urban and green space planning processes, laws, and policies. Based on the study of relationships between urban green space and urbanization indicators, three factors are used to designate study cities with similar existing conditions. These similarities include each cities' urban built-up area, the population density in its built-up area, and its green surface coverage. Existing issues among the study cities are also presented in this Chapter. Among the study cities, Xuchang is chosen as the case-study city.

2.1 Background

History Context and New Trends

Traditional values including "uphold nature," "return to nature," and "harmony between human and nature" were all commonly held by ancient Chinese people, and these principals guided the landscape planning and design in ancient China (Zheng, Zhao, and Yu 2010).

"Design based on existing landscapes" and "although made by humans, it should look like nature" were two major guidelines of mature Chinese ancient gardens (Zheng, Zhao, and Yu 2010). Under these two guidelines, several design methods were developed and commonly used. "Pi-hsing", as a technique of expression and a way of art-thinking finds a close parallel with the word "empathy" in the West. Chinese gardens were designed to refer to human emotions or evoke memories. Chinese gardens were also designed to create “blended setting and feeling” and “harmony between human and nature." The concept of a complete landscape sequence, including introduction, follow-up, transition, and conclusion was also very important in Chinese garden design, as was the influence of idealized perspective employed by Chinese landscape painting (Zheng, Zhao, and Yu 2010).

Another design method inspired by landscape painting was “hide before unveil." In paintings, the object the painter wished to emphasize was always hidden, like mountains behind mist and clouds, an indistinct house behind a forest of trees, or a fisherman in a small boat at the end of a river. When applied to garden design, the concept meant that open views were similarly hidden behind small paths or landscape walls.

The Chinese Bourgeois Revolution, World War II and the Great Proletarian Cultural Revolution in the twentieth century all led to the disintegration of traditional values. Nature became a resource for food and clothes, and an appreciation of nature was belittled as feudal, a corrosive hobby of the bourgeois. Traditional gardens were damaged or destroyed along with ancient buildings. Among all types of green spaces, only productive land was valued. Rapid population growth exacerbated the need for food and the extreme development of farmland, which quickly replaced forests and pristine land, a transition leading to severe environmental damage (Lu 2011).

Since the reform and opening up in 1978, China has developed quickly. During this rapid urbanization process, farmlands, remaining forests and other natural habitat areas are becoming more and more fragmented. As the expected and planned-for ecological functions of urban green spaces were overcome by land use change, concepts such as "ecological city" and " landscape city" began to be encouraged by many scholars, as was the concept of sustainable development. These factors allowed greenway and landscape ecology principles to be more widely accepted. In 2002, ministry of construction released its “Urban Green Space Classification Standard” and “Regulations about Indicators of Urban Green Space Planning” guidelines. These marked the establishment of China’s first policy and regulation system of urban green space planning (Ziyu and Wowo 2011).

In the late twentieth century, large Chinese cities including Tianjin, Shanghai, Beijing, Nanjing, Shenzhen, and Guangzhou all began to renovate urban green spaces. Green space plans for big cities were now usually inclusive and well integrated in city overall comprehensive plans. However, since in an earlier phase of these cities’ development, economic benefits were the first concern and the value of green spaces was neglected, large cities now face the awkward problem of saturated building density and lack of green and public spaces, a problem which is very difficult to solve. Another big issue is the lack of unique city and regional characteristics due to standardized regulations and design methods. Approaches of green infrastructure planning need to be explored to solve these problems.

Urban Planning In China

In China, land ownership is public. Land use and land ownership are separated in an established land market legal system. The owner of the land is the country and the ownership cannot be transferred, but the right to use land for a certain period can be leased and transferred legally. The management of land is centralized. Urban planning is made and approved by city government and state council, and green space planning is integrated in overall planning in the same process. The main purposes of urban green space planning are to define and regulate parameters, and to arrange all types of green spaces and the spatial layout of green spaces according to city character, development purpose, and land use in overall city planning. The process of urban planning in China is shown in Table 2-1. Usually the city government in the main formulator of city overall planning, then in a series of meetings the plan is evaluated by invited scholars and finally approved by upper government.

Table 2-1 Process of urban planning in China, table created by auther based on Urban and Rural Planning Law of People's Republic of China, 2008.

PHASE	STEP	CONTENT	PLAN MAKER	APPROVAL
Overall Urban Planning	Overall Planning Outline	Development goals Primary principles	City government	City government
	Overall Planning	Mandatery: Planning boundary Development land and non-development land Restricted construction area (ecological, historical, etc.) Land use plan (20 years) Land use plan (5 years)	City government	State Council of China
	District Planning (only for big cities)	Supplementation and detailization of overall planning	Planning department of city government	City government
Detailed Planning	Regulatory Planning	Detailed land use plan FAR and other indicater values of blocks Building height control Setback control Major to branch streets sections Utility lines design Land use and building administrative details	Planning department of city government	City government
	Site Plannig	Buildings, streets and landscapes layout; master plan Transportation and streets planning and design Green space planning and design Vertical planning and design Construction amount and cost	Interprises and institutions who plan to develop designed areas	Planning department of city government

Laws, Regulations and Standards

In China, principles of green space have been codified. On a comprehensive planning level, the "Urban and Rural Planning Law of People's Republic of China (2008)" is the law that guides all planning and construction in both urban and rural areas. This law states that a green network plan should be included in each comprehensive plan. "Measures for Formulating City Planning" (2005) and "Standard for Classification of Urban Land and for Planning of Constructional Land (GB50137-2011)" defines urban green space types, determines a minimum green area per person, and regulates the percentage of land allotted to each land-use category. In addition, "Urban Green Space Classification Standard," "Urban Greenery Regulation," "Regulations About Indicators of Urban Green Space Planning," "Urban Trees Protection and Management Measures," and "National Ecology Garden City Standard" provide even more detailed regulations and guides for urban green space planning, design, construction, and management.

In "Urban Green Space Classification Standard," urban green spaces are divided into five broad categories, which include park (subcategories include comprehensive park, neighborhood park, theme park, liner park and street-side park), productive green space, protective green space, attached green space (green space that belongs to other land use categories such as residential land or industrial land), and other green space (green space that was not in constructional land and can provide recreational and ecological services for urban area). In "Standard for Classification of Urban Land and for Planning of Constructional Land (GB50137-2011)," "G" is used as the overall land use code for green space under development, with "G1" representing parks, "G2" representing protective green space, and "G3" representing the public square, which is public open space made mainly of hardscape. Affiliated green spaces share the same land use code as those they are "attached to." Productive land, including farmland and orchard land, is coded under non-development land as "E1," "E2," or "E3."

Table 2-2 Urban development land use code in China, table created by author based on Urban and Rural Planning Law of People's Republic of China, 2008.

Land use category	Residential	Adminis-tration and public services	Commercial and business facilities	Indus-trial	Logistics and ware-house	Street and transpor-tation	Municipal utilities	Green space
Code	R	A	C	M	W	S	U	G

Indicators are used to regulate required green space area in development land. Green space (G) per capita is 10.0 square meters (107.6 square feet), among which park land (G1) per capita should be at least 8 square meters (86.1 square feet). Suggested green space (G land) and total development area ratio is 10% to 15% percent. City greening rate (ratio of green space area and development land area) should be as least 30%, and city percentage of greenery coverage (all planted areas) should be at least 35%. Calculation of city greening rate is strict. For example, green space with less than 1.5 meter (5 feet) of earth cover (such as green roofs and green space above underground parking), width narrower than 8 meter (25 feet), or area less than 100 square meters (1076 square feet) are not included in green space area calculation. Calculation of city greening rate is variable, and all areas that are covered by plants, including scattered trees, grassland, green roof, vertical greening and street greening are included. By regulating and differentiating these two indicators, the importance of essential urban green space is strengthened and supplemental types of urban green space are encouraged.

2.2 Xuchang and Similar Cities

Urbanization Factors and Green Coverage Rate

In China, due to rapid urbanization, natural ecosystems are increasingly being replaced by urban development. The built-up area in China nearly doubled in the early 2000s, from 21525 km^2 in 1999 to 40058km^2 in 2010 (Ge 2012). As cities continue to sprawl and urban populations continue to grow, the remaining semi-natural areas within cities become ever more important (Crane and Kinzig 2005).

Although it is commonly assumed that this rapid urbanization has led to a reduction in urban green spaces (McDonald et al. 2010; Pauleit et al. 2005) in China, a recent study of urban green space change over the last two decades shows that green space has increased steadily over the last two decades, from 21.8% (1993) to 35.2% (2013) of total urban built-up area, an increase due partly to governmental encouragement to increase green space construction in urban areas (Zhao, Chen et al. 2013). Green space coverage is an index recorded in China’s early statistical yearbooks and is also one of the most important measures in urban green space planning, management and research (Fang 2008; Zhou and Wang 2011).

Even more than climate or geography, urbanization has a significant effect on green space coverage and urban green space conditions. Unlike in natural forests, however, green spaces in built-up areas in Chinese cities are mostly man-made, and are intensively cultivated (Zhao et al. 2013). While urbanization and urban sprawl cause the reduction of natural ecosystems in rural areas, they at the same time spur an increase in newly constructed urban green spaces (Zhao et al. 2013).

In the same green space study, among nine urbanization factors, three are closely related and are found to have the closest relationship with urban green space coverage and urban green space conditions; an identified built-up area, the population within area, and, finally, the population density in the area. The urban greening process is also closely related to government policy, urban planning, construction guidelines, and policies based on the classification of cities according to size. Thus, urban green coverage rate, urban built-up area, population in urban built-up area, and population density are all used as factors in defining study cities with similar existing urban green space conditions. These study cities could commonly share various urban green infrastructure strategies.

Xuchang and Similar Cities

Based on data from China City Development Statistical Yearbook 2012, a statistical summary factoring all Chinese cities (above county-level) is shown in below.

Table 2-3 Summary statistics of distribution of Chinese cities by urban built-up land area (km^2), table made by author

Mean	66.7
Upper 95% Mean	75.9
Lower 95% Mean	57.4
25% quartile	20.4
median	33.4
75% quartile	62.9

Table 2-4 Summary statistics of distribution of Chinese cities by population in built-up area (thousand), table made by author.

Mean	550
Upper 95% Mean	660
Lower 95% Mean	439
25% Quartile	155
Median	250
75% Quartile	464

Table 2-5 Summary statistics of distribution of Chinese cities by population density in built-up area (thousand/km^2), table made by author.

Mean	7.8
Upper 95% Mean	8.1
Lower 95% Mean	7.7
25% Quartile	6.3
Median	7.7
75% Quartile	9.3

Table 2-6 Summary statistics of distribution of Chinese cities by green coverage rate (%), table made by author.

Mean	36.5
Upper 95% Mean	37.2
Lower 95% Mean	35.7
25% Quartile	32.8
Median	38.5
75% Quartile	41.8

Urban built-up area and population in built-up area are factors used in describing city characteristics. Administratively, Chinese cities are divided into super-large, large, middle, and small cities (Ziyu and Wowo 2011). Accordingly, city land use policies differ among these designations. Usually, middle-sized cities are non-municipal and non-provincial capital cities. These are not the most developed and urbanized Chinese cities and are sometimes overlooked by researchers. Even so, a middle-sized city may have essential regional importance and influence as well as offering the economic conditions suitable for better urban green infrastructure (Zhang 2010).

In recent years, middle and small-sized cities have become important to sustained economic growth and social development of China. Problems common to larger cities such as heavy traffic, high housing prices, and high cost of living expenses have driven population movement from big cities to smaller ones. The period from 2010 to 2030 is projected to be a golden period for the development of Chinese middle and small cities. This trend toward smaller cities in China has not only provided cities a strong economic foundation, it has created new impetus for urban planning and an energized effort to provide citizens a greener living environment (Zhang 2012).

The focus of this study is urban green spaces in middle size cities. Middle-sized cities are defined as cities with a population between 155,000 (25% quartile) and 464,000 (75% quartile), with an urban built-up area from 20.4km^2 (25% quartile) to 62.9km^2 (75% quartile).

Population density and existing green coverage rate are related to cities' urban green space conditions. Increasing green coverage in urban areas can help a city mitigate environmental problems like air pollution and, to some extent, an urban heat island effect, all while providing more access to parks for urban dwellers. According to Zhao's research, cities with high green coverage in 2009 also had maintained high green space coverage over the previous two decades (Zhao et al. 2013). These cities already have strong natural environment resources, and can base future green space planning on existing natural characteristics, and established landscape features. Lowering population density mitigates the pressure of land shortage and can allow for increased green infrastructure as less land is used for residential and gray infrastructure (Chaolin, Liya, and Cook 2012). These factors provide more opportunity for green infrastructure possibilities in Chinese cities.

This thesis aims at utilizing these cities' existing healthy green coverage conditions, and integrating them into new urban green infrastructure networks. This narrows the study cities down to ones with a population density between 4,500 and 7,000 (km^2), and green coverage rate between 38.5% (median) and 41.8% (75% quartile).

To sum up, medium-sized cities with lower population density and a high green coverage percentage (Table 2-7) have, when compared with other cities, the best opportunities for successful overall urban green infrastructure. Studying these cities can provide examples and inspiration for cities with higher population density and less existing green coverage. Mid-sized cities with healthy green space may also be instructive to bigger cities with more complex conditions and issues.

The city government of Xuchang values its advantage in cultural and natural resources and has been very supportive in urban greening projects. The current Comprehensive Overall Plan of Xuchang (2005-2020) is about to be replaced by a new one (2014-2030), which is still in the making process. This is an opportunity for the study of green infrastructure planning in Xuchang to contribute to the new Comprehensive Overall Plan and Green Space System Plan, and to improve the ability of Xuchang's green space to provide ecosystem services for a better and healthier living environment for both residents and wildlife. Thus, Xuchang is chosen to be the main case study city, and the planning and design approaches developed in later Chapters for Xuchang are meant to serve as examples for other similar cities (Table 2-7).

Table 2-7 Study cities , made by author.

City	Urban built-up area (km^2)	population in built-up area (thousand)	Population density (thousand/km^2)	Green coverage area (km^2)	Green coverage rate (%)
Wuzhong	36.28	191.4	5.28	14.15	39.00
Zoucheng	41	248	6.05	16	39.02
Tengzhou	48.17	335.4	6.96	18.84	39.11
Zhaoyuan	29.5	172	5.83	11.65	39.49
Xuchang	**61**	**416.9**	**6.83**	**24.3**	39.84
Pingdu	48	258.8	5.39	19.19	39.98
Hezhou	31.01	180.5	5.82	12.51	40.34
Zhuanghe	37	186.3	5.04	14.94	40.38
Nanping	28.18	193.6	6.87	11.41	40.49
Jingyuan	60.39	393.3	6.51	24.48	40.54
Danjiangkou	27.6	155	5.62	11.21	40.62
Laiyang	42	286.9	6.83	17.07	40.64
Liuan	64.3	395.5	6.15	26.23	40.79
Penglai	25.53	156.6	6.13	10.47	41.01
Yongkang	34.58	158.9	4.60	14.19	41.04
Zhangqiu	38.5	253	6.57	15.82	41.09
Kaiping	31.3	201.4	6.43	12.9	41.21
Tongxiang	36	194.4	5.40	14.87	41.31

Barriers of Urban Green Space in Study Cities

Even though these cities are relatively less urbanized among Chinese cities, they are still very densely developed compared to other cities around the world, which makes urban green space and green infrastructure development very challenging. In addition, high green coverage rates are largely due to policy control and encouragement. For example, the threshold of green space coverage to apply for the National Garden City award is 35%, so a lot of cities put this as their primary target in city planning. However, the indicators used are mainly quantity control. The quality of urban green space, and the services that urban green space provides are not guaranteed, and many urban green spaces are in poor condition or are "unusable" spaces, and only built for a better "city perception" (Ma 2012).

There are nine major weaknesses and constraints concerning urban green space in the study cities, and some of them apply to most other Chinese cities as well. The first six issues are made up of observed existing problems of urban green space, and the following three issues relate to external constraints that have negative effects on future urban greening projects.

(1) Lack of system thinking and planning

In the overall planning phase, many middle and small cities do not pay enough attention to green space and landscape planning. As a result, green spaces are usually randomly filled-in at less important spaces just to meet minimum requirements. Street greenings, often made up of left over spaces between other land use boundaries and open spaces beside buildings, are commonly built without connections or corridors, and seldom combine to create efficient systems or networks (Ma 2012). Too often, urban public green spaces and landscape patches are fragmented and disconnected from each other and rural natural areas (Zhang 2010).

(2) Lack of public green spaces

People need public green spaces that are within walking distance of home or work, well-designed, and have suitable amenities. Unfortunately, because of the government's overwhelming power and lack of public input, public green spaces often focus on appearance instead of actual functions (Liu and Jiang 2002). Large green spaces are usually built next to government buildings to suggest or magnify their importance, and few people visit them for recreational purposes. Large amounts of both money and land are expended on spaces that are seldom used (Meng 2012).

(3) Aesthetic issues

Urban green space can enhance city aesthetics and help shape urban form (Laurie 1989). However, the aesthetic value of urban green space in Chinese middle and small cities are becoming the single foremost concern in planning process (Ma 2012). Community needs, ecological functions and cultural and historic context are frequently overlooked, and cities' long-term sustainable and ecological development can be threatened (Ma 2012).

The idea of "the newer, the better" only makes things worse. Natural plant communities are being replaced by "new" and "modern" landscapes as existing habitats are being destroyed. Another threat is "the bigger, the better." In most cases, large-scale green space is not suitable for medium-sized cities, yet many attempt to replicate the successful, large-scale landscapes of big cities. Sometimes these plans won't be carried out because of insufficient funding. In addition, water features are important element in traditional Chinese gardens, and some governments and even planners and designers tend to create artificial waterscape features in inappropriate conditions. Dams are built to store more water within cities, and areas are dug to create lakes in central districts, even in areas where water resources are extremely scarce, and in spite of other feasible water sources or recycling water (Zhang 2010).

(4) Ecological issues

Urban sprawl caused by rapid urbanization has diminished the surrounding natural ecosystem's regulating functions of urban areas. Urban green space in many cities has not efficiently mitigated the negative effects of urbanization. In central urban areas, the lack of green infrastructure has caused "heat-island" effects, inadequate carbon sequestration, and exacerbated air and water pollution. Simple plant structure and landscape types cannot provide a full-range of ecosystem services. Landscape fragmentation has sharply diminished wildlife habitats and biodiversity (Chaolin, Liya, and Cook 2012).

(5) Poor management

Many cities invite famous urban planning and design institutes to create their green space system plans, though a high percentage of these cannot be carried out thoroughly (Ziyu and Wowo 2011). The responsibility for creating urban green space along with its maintenance and management is often left unclear due to the lack of laws and regulations. This ambiguity allows government departments to avoid or shift responsibility. Green spaces are frequently overused or taken over by illegal construction or other usages, and plants are often in poor condition. Improvement happens and attention is paid only during environmental appraisals and censored periods (Ziyu and Wowo 2011).

(6) Value issues

Cultural and value reasons partially caused all issues discussed above. The lack of awareness of regional cultural values has allowed municipalities to overlook the importance of public green spaces and has led to a loss of traditional culture and historic heritage. The neglect of economic benefits of urban green space has had a negative effect on urban green space's development, restoration, and maintenance (Zhang 2010).

Despite economic and physical constraints, ecological issues are caused mainly by neglecting the ecological values of urban green space. The ecological services of urban green space can help regulate a city's micro-climate, absorb carbon dioxide and air pollutants, and mitigate heat-island effects, all combining to create a better living environment. Furthermore, cities not only provide a home for humans, but also for wildlife. It is now time to rediscover traditional views of nature, and to once more create harmony between human and nature, and consider the needs of other species. Only if we change our values, can our approach to urban green space achieve a step forward (Zhang 2010).

(7) Lack of public participation

As described in "Policy and Public Participation," the planning process is limited within political and technical groups. In most cases, Chinese citizens only have the "right to be informed" and not the "right to make decisions"(Meng 2012). People may examine published planning results and give suggestions, but are not allowed the opportunity to participate before or during the planning process (Meng 2012). There is no platform or established method for airing opinions from the public, and leaving people out of the planning process causes them to lose interest and passion (Meng 2012).

In addition, lack of public participation results in less outside investment in green projects, often leaving financially pressured city governments as the only funding source for public green space projects. Green spaces do have a positive economic effect, bringing additional value to surrounding land. City governments, though, have no way to profit from green space, nor do surrounding developers have much incentive to contribute to them (Meng 2012).

Furthermore, public green spaces can deteriorate with overuse, from being used inappropriately, or mismanaged. Lack of public participation tends to weaken the awareness that everyone is part-owner, of public green spaces and has a duty to protect them (Meng 2012). Having no adequate experience with the use of green spaces tends to make government management of them inefficient.

(8) Inefficiency of regulations and enforcement

The most commonly used regulating indicators of urban green space planning in Chinese cities are green space area per capita, park area per capita, green rate, and greenery coverage rate. These indicators control only the area of green spaces, not the quality of planning or design. In the detailed planning phase of residential districts, greenery coverage rate is usually used instead of stricter restricted green rate to meet the standards. This results in large portions of green space of poor quality, having scant grass and shrubs (Liu and Jiang 2002).

Government requirements are consistent among different cities, a policy which is easy to articulate, but harder implement, particularly because different cities have different needs and circumstances. Even though cities can be categorized by population and GDP, each cities' geography and natural history are unique, which should be reflected in urban green space regulations and policies. In addition, existing indicators are made for certain time periods, usually 5,10, 20, or 50 years, following the city overall comprehensive plan. Urban green spaces are part of urban ecosystems, and the time period necessary for an ecosystem to mature can be longer than urban development standards are designed to allow (Liu and Jiang 2002). Urban green space plans and relevant indicators should be adjusted accordingly. Also, urban green space's influence on a regional ecosystem extends beyond any particular urban development area. Scale and boundary are both regulating indicators which should be considered in different ecosystem contexts.

CHAPTER 3

XUCHANG, HENAN PROVINCE, CHINA

Xuchang is a historic city located in the middle of Henan province, China. The total area of Xuchang region is 187.52 km^2 with an urban built-up area of 61.2 km^2 (32.6% of total area of Xuchang region). The total green space coverage in the urban area is 24.3 square kilometers, and green coverage rate is 39.84% of total urban built-up area. Among the study cities defined in Chapter 2, Xuchang is one with a rich history and culture, as well as a good foundation and long history developing and protecting urban green space. It was designated as National Forest City in 2007 as one of the three cities with this award in Henan Province so far (State Forestry Bureau 2013).

Opportunities for further green infrastructure planning and development are inspired by the unique city pattern, which is shaped by a historic moat and two main river channels. Substantial green coverage and diverse types of green space and landscape including urban forest, street greening, and large area of riverside parks, also provide opportunities. The city government of Xuchang values the city's advantage in urban green space and is very supportive in urban green space construction (Zhong-xuan, Hui, and Zhi-yong 2010). The old Comprehensive Overall Plan of Xuchang (2005 – 2020) is about to be replaced by a new master plan; the City Planning Institute of Henan Province is just starting the process as of 2014. It is possible that this study can be taken into account in the planning process and contributes to the urban green infrastructure construction of Xuchang in the coming decades.

3.1 Historic, Economic and Ecological Context

Xuchang was founded in 100 BC during the Zhou Dynasty. It was established as the capital city of Wei in 196 AD, and became the political, economic and cultural center of ancient northern China. Xuchang is famous for its rich cultural heritage of the period of Three Kingdoms, and is listed as “Three Kingdom Culture Tourism City” by the Chinese national government. Modern Xuchang City was established in September, 1948.

Xuchang is located next to the capital city of Henan Province--Zhengzhou, and belongs to the Central Plains City Region. It has an urbanization rate of 29.5%, and the city GDP ranks fourth in Henan Province. Agriculture in the Xuchang region includes vegetables, flower and tree nursery, Chinese medicine production, and tobacco.

Xuchang is located on the Huaihai Plain. Its average slope is from 0.2‰ to 0.5‰, being higher in the west and lower in the southeast. It is in a warm sub-humid monsoon climate zone with four distinctive seasons. Spring is always dusty and dry. Summer is hot with a lot of rain. Autumn has clear, crisp weather along with long day light hours. Winter is cold and dry. Mean annual precipitation is 727.7 millimeters and falls mostly from June to September. Prevailing winds are from the northeast. There are five main rivers, 19 smaller rivers, with a total of 677 kilometers of river channels in the region. Groundwater in Xuchang is shallow, and mainly supplemented by rainwater infiltration. Xuchang is one of the 44 cities in China with severe water shortage.

Among the native wild animals living in Henan Province and the Xuchang region are tigers, leopards, hellbenders, gophers, musk deer, roe deer, minks, foxes, raccoons, hedgehogs, macaques, etc. The main bird species are pheasants, grouse, egrets, quails, cuckoos, and golden eagles. Chinese carp are the predominant fish species. Other animals such as amphibians, reptiles and crustaceans also live in Xuchang region (China Thematic Database for Human-earth System 2013).

3.2 Urban Area Descriptions

Development Zones

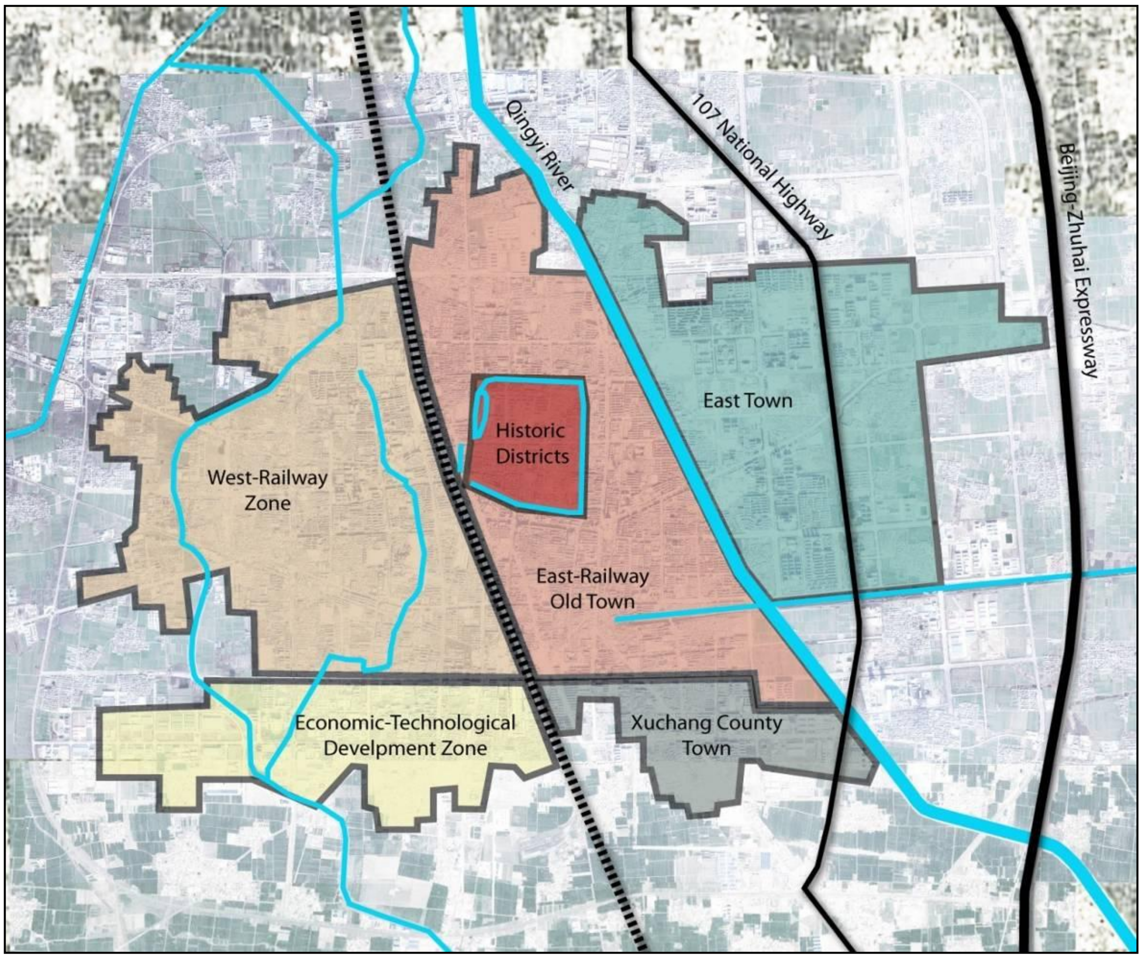

Figure 3-1 Existing development zones, map created by author.

The built-up, urban area of Xuchang consists of three main regions divided by the Qingyi River and the Beijing – Guangzhou Railway. The West-Railway zone was developed in 1960s to 1980s. It has industrial lands and residential neighborhoods. The building quality is relatively poor. Streets are narrow and fragmented. Green spaces are in short supply and there are large areas of vacant land.

The East-Railway Old Town has more mixed used districts. Important commercial, entertainment and public service buildings and utilities are concentrated in this zone. The historic districts of the ancient capital city of the Wei Dynasty is located in the center of this area and is surrounded by a historic moat, now known as the Shun River. Different land use types are mixed together, and many traditional residential neighborhoods are extremely compacted. Some newly built neighborhoods have more and better designed open spaces.

East Town is located at the east of Qingyi River. In recent years is has been rapidly developed. A new street system is being constructed as well as new residential neighborhoods. New government and office buildings are located or planned in this zone. The East zone is also the main entrance and gateway of the city of Xuchang, connecting it to Beijing-Zhuhai Highway.

There are two smaller zones south of the three main zones. The Economic-Technological Development Zone contains newly developed industrial land. Most of the people who work in these factories live in West-Railway zone. Xuchang County Town is an independent administrative small town governed by Xuchang city.

<u>Land Use</u>

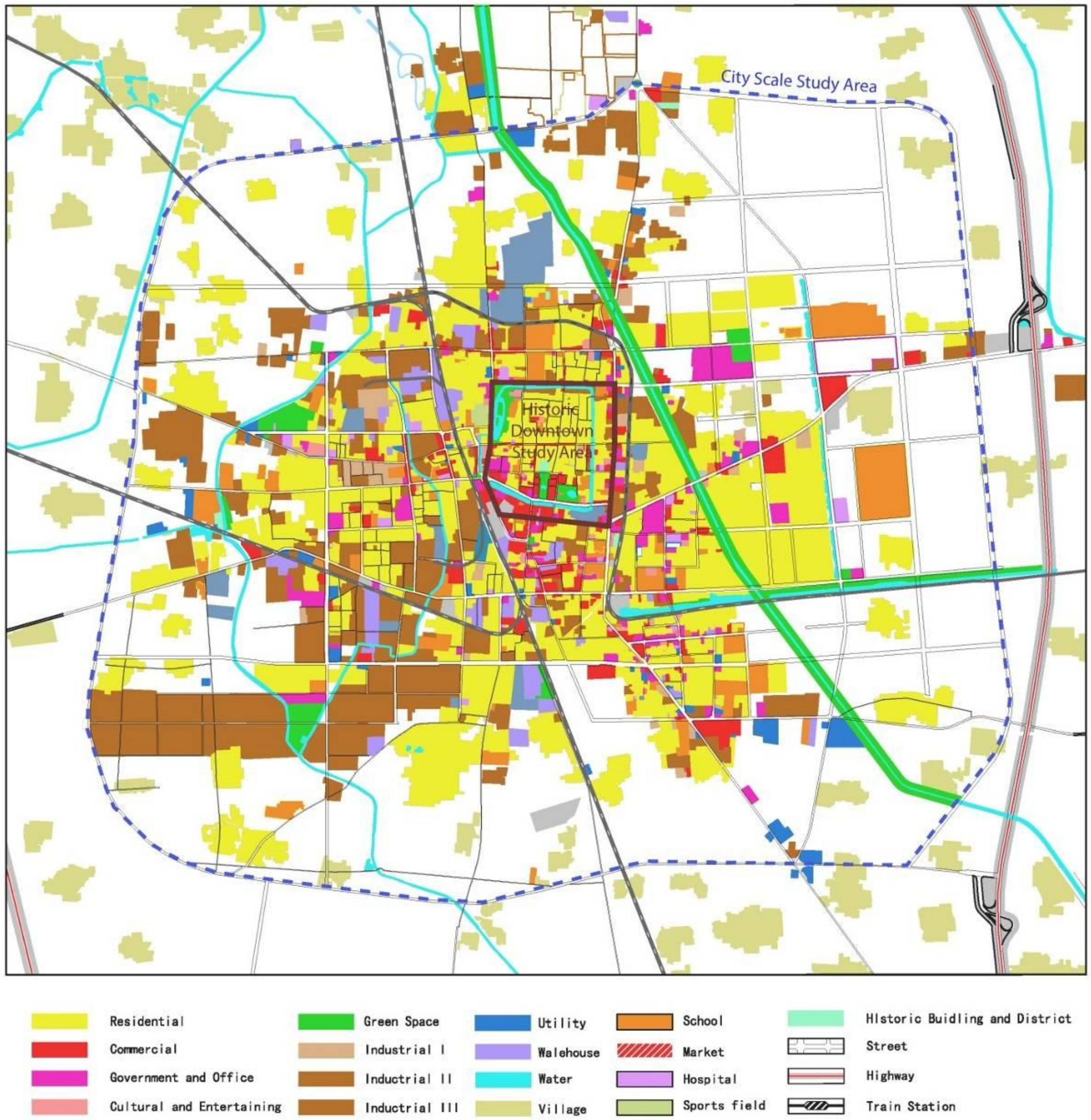

Figure 3-2 Current land use map, adapted from "Inventory Report of Xuchang Urban Development" (Xuchang Institute of Urban Planning and Design 2010). Note: Color scheme for land use types are based on "Standards for Classification of Urban Land and for Planning of Constructional Land (GB50137-2011)." The information of sub-categories of residential land use is missing in the reference resource, so all residential land is categorized together.

All of the urban development is within the outer ring road. Residences in the Old Town area are located within small blocks, while in East Town larger neighborhoods dominate the area. Commercial lands are concentrated in the central Old Town along the historic moat (Shun River) and Qiyi Road. Traditional industrial factories such as tobacco processing and textile are mainly in the West-Railway Zone; newer constructed factories are in the Economic-Technological Development Zone. Riverside greening is the major type of green space in Xuchang.

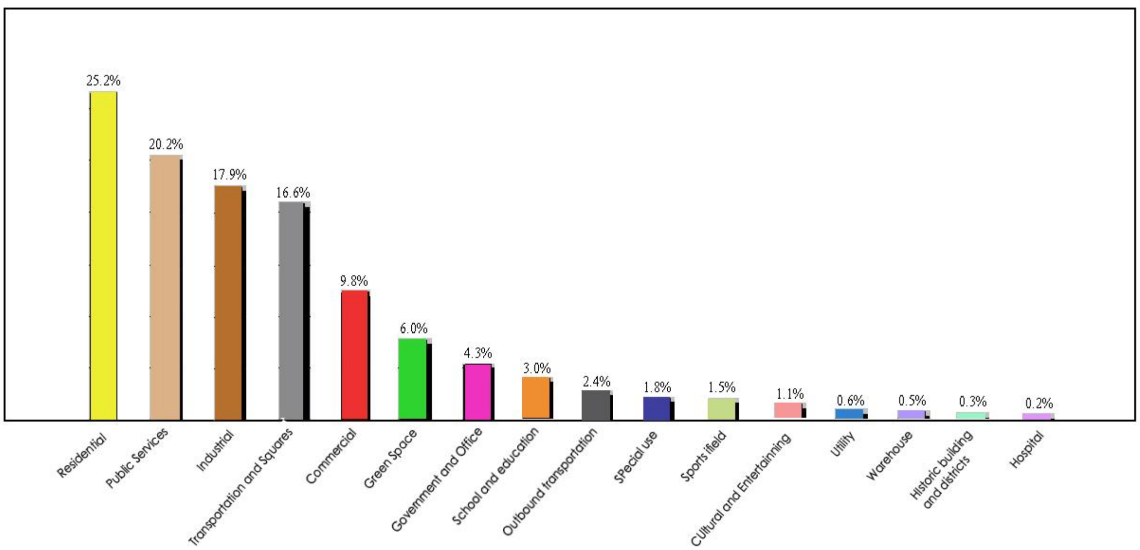

Figure 3-3 Current land balance index, graphic created by author based on data from Inventory Report of Xuchang Urban Development (Xuchang Institute of Urban Planning and Design 2010).

<u>Old Residential Neighborhoods</u>

There are two types of old residential neighborhoods in the built-up area of Xuchang. Traditional neighborhoods were built during the earliest urbanization period. The earliest existing communities were built at the beginning of the 20th century and are mainly in the East-Railway Old Town within and around the historic moat. They were built as traditional three-bay residential buildings facing streets and having backyards. Streets are still very narrow and planned before automobiles. As the urban area kept growing the surrounding villages were encroached upon, and farmlands were transformed into urban development; yet the residential buildings remained. Farmers lost their working croplands and began instead to have small retail businesses and rent their houses to migrant workers for income. This transformation of functions led to the change in the structure and environment of these neighborhoods. In both of the two types of old neighborhoods, land values increase. These residential locations in central cities lost open spaces to retail shops or restaurants. Safety and public health issues are severe in these neighborhoods. These neighborhoods need strategies to improve the living environment as well as retaining the traditions and their functions, which would support human communities in a more healthy way.

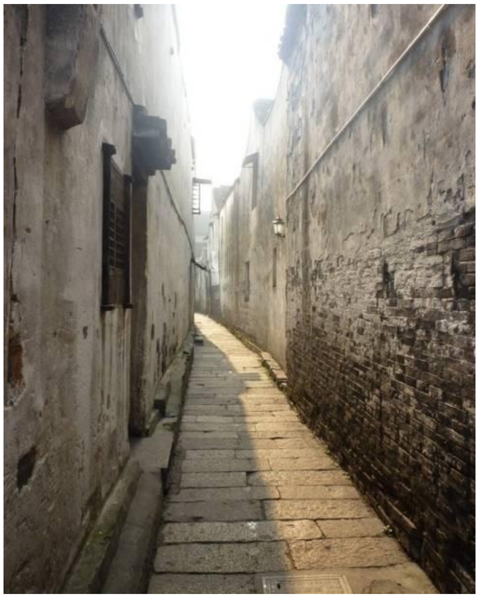

Figure 3-4 Traditional neighborhood roads in Xuchang. Photograph by author, 2012.

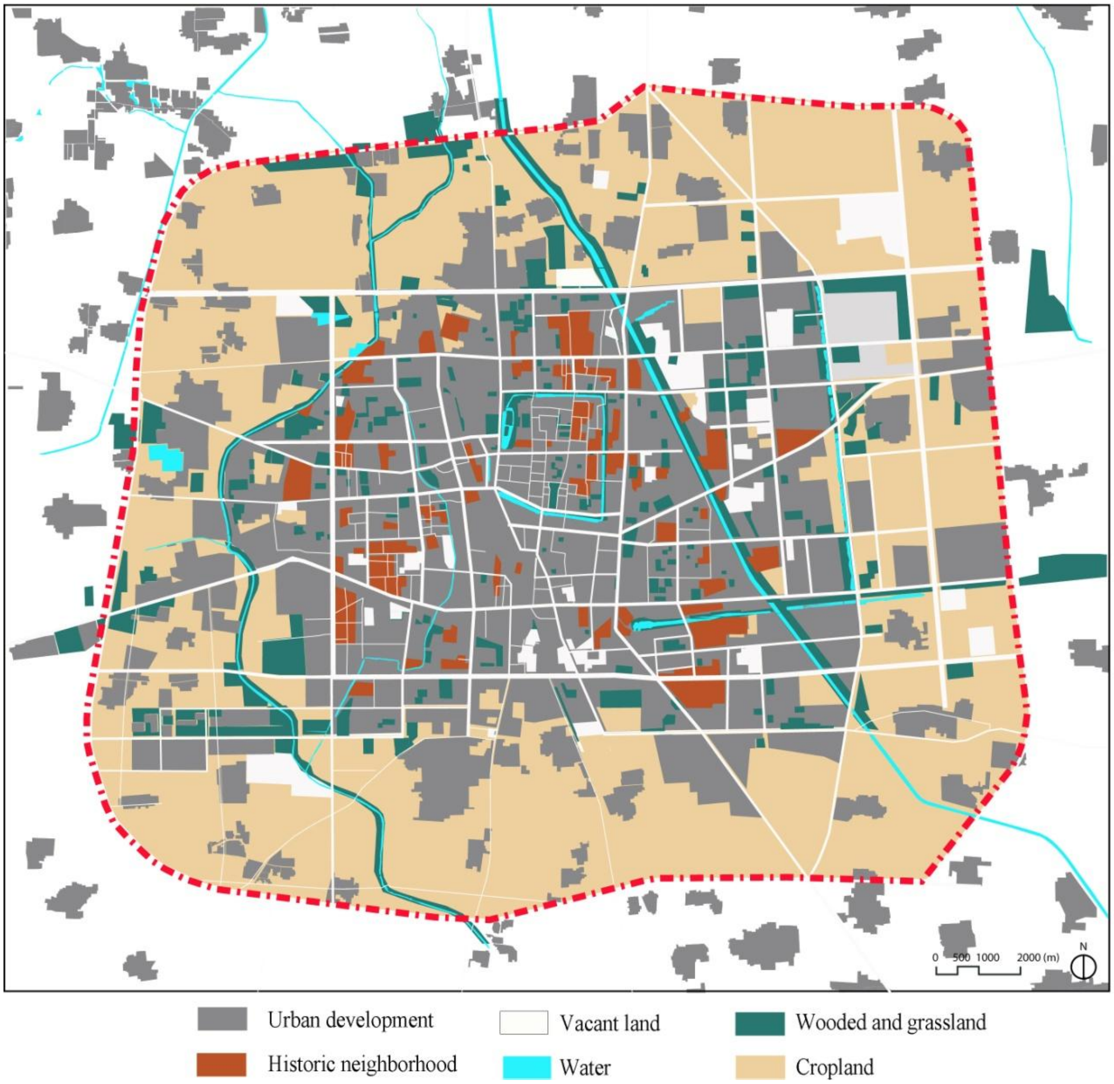

Figure 3-5 Historic neighborhoods and vacant land in Xuchang. map created by author.

Note: The map is derived based on Google Aerial map and field survey.

3.3 Urban Green Space

Land Cover

Figure 3-6 Land cover map created by author.

The existing land cover map of the built-up area of Xuchang shows that the city is compactly developed. The built-up area is surrounded by cultivated cropland with villages scattered among in those lands. Large wooded area and forest is very rare and mainly located on the urban fringe. In the built-up area, most wooded areas are along the Qingni River, Shun River and Qingyi River as buffers and parks.

Common native trees in Xuchang include Chinese junipers (*Juniperus chineensis*), cedars (*deodar*), persimmon trees (*Diospyross intenisii*), Chinese tallow trees (*Triadica loureiro*), Chinese white poplar bark (*Populus tomentosa*), Chinese scholar trees (*Styphnolobium japonicum*) , Willows, Silk trees (*Albiziajulibrissin durazz*) , etc. Native shrubs and popular landscape shrubs are crape myrtles (*Lagerstroemia indica*), Chinese redbud, Reeves' meadowsweet (*Spiraea cantoniensis*), winter sweet (*calyx canthus*), peonies (*Paeonia suffruticosa*), etc. Native animals in Xuchang include magpies (Pica pica), sparrows (*Passeridae*), vinous-throated Parrot bill (*Paradoxornis webbianus*), northern lapwing (*Vanellus vanellus*), siskins (*Carduelis spinus*), Kentish plovers (*Charadrius alexandrinus*), long-tailed shrike (*Lanius schach*), hedgehog (*Erinaceinae*), raccoon (*Procyon lotor*), macaque (*Macaca mulatta*), grass hare (*Lagurus ovatus*), yellow weasel (*Mustela kathiah*), etc.

Existing Urban Green Space Structure

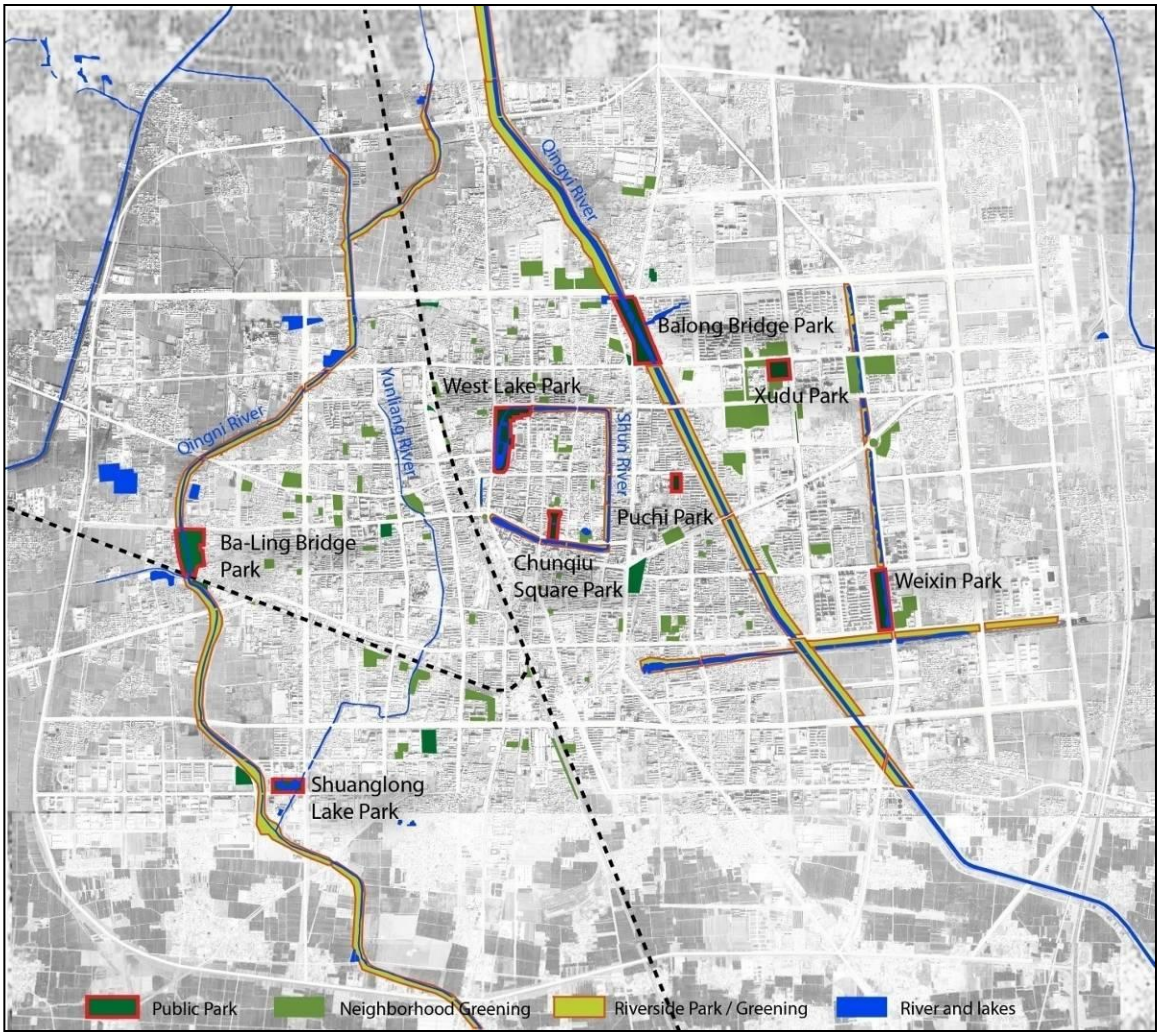

Figure 3-7 Existing urban green space map created by author.

Rivers of Xuchang

Three main rivers—the Qingyi River, the Qingni River and the Shun River--shaped the urban green space in Xuchang. The Shun River is the historic moat encompassing the historic districts of the ancient capital of Wei. The average width of the east river channel is 30m (about 90 feet). The north bank of south Shun River and the south bank of the north Shun River have three- to ten-meter green space buffers used as riverside parks that are vegetated, pedestrian accessible, and generally well designed for human use. Willows and native shrubs dominate the waterfront. The northern channel is connected with the West Lake in West Lake Park.

Figure 3-8 Waterfront landscapes of Shun River, winter photographs by author 2012

The river channel of the Qingyi River is 60 meters (approximately 180 feet), and has a 100-meter green buffer on each side. Green buffer zones are planted with pines and cedars. The Qingyi River is channelized with armored banks. Next to the bank are riverside parks built within riparian buffer zone that is accessible for pedestrians. This river channel allows for good recreational use and habitats for wildlife, especially birds. However, the plant communities are simplistic and plants are chosen for their aesthetic values only, rather than ecosystem support. Paths and plazas use impervious materials which weaken the infiltration and filtering function of the buffer. The riparian buffer zone of Qingyi River is more valued for their recreational functions for humans. They are frequently used by citizens who live within walking distance. The ability of these green spaces to provide ecosystem services and to maintain or conserve biodiversity still needs to be improved.

Figure 3-9 Waterfront landscapes of Qingyi River, winter photographs by author 2012

The Qingni River is an important water source for Xuchang. Fifty percent of Xuchang's water usage is from the Dachen Water Reservoir on the Qingni River (Zhong 2010). The average width of the Qingni River channel is 20 meters. Green Buffer is 10 meters on each side. Unlike Shun River and Qingyi River, Qingni River is more meandering. Riverside greening supports more natural environments which provide a productive edge for the thresholds between urban and rural communities. Qingni River connects to several important patches and parks, and has more complete ecological functions and cultural significance (Zhong-xuan, Hui, and Zhi-yong 2010).

Parks

In Chinese middle and small cities, parks tend to be used more by older people and children during workday hours (Zhong 2010). These groups access the parks usually by bus or on foot. Elderly people exercise, play music together, or simply just sit and talk to each other. At night, usually after dinner, many people take walks or gather together and chat in parks with their family or neighborhoods. During working hours people prefer visiting parks near their home, preferably within walking distance. During weekends and holidays, people may visit larger parks with more striking scenes and more varied amenities that are farther away.

Park design in Xuchang reflects and informs its rich history and cultural heritage. Large public parks such as West Lake Park, Chunqiu Square and Baling Bridge Park are important historic cultural landscapes, and they are representative of traditional Chinese gardens and views of nature. One problem of these large parks in Xuchang is that they are in "hidden" or otherwise not obviously available to the public. Although carefully designed, walls encircle them and they are disconnected from other green infrastructure and public open spaces. Often, they charge entrance fees. In author’s opinion, neighborhood parks and greening efforts that aim at providing a local service are rare and overlooked in the urban green space of Xuchang.

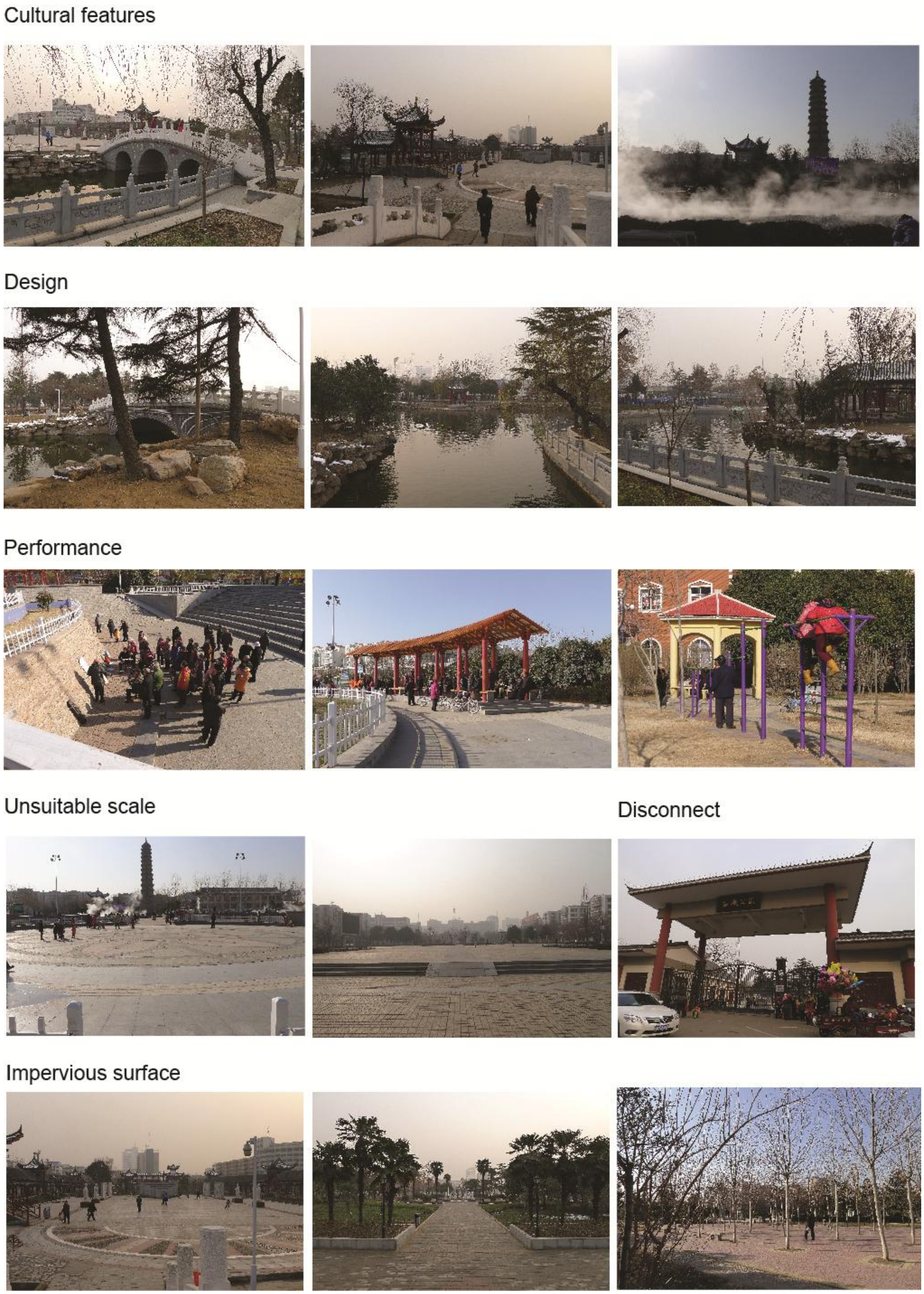

Figure 3-10 Beneficial and non-beneficial aspects of parks in Xuchang; photographs by author December 2012.

A further challenge is in regards to the impervious surface in public areas. the Turf survival is very difficult because of climate reasons in Xuchang ((Zhong-xuan, Hui, and Zhi-yong 2010). To reduce the maintenance labor and serve more people, parks have been designed with a lot of impervious pavement and concrete surfaces. To be able to offer more recreation and larger cultural events in these parks, some ecological functions and services are sacrificed (Zhong-xuan, Hui, and Zhi-yong 2010).

Street Greening Options in Xuchang

Figure 3-11 Street greening, from left to right: Main Street, secondary street, arterial street. Photographs by author December 2012

Street tree is an important part of urban green spaces in cities like Xuchang. Main streets in Xuchang consist of motorways, bike lanes and pedestrian paths. Vegetated median and street trees are used to separate different types of traffic lanes. Secondary streets and arterial roads also have lanes for cars and bikes, which in most cases have no medians and street trees are planted on the sidewalks.

3.4 Summary

Issues of Xuchang’s Urban Green Space

Based on the analysis of existing conditions of Xuchang urban development, several major issues exist:

A. Extension of human settlement is encroaching on the riverside green space, especially along the Shun River.

B. Currently, green spaces are scarcely distributed and are disconnected from life in the city .The locations of parks are mostly historical and cannot fulfill the needs of newly constructed neighborhoods. Finding parks, in general, can be difficult.

C. Urban green spaces in Xuchang are unevenly distributed. Most wooded areas are at the edge of developed areas and along the river corridors. The urban center is short of green spaces and parks. Residential areas don't have enough green space inside neighborhood yards, and there is not always accessible green space within walking distance.

D. Green spaces within built-up area emphasize aspects of beautification rather than ecological value, although both are very important for healthy environment.

E. The design of green spaces in Xuchang is not always at a human scale. Some of the huge squares are hardly used, which are also built for beautification rather than recreational values.

F. There are too many unnecessary impervious surfaces in Xuchang urban green space.

G. Urban green space types are too simple and "old-fashioned." Parks are traditional gardens. Streetscape sections and plantings are all the same. River corridors and riverside greenings are all alike and have the same design in built-up area.

These issues affect the well-being of both wildlife and humans. In the following chapters, systematic theory, methods and precedent cases will be studied to find suitable solutions to these issues and to enhance ecosystem services generated by urban green space in Xuchang.

CHAPTER 4

GREEN INFRASTRUCTURE

Urbanization threatens ecosystem functions (Alcamo and Bennett 2003). Existing barriers to enhancing urban green spaces in Xuchang require advanced and comprehensive approaches to improve environmental, social, and economic functions. Methods need to be explored to study the ecosystems functions to solve the problem of the overlook of ecological values of urban green spaces. Strategies are needed for enhance the benefits of both humans and wildlife derived from urban green spaces. The fragmentation of wildlife habitat, the accessibility and distribution issues of parks call for methods to link green spaces together to improve connectivity and form an interconnected green space and ecosystem network.

In the United States and in many European countries, the life-support services of ecosystems have come to the fore front of urban green space study. The concept of promoting ecosystem functions draws on the principles of landscape ecology, and linkages between ecosystems. The beneficial relationships between the access to green space and improving public health and well-being are increasingly recognized (Alcamo and Bennett 2003). These studies and concepts are being linked together in the theory called Green Infrastructure (GI). GI is considered supportive of both ecological processes and better human health and well-being. In urban regions, GI planning is as important as other essential urban infrastructure (Lafortezza et al. 2013).

In this Chapter, the theory of green infrastructure are reviewed. Relative approaches including ecosystem services and landscape ecology principles are also studied. Green infrastructure elements are also explored including urban forest, greenway, green roof, vertical greening and community garden.

4.1 Green Infrastructure

Benedict and McMahon define Green Infrastructure as an interconnected network of green spaces that conserves natural ecosystem values and functions, and provides associated benefits to humans, such as micro-climate regulation, recreational functions and visual enjoyment (Benedict and McMahon 2002). Traditional conservation approaches are typically isolated from, or in opposition to urban development (Lafortezza et al. 2013). Green infrastructure, on the other hand, connects ecological values and conservation actions to land development and built infrastructure planning (Benedict and McMahon 2002). It also creates a framework for environmental decisions, helps reduce the opposition between development and conservation, leverages and maximizes the return on investments in conservation and restoration.

Green infrastructure is a new idea which originated from two concepts: (1) creating linkages between parks for the benefit of people, and (2) connecting natural areas for preserving biodiversity and mitigating habitat fragmentation. Frederick Law Olmsted asserted that connected systems of parks and parkways are more complete and useful than isolated parks, and parks need to be linked together and to surrounding residential neighborhoods (Olmsted 1903). This idea of linking parks for the benefit of humans evolved in the modern greenway movement. Secondly, biologists and ecologists discovered long ago that an interconnected spatial system is the best way to preserve wildlife and ecosystems and prevent habitat fragmentation. Ecosystem management practices apply this knowledge by protecting and restoring connections between parks, preserves and other important ecological areas (Lafortezza et al. 2013).

In addition, two other important factors have influenced the concept of green infrastructure. One is identifying and protecting interconnected open spaces systems to benefit wildlife and ensure a sustainable future. The second is building upon the excitement and appeal of the modern-day greenway movements (Benedict and McMahon 2002).

The physical components of green infrastructure include: woodlands, open spaces, waterways, lakes, hedges, street trees, parks, gardens, agricultural land, grassland, and degraded land. Spaces can be natural, semi-natural, or human-built. These components are connected to form a network of “hubs” and "linkages" (Lafortezza et al. 2013). Hubs serve as origin and destination for wildlife, ecological process and people moving to or through them, such as urban parks and landscape patches. These hubs provide and protect critical ecosystem functions. Linkages are less wide features connecting hubs and enable the flows of people and wildlife through green infrastructure networks (Lafortezza et al. 2013).

Like other city infrastructure, green infrastructure should be planned before development along with other "gray" infrastructure such as roads and water and electric supply lines to ensure a city’s sound ecological functions and services. Also, green infrastructure planning should be implemented at different scales, from large regional planning or city planning to neighborhood and district design and planning (North West Green Infrastructure Guide 2007).

4.2 Ecosystem Services for Human Well-being

Green infrastructure provides significant ecosystem services, which are defined as “the benefits human population derives, directly or indirectly, from ecosystem functions” (Costanza et al., 1997). Ecosystem services studies the linkages between ecosystems and human well-being, and assesses the benefits that people obtain from ecosystems (Alcamo and Bennett 2003).

Ecosystem services have received increasing attention in China. Planned investments in ecosystem service payments there exceed 700 billion Yuan (96 billion dollar). The Natural Forest Conservation Program (NFCP) and the Grain to Green Program (GTGP) are among the largest programs of their kind in the world (Liu et al. 2008). However, compared to natural ecosystems, the ecosystem services of urban ecosystems are paid less attention to, and deserve more study (Bolund and Hunhammar 1999).

Ecosystem Services in Urban Areas

Ecosystem services are classified into three groups, which include provisioning services, regulating services, and cultural services (Capistrano 2005), shown in **Table 4-1**.

Although urban citizens are dependent on global ecosystem services to survive, services provided by urban green infrastructure are also important to the quality of urban life. Bolund and Per (1999) identified seven different urban ecosystems, including street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea, and streams, which are very similar to what are considered to be green infrastructure elements.

Table 4-1 Examples of ecosystem services provided by green and water areas in urban regions (adapted from Kremen 2005)

Group	Ecosystem service	Service generating unit
Provisioning services	Timber products	Different tree species
	Food	Different species in land and water
	Fresh water, soil	Groundwater infiltration, suspension and storage
Regulating services	Regulation of microclimate at the street and city level → changes in heating costs	Vegetation
	Gas cycles → Oxigen production, Carbon Dioxide consumption	Vegetation, especially forests
	Carbon sequestration and storage	Vegetation, especially trees
	habitat provision	Biodiverstiy
	Air pollution purification	Vegetation covered areas, soil microormanisms
	Noise cushioning in built-up areas and by transportation channels	Protective green areas, soft surfaces
	Rain water absorption→ Balancing storm water peaks	Vegetation cover, sealed surface, soil
	Water infiltration	Wetlands (vegetation, micro organisms
	Pollination→Maintaining floral populations→food production	Insects, birds, mammals
	Humus production and maintaining nutrient content	Litter, invertebrates, microorganisms
Cultural Services	Recreation of urban dwellers	Biodiversity, especially in parks, forests and water ecosystems
	Psycho-physical and social health benefits	Forest nature
	Science education, research and teaching	Biodiverstiy

The importance of various ecosystem services is different between urban and rural areas. In most cities, civic and cultural services are more important than provisioning services. Among the ecosystem services listed in **Table 3-1**, six are considered both locally generated and essential to urban areas: air filtering, micro-climate regulation, noise reduction, stormwater control, sewage treatment, recreational and cultural values (Bolund and Hunhammar 1999).

The ecosystem service of air filtering reduces air pollution caused by heavy transportation, industry and heating of buildings in many urban areas. It depends on the leaf area of vegetation filtering pollution and particulates from the air (Givoni 1991). The location and structure of vegetation affect the ability of air filtering. Up to 85% of air pollution in wooded park and 70% in street with trees can be filtered out (Bernatzky 1983).

The ecosystem service of micro-climate regulation helps mitigate heat island effects, which includes lowering local temperature and increase wind speed. This ecosystem service can be provided by all natural ecosystems in urban areas, such as water and vegetation. Water body can help even out temperature deviations. A mature tree can consume 1000 MJ of heat energy during evaporation process (Bolund and Hunhammar 1999).

The ecosystem service of noise reduction reduces noise pollution and its resulting health problems (Bolund and Hunhammar 1999). Soft ground cover such as lawn, vegetation and dense shrubbery help reduce noise, while vegetation such as evergreen trees can also act to shield the visual intrusion of traffic, making it less disturbing (Naturvardsverket 1996).

Stormwater control service provided by vegetated areas can help mitigate the problem of increased runoff, decrease peak flood discharges, and reduce water pollution resulting from increasing impervious surfaces in urban areas. This ecosystem service depends on the filtering, evaporating, and transpiration functions of vegetation (Bolund and Hunhammar 1999).

Sewage treatment service provided by urban ecosystems, mainly in wetlands, is under experiment in many cities worldwide. This ecosystem service depends on abilities of wetland plants and animals to assimilate nutrients and slow the flow of the sewage water. To improve the sewage treatment service and water quality, successful wetland restoration and biodiversity are very important (Bolund and Hunhammar 1999).

Recreational services of urban ecosystems include the providing places to play and rest for urban citizens and reduce stress. Vegetation and wild animals contribute to the recreational values of urban ecosystems. All urban ecosystems also provide cultural and aesthetic values, and help improve the psychological health of citizens (Gómez-Baggethun and Barton 2013).

Valuing Ecosystem Services

The importance or value of ecosystem services can be classified into ecological, socio-cultural and economic values (Capistrano 2005). Ecological value means the health state of ecosystems, measured with ecological indicators such as diversity and integrity. Socio-cultural values mean the level of importance people give to them, just as they would to cultural identity, for example, or historic heritage. Economic value includes both use and non-use values associated with a resource, which is usually measured with money (Groot et al. 2010).

Although many have been critical of economists for trying to put a “price tag” on nature, loss of ecosystem services in urban areas often involves economic costs in many forms, and economic valuation is very important in trade-off analysis in decision-makings (Groot et al. 2010). Methods of calculating monetary values of ecosystem services are used worldwide, and some socio-cultural values are translated to monetary values.

Because of the importance of ecosystem services valuation in China, Costanza (Costanza et al. 1997) estimated the current economic value. Based on Costanza's work, Xie (2003) extracted the equivalent weight factor of ecosystem service per hectare of terrestrial ecosystems in China and modified the value coefficient of Chinese ecosystem, by surveying 200 Chinese ecologists (Ge 2012) (Table 4-2).

Xie's approach is a good reference for roughly estimating ecosystem service values in Chinese cities, especially in those without the capacity of conducting more city specific research, and are in need the numbers in making land use planning decisions. However, Xie's results are not aimed specifically at urban ecosystems and corresponding services, and an urban environment will influence some of the values, giving more value to those mainly locally generated for urban dwellers, such as recreational and cultural resources.

Table 4-2 Ecosystem Services Value Unit Area of Chinese Terrestrial Ecosystem (yuan/ha) (Adapted from Jim and Chen 2009)

Ecosystem services	Forest	Grassland	Cropland	Wet land	Water body	Barren land
Gas regulation	3.97	707	442	1592	0	0
Climate regulation	2389	796	787	15130	407	0
Water supply	2831	707	530	13715	18033	26
Soil formation and retention	3450	1725	1291	1513	8	18
Waste treatment	1159	1169	1451	16056	16086	9
Biodiversity	2884	964	628	2212	2203	300
Food produce	88	265	884	265	88	9
Raw material	2300	44	88.5	61	9	0
Recreation and culture	1132	35	8.8	4910	3840	9
Note: 1 Chinese Yuan = 0.16 US Dollar						

In cities where ecosystem services are assessed and used as base in land use planning or green infrastructure planning, such as Dujiangyan (Ge 2012), Panyu (Integrated Urban Land-Use Planning Based on Improving Ecosystem Service: Panyu Case, in a Typical Developed Area of China 2011) and Xingguo (Hualin, Jinzheng, and Jing 2012), only part of ecosystem services or value dimensions are examined, and these are primarily monetary values. Description or measurement of symbolic, cultural, identity, and other non-economic values remain largely unexplored. These too are very important and deserve more exploration, especially in a country of such rich history whose values and beliefs once focused so closely on nature.

Ecosystem Services for Green Infrastructure Planning in Xuchang

Table 4-3 Ecosystem services inventory in Xuchang (adapted from Bolund and Hunhammer 1999)

	Ecosystem services	Indicator	Green infrastructure
Provisioning Services	Food supply	Production amount of fish, meat and vegetables	Cropland Community garden River and pond urban agriculture
	Tobacco production	Production amount	Tobacco plantation
	Plants materials	Production amount of ornamental plants and saplings	Seedling plantation
	Fresh water supply	Total mount of water	Water storage of river, lake and pond

Table 4-3 Ecosystem services inventory in Xuchang (Continued)

	Ecosystem services	Indicator	Green infrastructure
Regulating Services	Air Filtering	CO_2 sequestration O_2 production Removal of noxious gas and particles	All green infrastructure
	Microclimate Regulation	Leaf area m^2 index; Temperature decrease by tree cover × area of plot trees cover (^0C)	All green infrastructure
	Noise reduction	Leaf area (m^2) and distance to roads (m); noise reduction dB (A)/ vegeration unit (m)	Buffer woods; street trees; shrub buffers; soft covers, eg. Grassland
	Water flow regulation and runoff mitigation	Soil infiltration capacity; permeable surface	Permeable surface; rain garden; roof top garden;
	Waste treatment	P, K, Mg and Ca in mgkg−1 compared to given soil/water quality standards	Urban wetlands
	Habitat and corridor provision	Species diversity and abundance of birds, fishes, aquatic organism, bumble bees and vegetation	All green infrastructure
Cultural Services	Recreation	Surface of green public spaces; area in shade; amenities; number of people in park; survey	parks; grassland; river; riverside parks; trees
	Aesthetic Pleasing		All green infrastructure
	Educational	Researches and outdoor classes	Parks; river; wetland
	Sense of place	Use of native plants; landscape uniqueness; survey	Native plants; landscape integraty
	Cultural heritage	preservation of cultual landscapes and historic trees; traditional values embeded in landscape design	

4.3 Landscape Ecology Principles for wildlife

Landscape ecology studies the biodiversity patterns and natural process in landscape mosaics. The focus of landscape ecology is on the spatial, structural pattern of a landscape or region, a pattern composed of three elements; patches, corridors, and matrix. These three elements form the land mosaics. The spatial language of landscape ecology is similar to that used by landscape architects and land use planners, and is easily applicable in GI planning (Dramstad, Olson et al. 1996). Key principles of landscape ecology are summarized and can be easily used in land-use planning and landscape architecture (Dramstad, Olson et al. 1996). These principals can also serve as a useful guide for the wildlife conservation and biodiversity considerations in GI planning in Xuchang.

Terms

Key terms used in landscape ecology were defined by Richard Forman in his book Landscape Mosaics: The Ecology of Landscape and Region (Forman 1995), and are paraphrased below:

- Patch: Patch is a relatively homogeneous area that differs from its surroundings (Forman 1995).

- Edge: Edge means "the portion of an ecosystem near its perimeter, where influences of the adjacent patches can cause an environmental difference between the interior of the patch and its edge (Forman 1995)."

- Corridor: Corridors are "narrow strips of land which differ from the matrix on either side. Corridors may be isolated strips, but are usually attached to a patch of somewhat similar vegetation (Forman 1995)."

- Network: Corridors connected with one another form networks. Networks focus on the functioning of landscapes and may be used by planners and landscape architects to control “flows and movements across a land mosaic (Forman 1995).”

- Matrix: Matrix is the “background ecological system,” the most extensive and connected element of a landscape, and it can be continuous, discontinuous, or web-shaped (Ingegnoli 2002).

- Mosaic: Mosaic describes the pattern of patches, corridors and matrix that form a landscape in its entirety. Pattern and scale are two major terms used to describe and evaluate the overall structural and functional integrity of a landscape mosaic (Dramstad, Olson, and Forman 1996).

Principles

Landscape ecology principles that should be considered in landscape design and land use planning are briefly addressed in Forman's book. The author divides these principals into four groups: patches, edges/boundaries, corridors/connectivity, and mosaics.

Patches of animal and plant habitats are scattered in developed urban areas. They are different in size, number and location. Normally, larger patches tend to support more species, making it less likely for particular species to go extinct locally. Dividing a large patch into two smaller ones will lead to the increase of edge habitat, which reduces the potential for interior species. Small patches can provide supplemental functions, serve as stepping stones for plants and animals, or may contain uncommon species. Patch removal caused by urban development will lead to habitat loss and reduction of population size of a species. Usually, more "unique" patches which have rare species, or patches which contribute most to an overall ecosystem should be given high priority in making conservation decisions (Dramstad, Olson, and Forman 1996).

Landscape edges have edge effects that support distinctive species composition or abundance. The shape and width of edge and boundary of patches directly influence the nutrients, water, energy, or species flowing through (Dramstad, Olson, and Forman 1996). Usually, coves and lobes along an edge, curvilinear "tiny-patch" boundaries, and edges with high structural diversity will support more edge species, have greater habitat diversity, less soil erosion, and provide more overall ecological benefits. But, a more convoluted patch will cause the decrease of the number of its interior species. In most common cases, the ecologically optimum patch shapes have a rounded core to protect its interior species, while also having curvilinear “legs” and “arms” stretching out to increase edge areas, connectivity and opportunity for species dispersal (Dramstad, Olson, and Forman 1996).

Habitat isolation is one of the major results of species loss, and the reduction of biodiversity. Corridors for wildlife movement form important linkages between habitat patches and landscape connectivity. Corridors' five basic functions include habitat, conduit, filter, source, and sink, which are determined by a corridor's width and connectivity (Dramstad, Olson, and Forman 1996). Similarity in vegetation structure between corridors and large patches usually makes it more possible for interior species to move between patches. A row of or cluster of small patches can serve as stepping stones to provide connectivity, although the connection is less effective than corridors (Dramstad, Olson, and Forman 1996).

Network connectivity and network circuitry affect the effectiveness of linkages for species movement through a ecological network. High circuitry indicates more alternative routes in a network and more efficiency of movement. Intersection effect usually occurs at the intersections of corridors, where some interior species exist and higher species richness occurs. Also, a small patch connected to or near a network tends to have richer species than a similar but isolated patch. In addition, a series of small patches or nodes along a corridor or network are important for species bred within the network and the dispersal of these species (Dramstad, Olson, and Forman 1996).

Due to change of landscape mosaic caused by human activities, fragmentation as a landscape pattern has increased and become an issue worldwide. Fragmentation leads to isolation and loss of habitat, especially interior habitat (Dramstad, Olson, and Forman 1996). Although isolated, fragmented patches often exhibit similar reactions when facing an outer force such as development, and essentially maintain their same pattern despite the reduction of size (Dramstad, Olson, and Forman 1996).

According to Forman, "a coarse-grained landscape containing fine-grained areas" (Figure 4-1) is the most ecologically beneficial grain size of mosaics (1996). To develop strategies of protecting biodiversity, the study of fragmentation should include landscape changes at different scales. A habitat that can be viewed as fragmented may be "perceived as intact habitat at a broad scale (Dramstad, Olson, and Forman 1996)." Usually, a finely grained habitat can be used as continuous habitat for many species, especially generalist ones, while a coarse-grained habitat is considered discontinuous for most species, especially specialist ones (Dramstad, Olson, and Forman 1996).

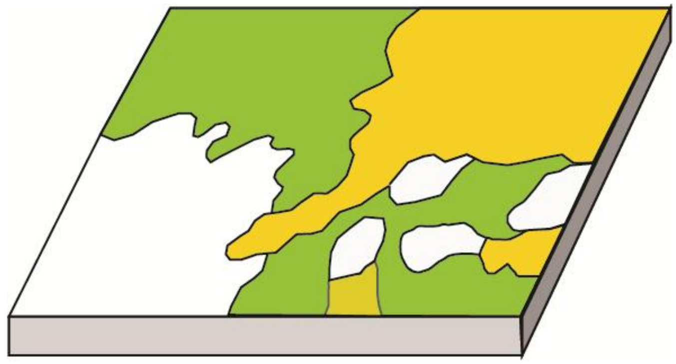

Figure 4-1 Ecologically beneficial grain size of mosaics, graphic created by author based on Forman 1996.

Urban ecological networks are the outcome of the principles of landscape ecology. In urban areas where landscapes are fragmented, ecological networks may be the only way to provide wildlife corridors. Also, recent ecological networks tend to utilize all types of ecological spaces in urban areas, including traditional "ecological" spaces like urban forests, woodlands, public parks, river corridors, private gardens, and street greenings, but also newly noticed space types like industrial sites, brown fields, vertical surface spaces such as green walls or vertical gardens, roof top spaces like green roofs or rainwater harvesting, and even including pervious pavements. (Ignatieva, Stewart, and Meurk 2011).

Landscape Ecology Principles for Xuchang

According to the landscape ecology terms and principles discussed above, and urban green space issues analyzed in Chapters 2 and 3, a series of strategies based on landscape ecology principles are suggested for the urban green infrastructure planning and design in Xuchang. These strategies are categorized under patch, edge, corridor, and mosaic, shown in Table 4-4. The table references "Ecological principles and requirements for the urban greening in Beijing Province (Feng, 2005)."

Table 4-4 Strategies based on Landscape ecology principles for Xuchang (adapted from Li and Wang 2005)

Concepts	Principles
Patch	1. Preserve the area of existing patches, avoid spliting or enroach by urban development. Rank the larger patches and linking patches in higher hiarchy in conservation process. 2. Enhance the biodiversity of patches and the ecosystem condition of plant communities to provide healthier habitat for birds, small mammals and insects. 3. Reduce the impervious serface in urban parks and forest. Use pervious pavement. 4. Define areas that are not allowed of construction and only limited contruction allowed.
Edge	1. Increase diversity of edge shapes, incorporating coves, lobes and fingers. 2. Increase the complexity of plant communities. 3. Use soft edges and small patch outreaches if applicable, especially in water banks. 4. Define boundaries of ecologically protected areas and create buffers again damage.
Corridor	1. Preserve the width of river corridors which enrich its vegetation structure with native plants. 2. Collect major river corridors with patches and avoid gaps. 3. Street greenings are important potential corridors that should be prioritized and designed to provide functional corridor services. 4. Stepping stones should be used to maintian or create connectivity. Unilize neighborhood greening, pocket parks and street parks. 5. Small patches should be provided along corridors.
Mosaic	1. Improve the connectivity and circuitry of GI Network. 2. Fragmented and isolated patches, corridors and other green infrastructure should be integrated and planning systematically. 3. Alternate routee should be provided incase of gaps or disturbances. 4. Corridor density and mesh size should be case specific depending on existing landscape and urban pattern. 5. Intersections of corridors have high species richness and should be payed more attention to. 6. Increase the diversity of landscape types including coarse-grained and fine-grained areas.

4.4 Green Infrastructure Elements

Achieving a comprehensive green infrastructure plan for enhancing ecosystem services in China's urban environment will involve green infrastructure elements developed and successfully implemented around the world. These elements include the use of urban streams, creating urban parks and forests, construction of green streets, green alleys and roofs, community gardens, and rain gardens. These approaches are proposed for green infrastructure planning in Chinese cities.

Urban Forests

Urban forests refer to wooded areas located within a city, and are integral components of green infrastructure. Forests can provide significant ecosystem services, such as air filtering, offsetting carbon emission, microclimate regulation and recreational services (Jim and Chen 2009).

The studies of urban forests in China mainly focus on three themes; analysis of urban forest structure, the ecosystem services urban forests provide, and the planning and management of urban forests. Jim and Chen (2009) recently researched ecosystem services of the urban forests in several major Chinese cities. This finding shows a high-level of ecosystem services generated by urban forests, namely landscape enhancement, education, biodiversity conservation and restoration, wildlife habitat, and erosion control (Jim and Chen 2009).

In Xuchang, urban forests are found mostly in parks or riparian buffers. These forested areas represent the main habitat patches in the city. However, these parks and green spaces are mainly valued for their recreational use, and large areas of impervious pavements and concrete surfaces have been built within them to provide spaces for recreational activities. With so many people relative to parks and forests readily available to them, these green spaces are often overused. Also, many urban forests in Xuchang are disconnected and isolated, which affects their accessibility by wildlife, and threatens the preservation of the whole urban ecosystem network. Strategies such as ecological design and conservation, and connecting Xuchang’s urban forest resources using greenways and pedestrian systems should be considered in the green infrastructure plan.

Greenways

Greenways are an important linkage element of green infrastructure, and central to the concept of green networks, which focus on the visual connectivity and recreational functions of urban green space. In the 19th century, European, greenways were constructed to provide accessibility to open space and green space, and to connect urban and rural areas (Ignatieva, Stewart, and Meurk 2011). Early greenway applications in the United States were led by the Olmsted brothers (Fábos 2004). The greenway movement in the United States and Canada and the green corridors movement in Europe lead to the development of urban ecological networks (Ignatieva, Stewart, and Meurk 2011). Modern greenways and ecological networks are designed to incorporate "biodiversity conservation, storm water management, recreation, and visual quality" (Hellmund and Smith 2006), and use many landscape ecology features (corridors, patches, matrix and connectivity) and landscape architecture principles (pedestrian and bicycle circulation). The particular feature linking these functions and principles together is the greenways' liner character (Ignatieva, Stewart, and Meurk 2011).

The greenway movement in Asia is expanding, especially in China, Japan and Singapore (Fábos and Ryan 2006). In China, although the term greenway is relatively new, many similar concepts and plans have been applied during its long history. Greenways in China are mainly found in three configurations; riparian greenways along rivers and water channels, greenways along transportation corridors, and greenways along farmland for wind protection. The functions of greenways in China are usually seen as protective and productive, with little consideration given to recreational use of greenways for cycling and hiking. Problems such as uniformly planted trees, single usage, and lack of science-based understanding of greenways and ecological networks need to be addressed as China begins to adopt a strategic modern greenway approach to the urban green infrastructure planning (Yu, Li, and Li 2006).

Until recently, the application of greenways worldwide has focused on single functions such as wildlife corridors and recreational parkways. Today, comprehensive greenways are beginning to draw increased attention (Teng et al. 2011). Maximizing a greenway's usefulness by designing for multiple functions can save money, land and resources; all is crucial in developing cities with high density to preserve ecosystem functions and services.

Riparian Greenways

River corridors are an important element of urban ecological networks, and act as cultural and recreational resources as well (Roy et al. 2005). Urban streams and riparian buffers provide important corridors for wildlife, store groundwater, filter waste and runoff, and provide access to water and water features for urban dwellers. Urban streams are also important components in greenway and green infrastructure systems.

An urban stream study investigated stream corridors and the factors which are important for integrating them into the Urban Greenway Plan (Asakawa, Yoshida, and Yabe 2004). The study focuses on nearby residents' perceptions and expectations of stream corridors. Residents indicated factors that were most important to them. The study found five factors that are most important; recreational use, participation, nature and scenery, sanitary maintenance, and water safety. According to the factor scores, the study concluded that when designing stream corridor greenways and integrating them with city green networks, the most important points are enhancing the ecological environment of the streams, enhancing circulation systems for recreational purposes (trails and bikeways), and integrating natural and cultural characteristics of surrounding areas. Other suggested strategies compiled by researchers include constructing or preserving stream buffer, maintain plant community for biodiversity, build more green spaces or parks along the streams, connecting the streams to parks and other green spaces, and maintaining water quantity (Asakawa, Yoshida, and Yabe 2004).

<u>Greenways Along Traffic Routes</u>

(1) Park Connectors

In Singapore, a park connector network was proposed by the Garden City Action Committee in 1991 (Tan, 2006). The term park connectors here refers to greenways "linking major parks, nature reserves, natural open spaces and other places of interest in Singapore (Tan, 2006)." For effective connectivity, drainage buffers, road reserves and additional public land are each utilized in greenway construction. Singapore's Garden City Action Committee proposed a basic typology for greenways on road reserves, recommending "a minimum width of 1.5m for footpaths, 2.0m for cycling paths while retaining 2.0 wide planting strips (Tan, 2006)." A street narrower than 5.5m is considered not suitable for greenway development according to the committee's recommendations. In addition, connections at road crossings are considered critical to ensure human traffic flowing along a continuous green network. Signalized traffic lights, underpasses or overhead bridges are also part of the committee's recommendations, depending on site and traffic conditions.

Figure 4-2 Kallang Park connector, photographs by Tan. In: "A Greenway Network for Singapore (Tan 2006)."

(2) Neighborhood Greenways

Neighborhood greenways are residential streets with light automobile traffic traveling at low speeds where bicyclists and pedestrians are given priority. The city of Portland, Oregon has devised a citywide network of safe, traffic calmed streets where people on foot, on bike and at play are given priority. There "neighborhood greenways" help improve the health, sustainability and livability of the city. The city does not designate a particular part of the street for the exclusive use of people riding bikes. Instead it highlights the presence of bikes to remind everyone to share the road safely. Design strategies used for these neighborhood greenways are: speed bumps and traffic diverters, which helps deter traffic from neighborhood streets and to slow existing automobile traffic along greenways; using pavement markings to alert drivers to expect bicyclists, building improved crossings and curb ramps make pedestrian mobility easier and safer; using markings on the pavement and other signage to provide direction and indicate nearby parks and business districts (Portland Bureau of Transportation 2014).

Figure 4-3 Neighborhood greenway in Portland, Oregon. Portland Bureau of Transportation, *Neighborhood Greenways*, 2011, https://www.portlandoregon.gov/transportation/50518.

(3) Green Streets

Green streets have planted street-side planters or swales that capture storm water runoff and help it soak into the ground, thus allowing soil and vegetation to filter pollutants. Storm water is considered a resource to replenish groundwater supplies in green street projects instead being seen as waste water. Green streets are also attractive streetscapes, provide aesthetic values to city streets, and can be designed to accommodate the different requirements of automobiles, pedestrians, and bicyclists. In addition, green streets can serve as greenways and habitat corridors for birds.

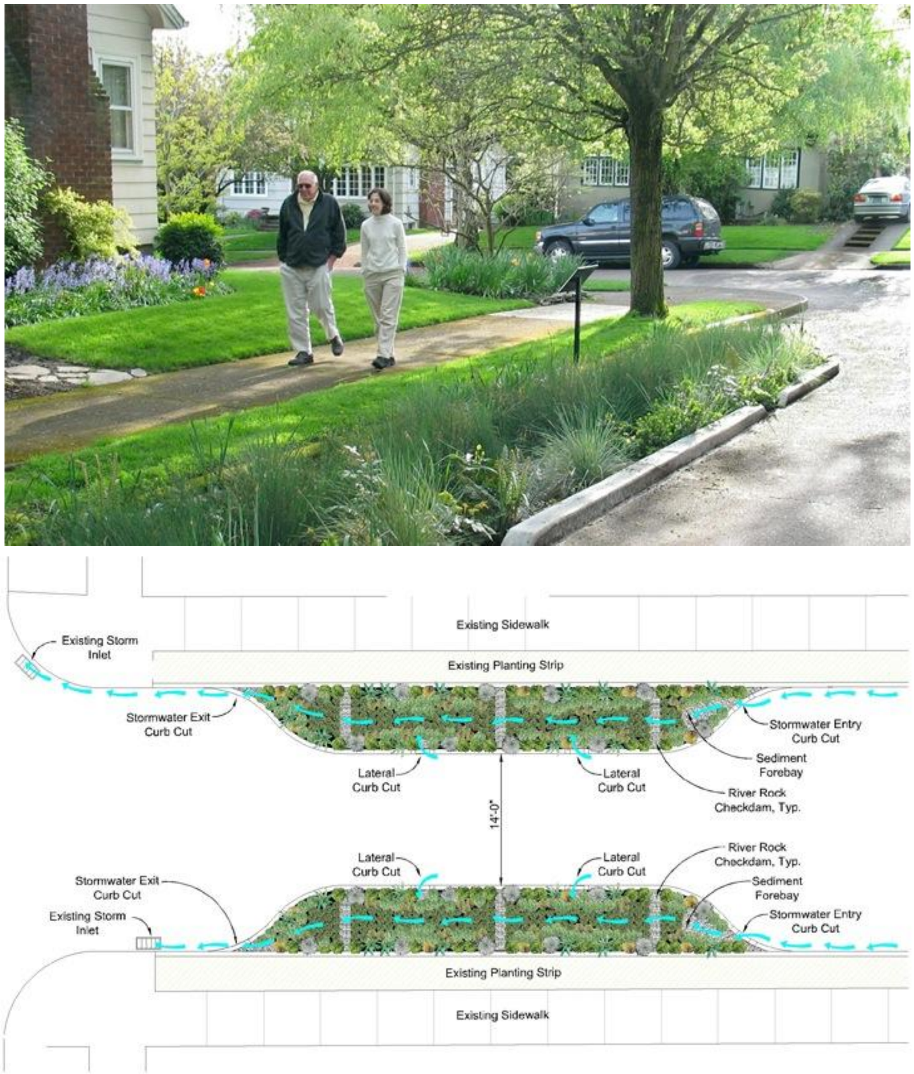

Figure 4-4 Green street strategy, adapted from Kevin Robert Perry, *NE Siskiyou green street in Portland, Oregon,* 2006, http://www.asla.org/sustainablelandscapes/greenstreet.html.

(4) Green Alleys

An innovative strategy is emerging among cities in Chicago, Baltimore and Los Angeles, which is to green long-neglected back alleys to achieve a suite of ecosystem services and public health goals. The potential benefits of alleys as green infrastructure include facilitating urban runoff management through infiltration, groundwater recharge, heat island reduction, and expanded wildlife habitat (Wolch et al. 2010). Benefits from this strategy include improving ecosystem functions such as air filtering, water regulation and runoff mitigation, and micro-climate regulation.

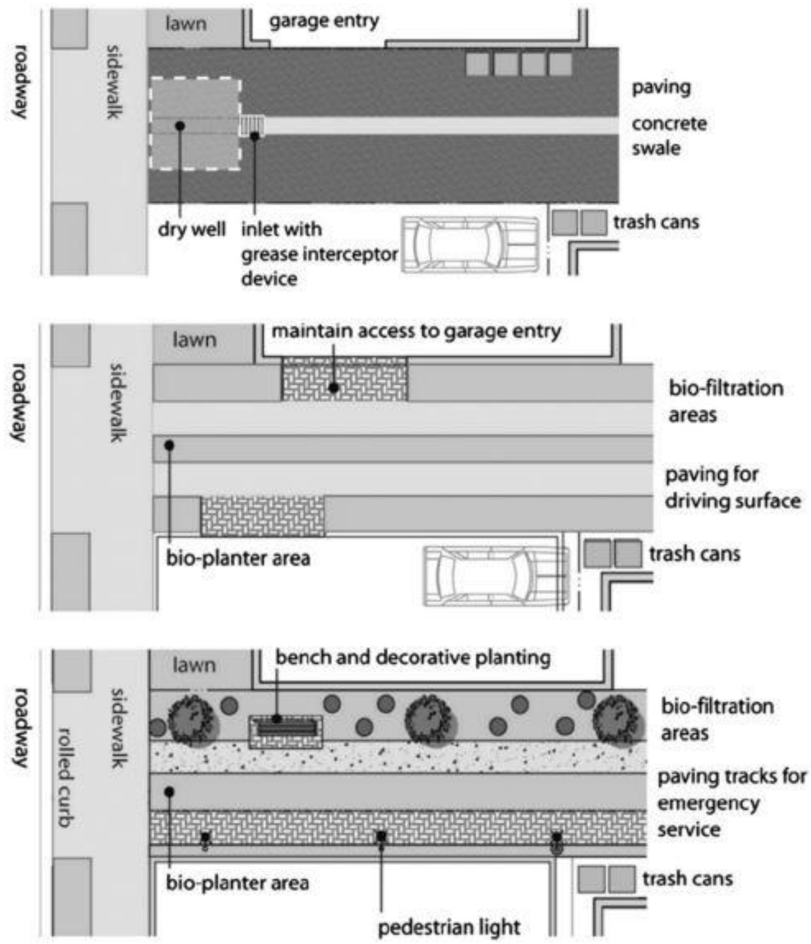

Figure 4-5 Select options for alley greening. From top: infiltration of rainwater with drywell; use of bio-filtration borders and reduced paving; full conversion to pedestrian use. Graphics adapted from City of Los Angeles Green Alleys Subcommittee, *Select Options for Alley Greening*. In: " Green Alley Programs: Planning for a sustainable urban infrastructure ? (Newell et al. 2013)."

Other Green Infrastructure

(1) Green Roof and Vertical Greening

A green roof is a layered roof system designed to provide the ecosystem services of mitigating a heat island effect and absorbing a limited amount of rainfall. In densely developed urban core area such as Xuchang's historic downtown area, green roofs also fill recreational and aesthetic functions. Green roofs can also be designed together with community gardens to supply vegetables and fruit. The layers of green roof include a waterproof membrane, a drainage mat, a root barrier, growing medium, and plants serving as a created ecosystem. A related concept is that of a blue roof, or roof pond, which uses a roof to store water (usually from rainfall) for reuse, such as irrigating a green roof or helping cooling a building (Teemusk and Mander 2009).

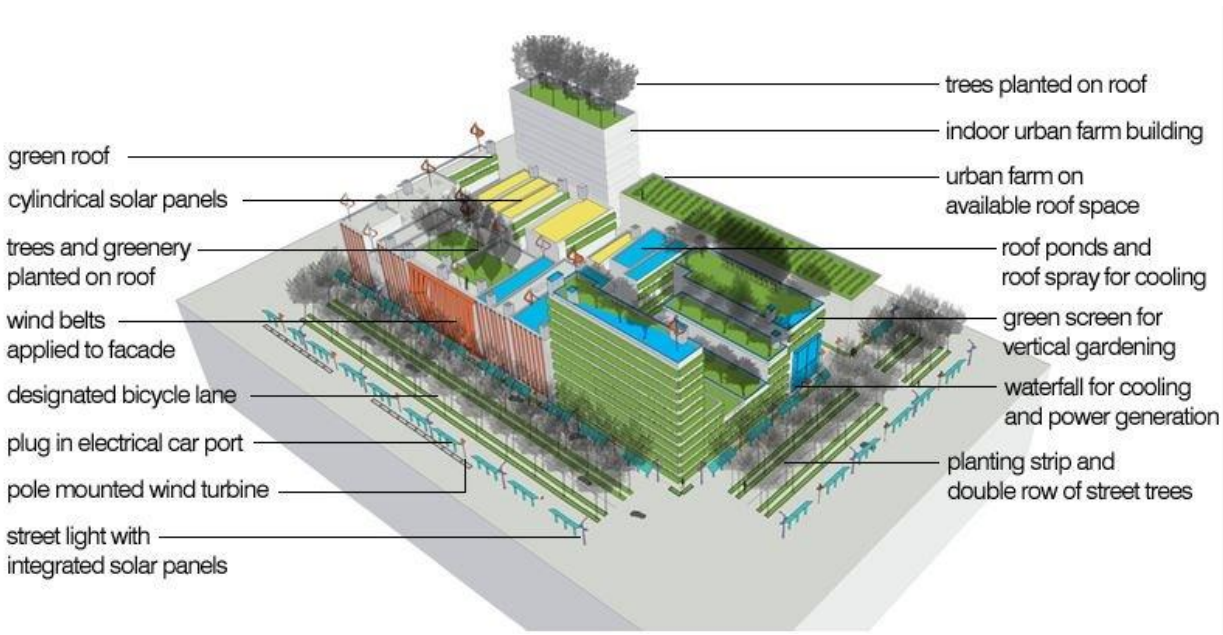

Figure 4-6 Green roof and vertical greening strategies, adapted from Urban Omnibus, *Green Roof and Vertical Greening Strategies*, 2007, http://www.greeninfrastructurewiki.com/page/Blue+Roof.

(2) Community Garden

Community gardens are places adopted, managed and tended by volunteers where community members can grow ornamental and food plants. Community gardens can be designed along with neighborhood greening in residential neighborhoods and as part of rooftop greenings. They also promote healthy communities and create recreational and therapeutic opportunities for a community (Ghose and Pettygrove 2014).

Figure 4-7 Comella community garden in Cleveland. Photograph by Jeff Schuler, 2007, http://upload.wikimedia.org/wikipedia/commons/6/62/2007_Comella_community_garden_ClevelandOH_1353039387.jpg.

Growing food in backyards was a tradition and common activity in China. With urbanization, most Chinese people now live in cities apartments and have little or no access to garden space. Community gardens provide an opportunity for urban dwellers in China who wish to grow their own food. In addition, in Xuchang and other similar Chinese cities, the urbanization process has included elder people who were farmers in the countryside. Now often living with their children, these elders are often eager to grow plants and food if given an opportunity to do so. Community gardens can provide this opportunity as well as contribute to the physical and psychological health of those who use them.

4.5 Summary

Green infrastructure contributes significantly to an urban environment and its inhabitants (Mansor 2012). In this Chapter, green infrastructure approaches including ecosystem services and landscape ecology principles are reviewed. A variety of green infrastructure elements including urban forest, greenway, green street, green roof, community garden have also been explored.

Green infrastructure offers significant ecosystem benefits, defined as “the benefits human population derives, directly or indirectly, from ecosystem functions (Costanza et al. 1997).” These ecosystem benefits or services are classified into three groups; provisioning services, regulating services, and cultural services (Capistrano 2005). Important ecosystem services derived from green infrastructure in Xuchang were identified in this Chapter and will inform the goals and objectives of green infrastructure planning in the study cities.

Landscape ecology studies the spatial structural pattern of a landscape or region, and includes the study of three types of elements: patches, corridors and matrixes (Dramstad, Olson et al. 1996). Forty-five principles of landscape ecology that should be considered in landscape design and land use planning are studied, and strategies for urban green infrastructure planning and design of Xuchang and other similar study cities based on these principles are proposed.

A variety of green infrastructure approaches are being implemented around the world. Urban forests are integral components of urban green infrastructure, and provide significant ecosystem services, such as air filtering, offsetting carbon emission, microclimate regulation and recreational services (Jim and Chen 2009). Greenways are an important linkage element of green infrastructure, incorporating "biodiversity conservation, storm water management, recreation, and visual quality" (Hellmund and

Smith 2006). Greenways include many landscape ecology features (corridors, patches, matrix and connectivity) and landscape architecture principles (pedestrian and bicycle circulation). Green roof, vertical greening and community garden approaches can help mitigate heat island effects, absorb rainfall, and can help enhance the social and physical health of neighborhood residents. These strategies underpin design interventions for Xuchang and are discussed in the next chapters.

CHAPTER 5

PRECEDENT CASES ANALYSIS

This Chapter explores the theoretical approaches to green infrastructure planning discussed previously using three examples of precedent projects. Because GI planning approaches are relatively new to China, most relevant examples of completed projects are from the larger provincial capital cities, which tend to have better academic and economic resources. Although much larger than Xuchang and the other study cities, these wealthier cities are similar to the study cities in terms of population density and green coverage rate. Likewise, the development goals of the larger cities also apply to the study cities.

One precedent case is that of Nanjing's Comprehensive Green Space Planning, which is aimed at creating an integrated green space network to provide recreational functions, wildlife habitats and environmental benefits (Jim and Chen 2003). The Kunming Greenways Project is the second case study. Completed by the landscape architecture firm of Turenscape in 2009, the completed project is large enough in scope to impact the entire region of Kunming, not just the city itself. Four distinct networks were planned, including a wildlife habitat network, a cultural heritage network, a pedestrian-bicycle transportation network, and a greenway network. Combined, these networks serve as the ecological infrastructure to help drive renovation of urban development adjacent to the greenway system. The third precedent project is that of new park planning in Bonab City, in Iran. Different from the comprehensive urban green space planning approaches in Nanjing and Kunming, the Bonab City project focused on public parks planning based on the Analytic Hierarchy Process (AHP) and a suitability analysis.

5.1 Nanjing: Comprehensive Green Space Planning

Introduction

Nanjing is the capital city of Jiangsu Province. The built-up areas of Nanjing total 194km^{2,} and accommodate 2.47 million people, with a density of 12,700 people/km^2. The Comprehensive Green Space Plan of Nanjing City was completed in 2002 by Hong Kong University and the Institute of Geography and Limnology in the Chinese Academy of Sciences, this plan aimed at facilitate for future urban expansion, green field acquisition, recreational functions, wildlife habitats, and other environmental benefits. The plan consists of greenways, and green extensions that incorporate urban green areas at a metropolitan scale, city scale and neighborhood scale, based on landscape ecology principles (Jim and Chen 2003). The city scale and neighborhood scale green space planning will be the focus in this Chapter.

Nanjing's urban built-up area is much bigger than Xuchang’s, but the density and green coverage rate are similar to that of Xuchang and other focal cities. Nanjing also shares similar spatial features with Xuchang, such as an historic urban core, with nearly 2000 years of history, abundant urban streams and water features, and good urban green space foundations with generous tree cover.

A series of hills located from east to west form the watershed between the Jinchuan and Qinhuai River valleys. On upland, parks have been built, preserving semi-natural to natural areas within urban area of Nanjing. Nanjing's drainage system is defined by two lakes, Xuan Lake and Muchou Lake, and two rivers, Qinhuai River and Yangtze River. Qinhuai River bifurcates into a cluster of tributaries spreading into south Nanjing. The main branch, running along the ancient city-wall, is called Outer-Qinhuai. South Nanjing is more densely populated than the north. Buildings are densely situated, separated only by narrow streets, with scant open spaces. The north side of Nanjing city has more government agencies and institutional lands. Residential neighborhoods in Nanjing are mostly built in the closed-yard style and were built after 1949 (Wu, 1993).

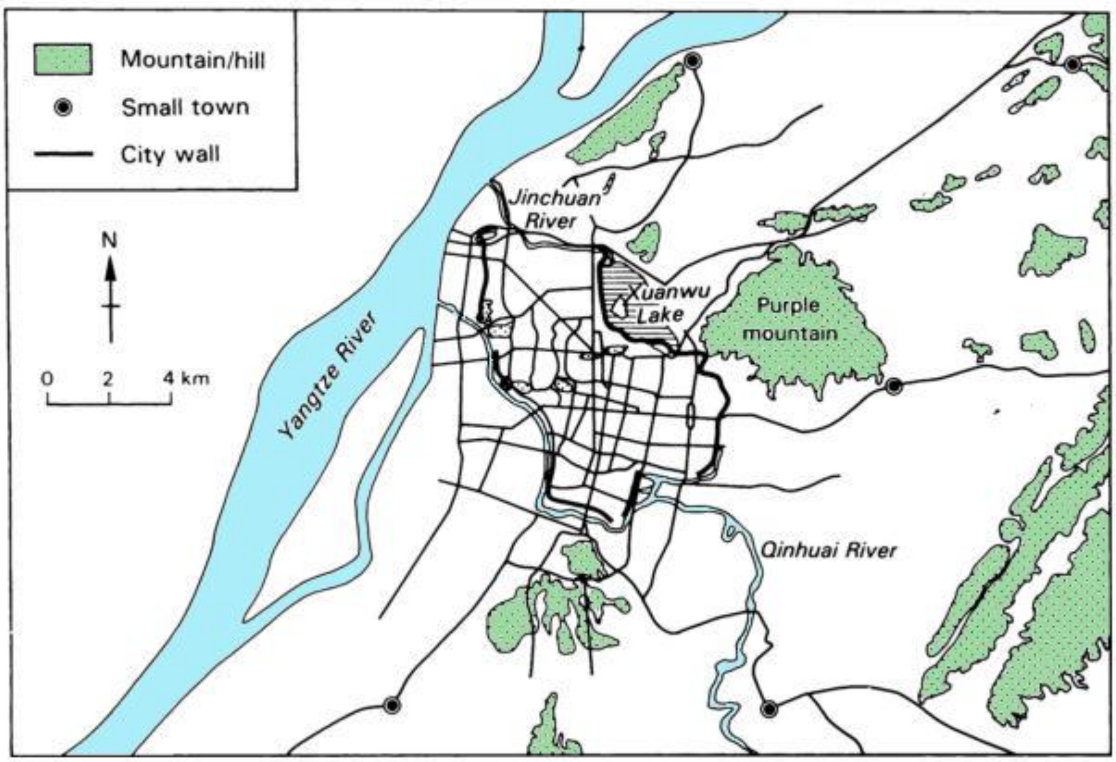

Figure 5-1 Graphic adapted from Jim and Chen, *Major landform features, main roads and old city-wall of Nanjing*. In: "Comprehensive green space planning based on landscape ecology principles in compact Nanjing City (Jim and Chen 2003)."

Methods

(1) Conservation Elements Assessment

First, the conservation elements of urban green spaces in Nanjing are identified, which include existing open spaces, cultural relics, historic sites, wildlife species, and wildlife habitats. Existing open spaces in Nanjing include urban parks, plazas, and small pocket parks, all of which are important components in the greenway system. One Hundred Forty-two historic cultural features have been identified as having the potential to enrich the attraction of Nanjing's greenways and recreational services. The Ming Dynasty city-wall landscape belt was previously incorporated into the Comprehensive Overall Master Plan of Nanjing, and is also part of the greenway plan, which specifies fewer main streets going through the green belt, with remaining streets designed to facilitate access to green spaces.

(2) Greenway Network Planning

The proposed greenway network of Nanjing is based on the existing landscape, urban context, and conservation considerations (Figure 5-2). A proposed city-wall circular greenway would follow the remnant portions of the Ming Dynasty city-wall, which is 21 km long, and has been almost completely hidden behind nearby buildings and spontaneous vegetation. The remaining in-tact city wall is equipped with easy access, simple facilities and a trial lined by vegetation. Linear woodland corridors are used to connect fragmented walls to fill the gaps. Ten existing parks are already located along the wall perimeter, all featuring significant natural and cultural resources. The proposed greenway connects them and enhances their accessibility and the recreational opportunities they provide. New parks are also proposed. These would be located at the intersections of streets and the greenway to from nodes or hubs.

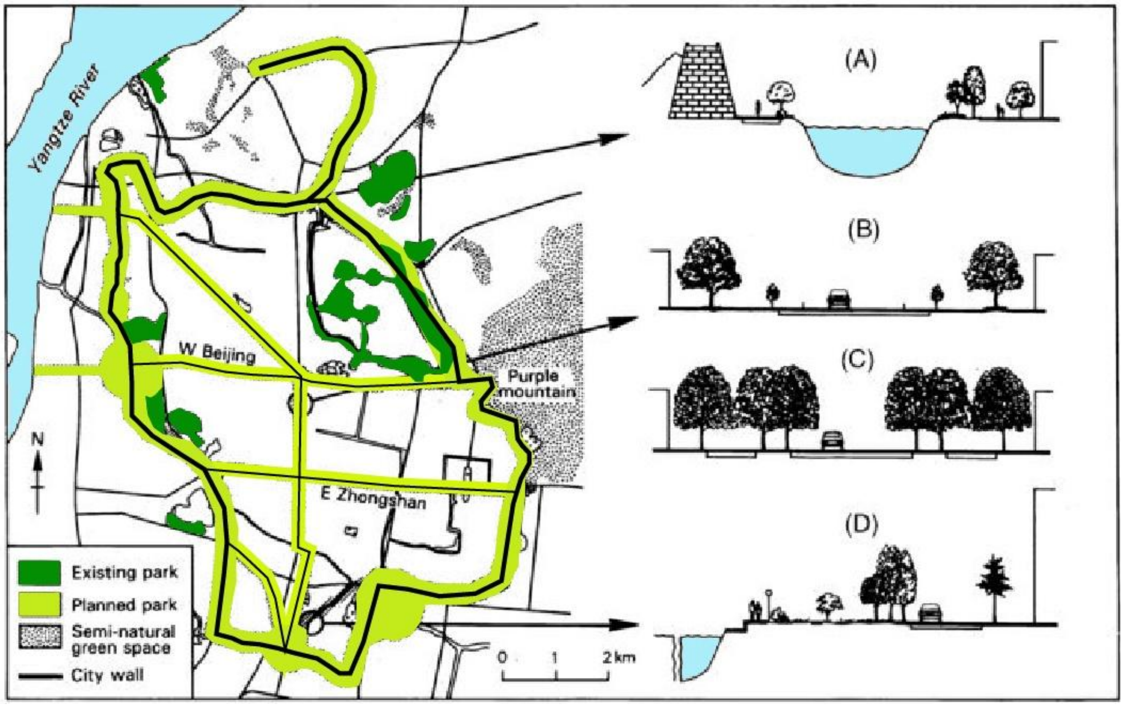

Figure 5-2 Proposed greenways in Nanjing:(A) city-wall circular greenway; (B) canopy-road greenway exemplified by the Zhongshan Road parkway; (C) Zhongshan Rad parkway before it was degraded by the recent tree removal; (D) Inner-Qinghuai-River greenway. Graphics adapted from Jim and Chen, *Proposed greenways in Nanjing*. In: “Comprehensive green space planning based on landscape ecology principles in compact Nanjing City (Jim and Chen 2003)."

A tree-lined road makes up part of the proposed greenway. Zhongshan Road would link the main commercial centers of Nanjing, and would serve as a symbolic city axis. Zhongshan Road was originally designed as a 40m-wide parkway influenced by the early 20th century American parkway movement (Wilson, 1989). The street trees had reached huge dimensions and provided significant cooling effect and noise reduction services. However, in 1994, a road widening project removed the four rows of trees along the middle of the parkway. At that time, remaining trees were also threatened by ever-increasing traffic demands and conflicts between trees and adjacent buildings.

Figure 5-3 Development history of Zhongshan road. Left: Zhongshan road in 1937, photograph by Xing Li, 1937, http://image.baidu.com/i?ct=503316480&z=&tn=baiduimagedetail&ipn. Middle: Zhongshan road in 1995, photograph by Xu Hu, 1995, http://www.zhulong.com. Right: Zhongshan road in 2005, photograph by Zhuoheng Xu, 2009, http://world-hzrb.hangzhou.com.cn/system/2009/09/08/010169405.shtml.

A proposed canopy-road greenway would restore the degraded parkway. Strategies included: reducing carriageways and improving transportation management to retain the same traffic capacity as well as to provide more growing space for trees for at least; trees, shrubs and grasses should be established as a native and natural plant community; set up a minimum 6m distance between tree trunk and buildings to reduce conflicts; and, a separated pedestrian-bicycle path parallel to carriageways was proposed, along with footbridges and underpasses.

The Inner-Qinhuai River greenway is planned along the south branch of Inner-Qinhuai River, which runs through Nanjing's old urban center. This part of the river is 4,069m long and 12-30m wide. Some historic buildings from Ming (1368-1644) or Qing (1644-1911) Dynasties are preserved along the river where in ancient times rich people lived. Modern Nanjing shifted its center north from old downtown to Xinjiekou Districts. Buildings in the old downtown are in poor condition, green and open spaces are being encroached, and the river is being polluted by sewage. The Inner-Qinhuai River greenway is aimed at shedding light on the old downtown with a linear park, a waterfront esplanade and a green street (Figure 5-2 D). A pedestrian path is proposed, which would run through the linear park along the rehabilitated riverbank to provide accessibility to waterfront. Historic buildings can also be incorporated in the linear park, adding important cultural features. This greenway can improve the living environment and public health of the old downtown area, and attract commercial development for revitalization (Jim and Chen 2003).

The City-wall circular greenway, the Canopy-road greenway, and the Inner-Qinhuai River greenway form the primary framework of Nanjing's green system. Additional greenway corridors are also planned to interweave with or extend from the major greenways to make connections and constitute a greenway network within urban fabric of the city. Furthermore, proposed greenways would extend into neighborhoods, along existing streets and along river corridors. Historical canals and urban streams are also essential locations of these greenway extensions into compact residential neighborhoods. Six river corridors and three new parks at road junctions adjacent to the rivers with recreational facilities, shaded pedestrian and bike access and forest strips are proposed as extensions of main greenways (Figure 5-4).

Figure 5-4 River corridors strategies: (A) location of the target area; (B) layout of the six green corridors; (C) design recommendation for the green corridor. Graphics adapted from Jim and Chen, *River corridor strategies*. In: "Comprehensive green space planning based on landscape ecology principles in compact Nanjing City (Jim and Chen 2003)."

(3) Neighborhood Greening

Jim and Chen suggest that green extensions at neighborhood scale provide social functions such as encouraging informal community meetings, providing access to nature, and creating a hometown sense of place, ecological benefits, and noise reduction (2003). The proposed projects would also be designed to reduce energy consumption, sustain rare plant species, and enhance wildlife habitats (Jim and Chen 2003). The neighborhood greening elements in Comprehensive green space planning of Nanjing include riparian linkage, a pedestrian route, street greening, new parks, green walls, and green roofs.

5.2 Kunming: Kunming Greenways

Introduction

Kunming is the capital city of Yunnan Province, China. It is located in the fertile lake basin of the Yungui Plateau. The city is known for having one of the mildest climates in China and for its Dianchi Lake. It lies near the border of Southeast Asian countries, India and Tibet. Kunming is a popular tourist destination and a huge horticultural center, the largest flower export center in Asia. Kunming's Pan Long River is 23km-long, and runs through the central business district. The river was channelized and had become surrounded by a hardened landscape during the city’s urbanization process. Only 10-20m wide, the river was embanked with 100-year-flood concrete steep slopes. Once the cultural and social center of Kunming, it became neglected and disconnected from city activities, a relic of former times. There was no convenient way for people to access to the river front, and there were no existing natural vegetated buffers between urban development and the river.

The Kunming Greenways Project was is completed by Turenscape in 2009. The project is across multiple scales (region, city and district) with a focus on the Dianchi water system and the Pan Long River corridor waterfront area. In all, the project integrates thirty-five rivers to form a wildlife habitat network, cultural heritage network, pedestrian-bicycle transportation network, and greenway network. This multifunctional urban ecosystem network is aimed at serving as the ecological infrastructure to solve Kunming's water environment problems, and to drive renewed urban development adjacent to the greenway system.

Methods

At the scale of the region, "ecological infrastructure" and "security patterns" were planned based on inventory and analysis. The concept of ecological infrastructure is similar to green infrastructure, which is "intended to secure the integrity and identity of the landscape by identifying and working with essential natural, biological and cultural processes (Yu, 2006)." The ecological infrastructure for Kunming is focused on three categories of processes; abiotic (water management), biotic (native species/biodiversity conservation), and cultural (heritage protection and recreation) (Yu, 2009).

(1) Flood Security Pattern

The flood security patterns at the regional scale provided multiple alternatives to the usual engineered flood mitigation methods by creating a self-sustaining system using natural landscape structures, including interconnected networks of wetlands, low-lying grounds, waterways, and lakes. Other design strategies include seasonal flood pockets and new river and canal embankments. Storm-water management and flood protection now depends on these landscape features, which provide a substitute for concrete dams and riverbanks. Low, medium, and high security patterns were developed for 20, 50, and 100 year floods accordingly.

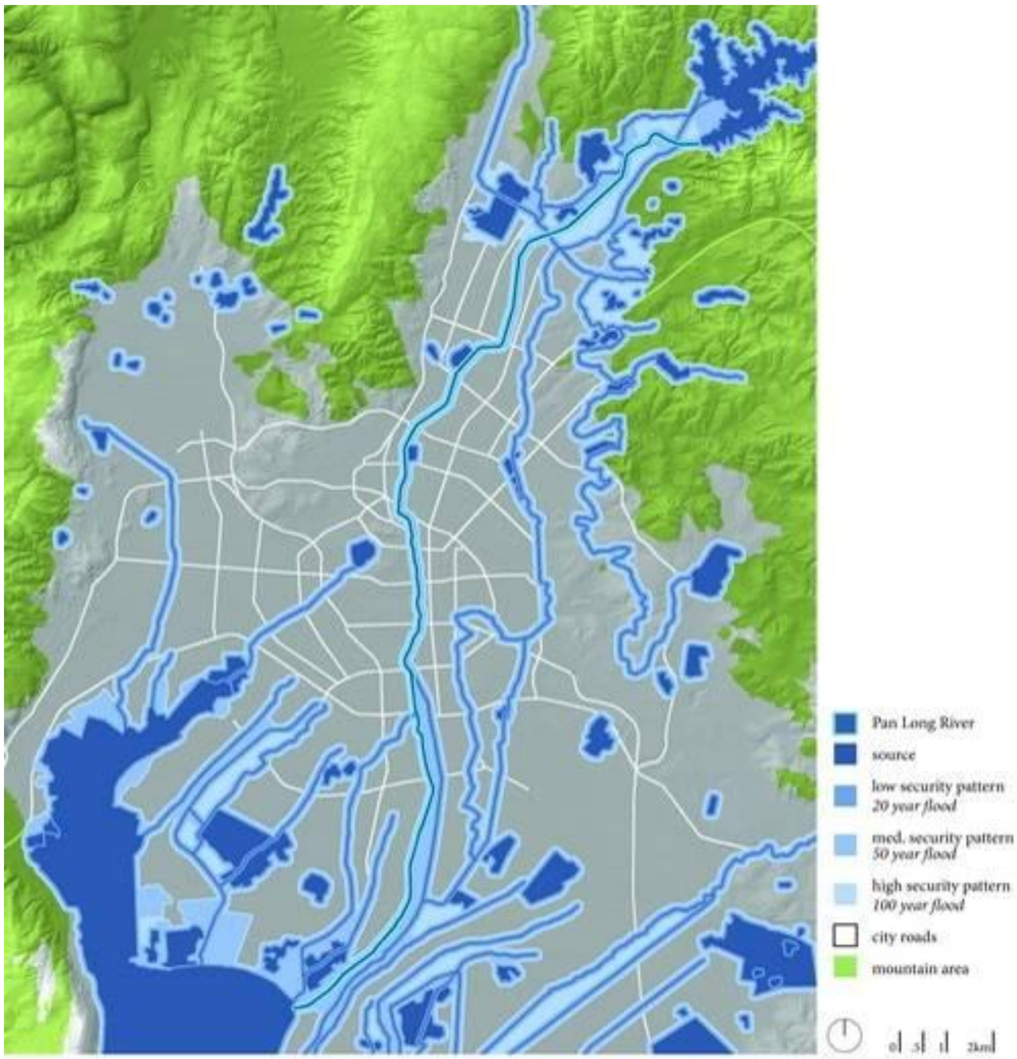

Figure 5-5 Flood Security Pattern Map adapted from Turenscape, *Flood security pattern*, 2009, http://www.turenscape.com/english/projects/project.php?id=4557.

(2) Biodiversity Security Pattern

A biologically diverse conservation plan for Kunming was based upon analytical maps of land use and vegetation. The plan incorporates a habitat suitability analysis based on the spatial relationships between habitats and landscape ecological principles. Strategic points and critical areas were identified as the primary concerns for the management and design of interconnected ecological corridors. At the intersections of roads and the natural corridors, underpasses and bridges for wildlife and water flow were proposed.

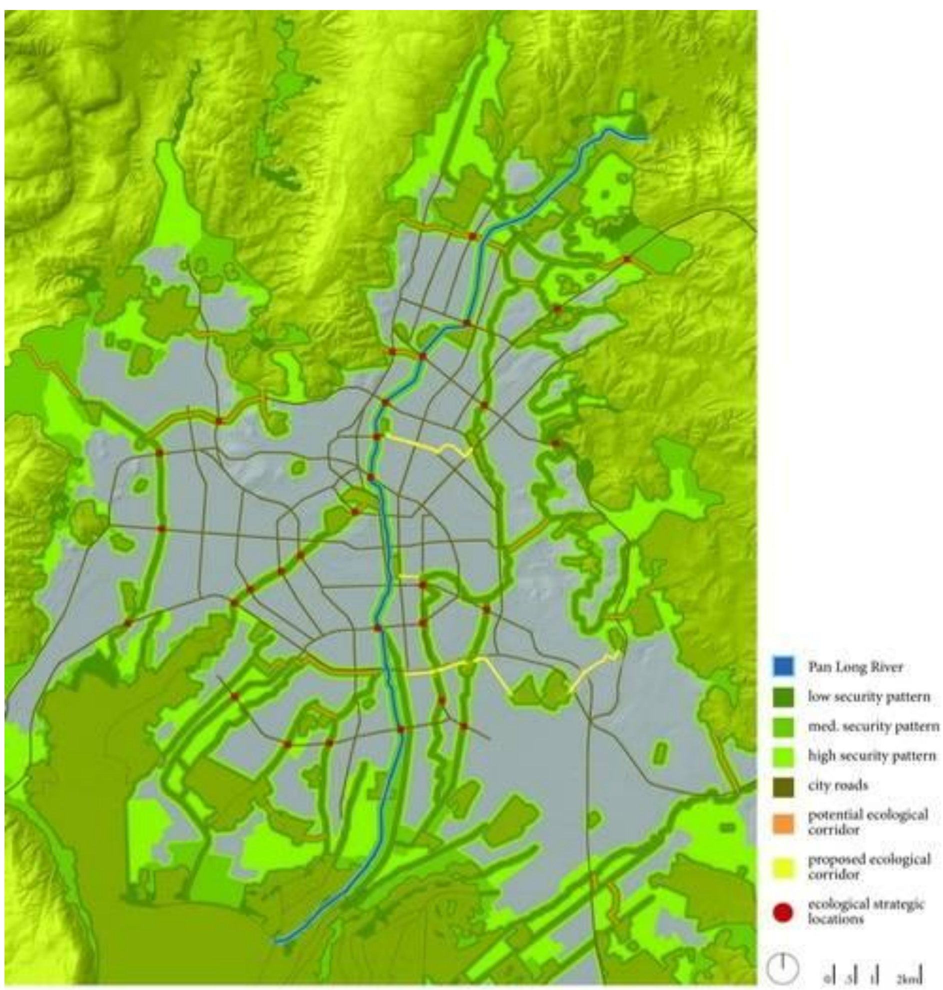

Figure 5-6 Biodiversity Security Pattern Map adapted from Turenscape, *Biodiversity security pattern*, 2009, http://www.turenscape.com/english/projects/project.php?id=4557.

(3) Cultural Security Pattern

Security patterns for cultural heritage protection and recreation were designed based on existing heritage sites and potential linkages between them. New greenway extensions including rural waterside pathways, pedestrian streets and bicycle lanes were developed to connect cultural heritage sites.

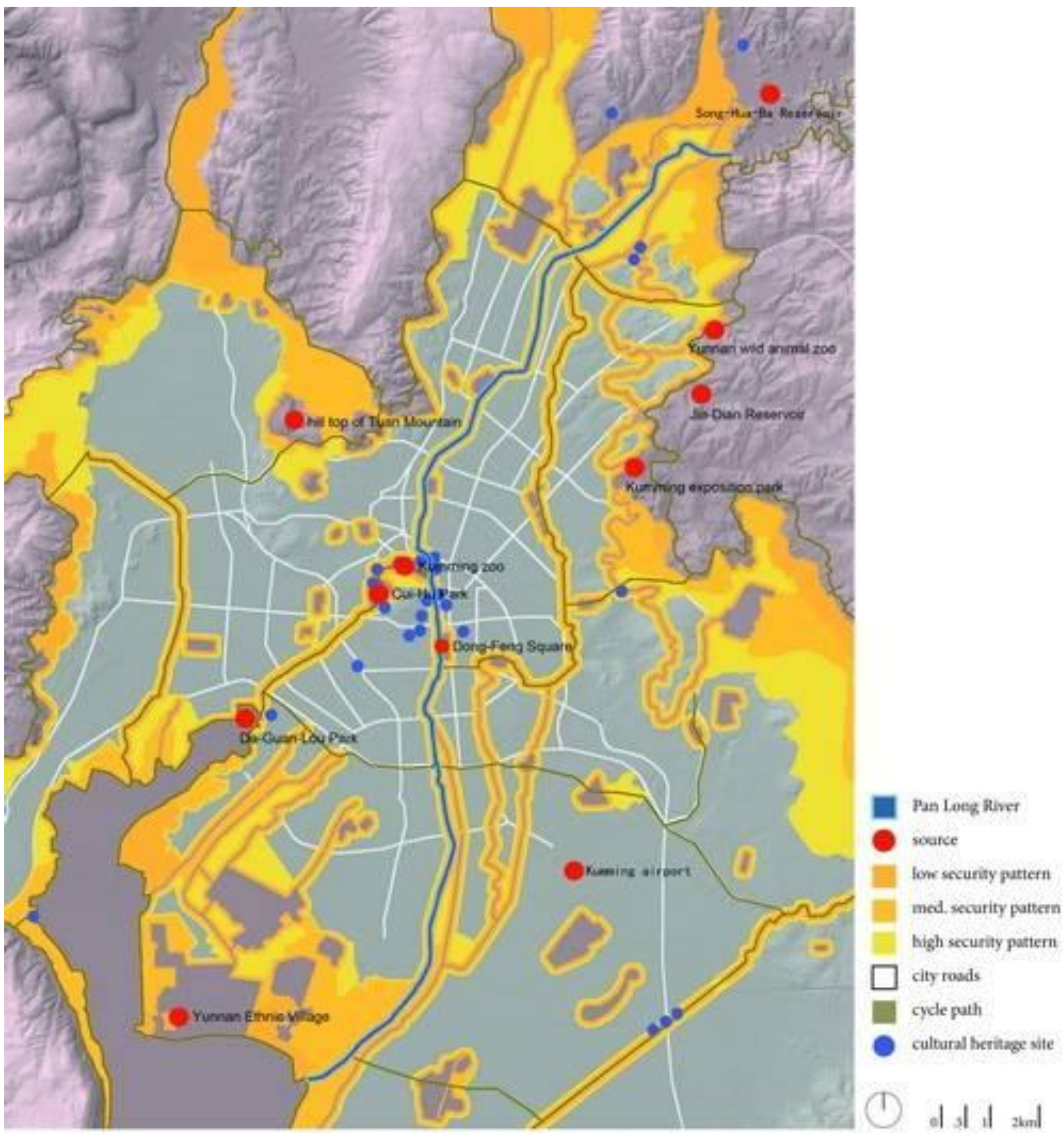

Figure 5-7 Cultural Security Pattern Map adapted from Turenscape, *Cultural security pattern*, 2009, http://www.turenscape.com/english/projects/project.php?id=4557.

(4) Pilot Project of Pan Long River

North and south of Plan Long River were rural and agricultural areas, where new housing clusters were developed. Constructed wetlands and swales were proposed to preserve existing rural fish ponds in villages. The goal was to create a new urban/rural morphology and housing typologies. The central part of Pan Long River runs through the CBD of Kunming, and was developed as a system of parks and greenway extensions linking cultural amenities, creating public promenades and a low speed traffic system for Kunming (Yu 2011).

Figure 5-8 Pilot project. From left to right: Pan Long River restoration; path and platform along riverbank; soft bank. Photographs by Kongjian Yu, 2010, http://www.turenscape.com/english/projects/project.php?id=4557.

5.3 Bonab City: Neighborhood Parks Planning

Introduction

Bonab Township is located in Iran. The area of the city is 778.79 km2, with an urban population of 76,586. The city is growing as the residents of surrounding rural areas gravitate to Bonab City. The city consists of three main urban districts and thirteen distinct neighborhoods (Sarvar 2011).

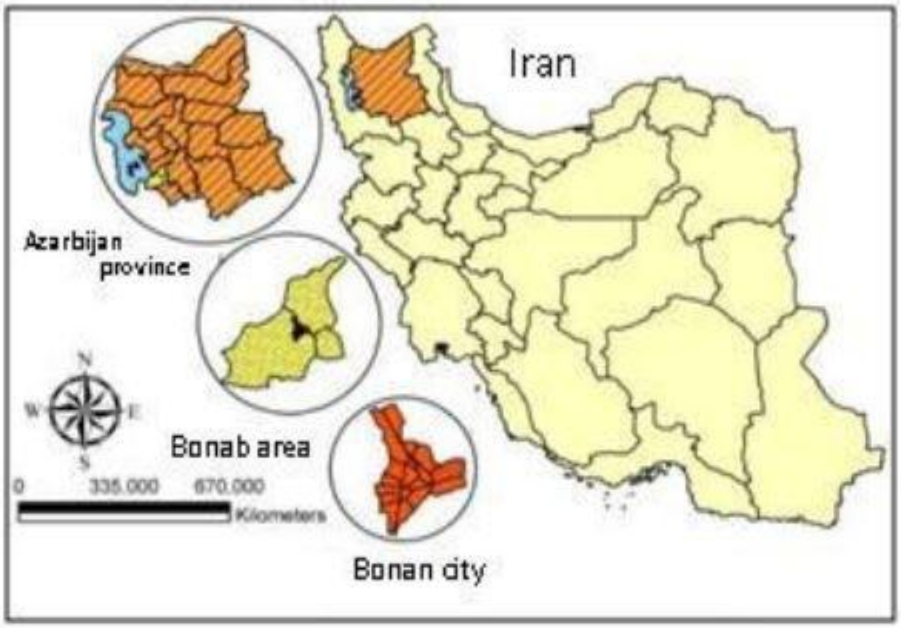

Figure 5-9 Bonab City Location Map adapted from Sarvar, *Bonab City Spatial Position and the Study Area*. In: "Optimum Location of Neighborhood Parks in Bonab City Using Analytic Hierarchy Process (AHP) (Sarvar 2011)."

A GIS-based Multi-Criteria Decision-Making (MCDM) study was done to qualify new sites for neighborhood parks within Bonab City in 2011. The Analytic Hierarchy Process (AHP) and a suitability analysis based on GIS weighted overlay were employed in this study (Sarvar 2011). To find the most suitable sites, eleven elements were analyzed. These included land area, population density, household density, household dimension, slope, the distance between the site and residential, cultural and educational centers, access to major roads, the distance away from rivers, and the distance away from the existing parks and green spaces (Sarvar 2011). Relationships between the elements and the comparisons were conducted to assign weighting values. The spatial information of the eleven elements and their impacts on parks were analyzed using weighted overlay to obtain the composite suitability map for the optimum locations of new parks (Sarvar 2011).

Methods

(1) Evaluation Criteria

The related elements to the neighborhood parks were defined according to literature reviews and querying the related authorities. Based on the thematic similarities, the selected elements were divided into social indicators, physical indicators and spatial indicators (Sarvar 2011).

Table 5-1 Criteria and elements for locating new parks (Sarvar 2011)

Indicators (clusters)	Elements
Physical indicators	Slope, land area
Social indicators	Population density, household density, household dimension
Spatial indicators	Accessibility to thoroughfare network; proximity to education centers; proximity to cultural centers; proximity to residential centers; distance away from the current green space; distance away of lands alongside the river and watercourse

A set of criteria were developed to analyze the suitability of attributes within each element. Criteria were used to determine the desirable state associated with various geographical spaces. For choosing the correct set of evaluation criteria, literature and survey of opinions were carried out (Sarvar 2011). These evaluation criteria for each element were produced in GIS as thematic maps (Figure 5-12). Thematic maps show how the attributes are distributed spatially and represent a set of alternative places to inform decision making.

For the slope map, 2-15% was identified as the best slope for parks. For the land area map, blocks with 0.5 to 2 ha land area was identified as the best area. Population density rate of each block was divided by the land area to get the results of population density, and then divided into 5 classes using the classification method of natural breaks. Blocks with higher population density were evaluated as more suitable for park locations. The household density was derived by dividing household numbers by block area, and higher density was considered more suitable for future park development. Maps of social cluster elements including cultural, education and residential land use blocks were derived from land use maps, and the distances of lands to these block centers were calculated in GIS. These distances were classified into five groups, and lands closer to these features were more suitable for future parks. Maps of parks and the current green space, main roads, and water body and rivers were also derived from existing land use maps. Similar to social cluster elements, distances were calculated. For these elements, proximity was treated as negative attribute.

(2) Assigning Weights

Weights need to be assigned to get the ratio value of each thematic map to reflect the "relative preference of a criterion element more than another (Collins et al. 2001)." The weights assigned were expressed in a cardinal vector normalized criterion preferences, and sum of weights of all the elements should be 1 (Collins et al. 2001). To arrange the criteria according to its relative importance, the Analytical Hierarchy Process (AHP) is used in this case. AHP uses comparison method for criterion weighting, which was proposed by Saaty (1980). AHP has been incorporated into the GIS-based land use suitability procedures (Marinoni 2004). The advantage of this method is that only two elements or factors need to be compared to each other (Sarvar 2011).

Firstly, a comparison matrix was generated and contains values from 1/9 to 9, which means the importance of one element against another in the pair. The bigger the value means that the element is more important. The number one means equal importance. Then, calculations include: sum the values from each column and divide every value in the matrix by the sum of the respective column to get the normalized comparison matrix; calculate the average from the values in each row of the normalized matrix; calculate the average of all weighting results from decision makers to get the final weights (Sarvar 2011). Results are shown in Table 5-2.

(3) Weighted Overlay in GIS

The obtained weights are applied to the layer information of each element. The vector layers of elements were converted to Raster format and reclassified by the suitability scores from 1-5 based on previous criteria. By using weighted overlay tools and assigning the weighting values for the four raster layers, an overlaid suitability layer was generated. The suitability values of cells were then classified using equal interval method into 5 categories. From the highest suitability value category to the lowest suitability value category, they are defined as the most suitable areas, suitable areas, moderately suitable areas, least suitable areas and not suitable areas. At last, the map of optimum locations for building neighborhood parks at Bonab city was generated.

Results

Table 5-2 Weighting matrix of all elements related to new park locations (Sarvar 2011)

		Physical indicators		**Social indicators**			**Spatial indicators**					
		slope	Land area	Household dimension	Population density	Household density	Accessibility to thoroughfare network	Proximity to residential centers	Distance away from the current green space	Proximity to cultural centers	Proximity to education centers	Distance away from lands alongside the river and watercourse
Physical indicators	Slope	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
	Land area	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Social indicators	Household dimension	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136
	Population density	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
	Household density	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169
Spatial indicators	Proximity to thoroughfares network	0.122	0.122	0.122	0.12	0.122	0.122	0.122	0.122	0.122	0.122	0.122
	Proximity to residential centers	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112
	Distance away from the current green space	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
	Proximity to the cultural centers	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
	Distance away from the education centers	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
	Distance away from lands alongside the river and watercourse	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018

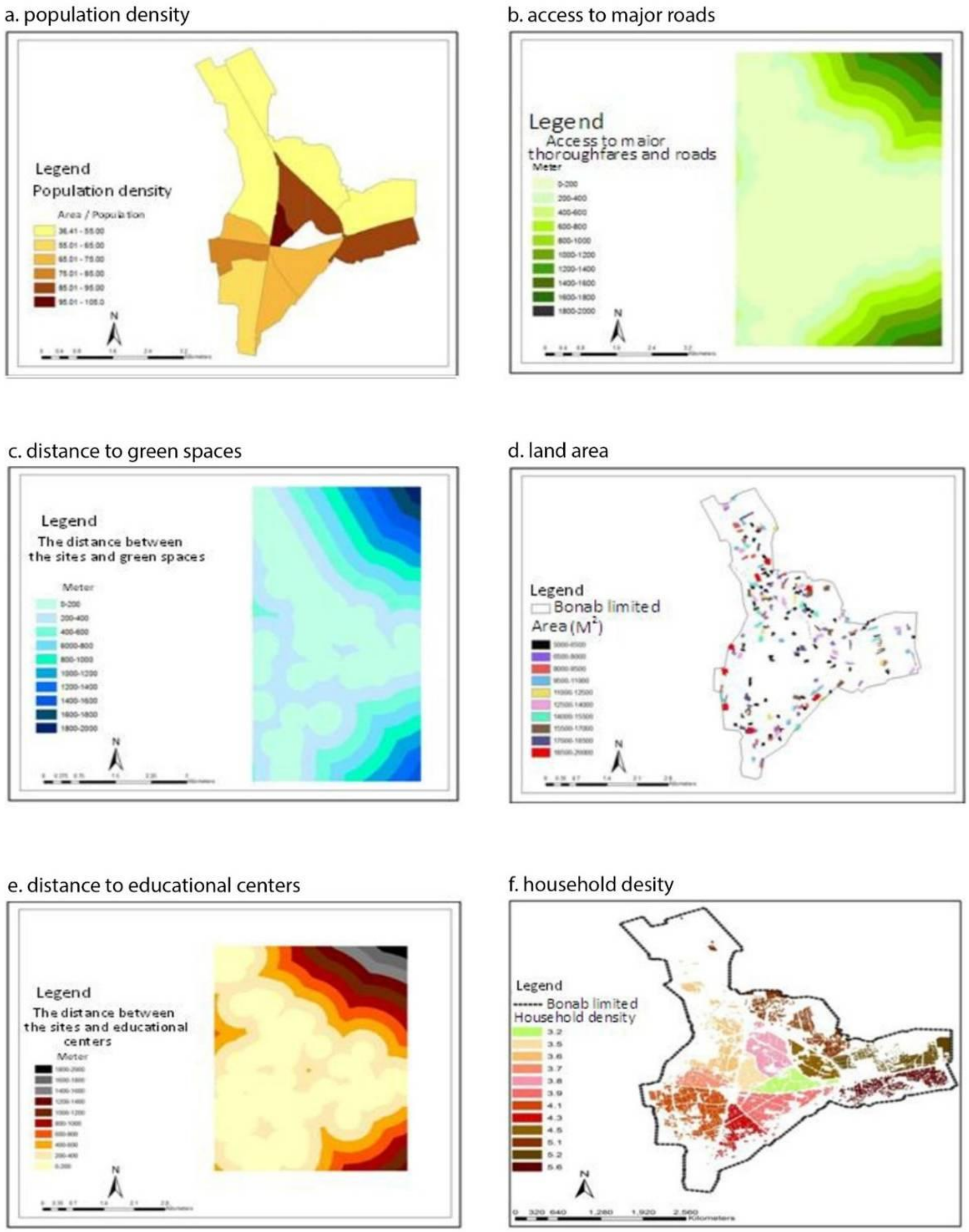

Figure 5-10 Thematic maps, adapted from Sarvar, *Thematic maps for each element in ARC GIS environment*. In: "Optimum Location of Neighborhood Parks in Bonab City Using Analytic Hierarchy Process (AHP) (Sarvar 2011)."

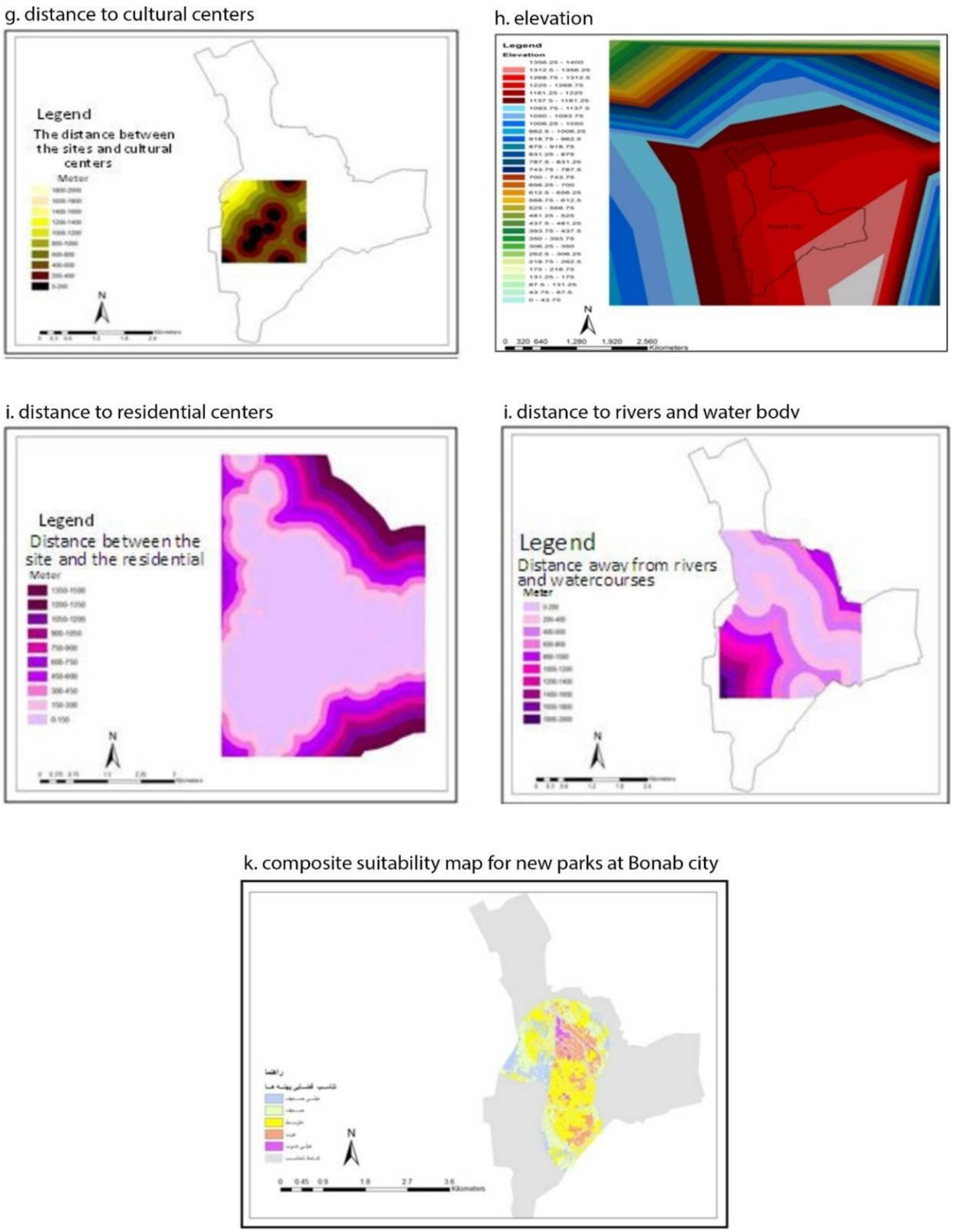

Figure 5-11 Thematic maps for each element in ARC GIS environment and composite suitability map for new parks, adapted from Sarvar, *Thematic maps for each element in ARC GIS environment and the optimum locations for building neighborhood parks at Bonab City*. In: "Optimum Location of Neighborhood Parks in Bonab City Using Analytic Hierarchy Process (AHP) (Sarvar 2011)."

The result incorporated 11 important elements and related criteria that influence the suitability of new park locations to increase quality of park services and improve the social, cultural and environmental condition of the urban area of Bonab City. Analytical Hierarchy Process (AHP) was used and comparisons were carried out using questionnaires to determine the relative importance of each element and their weights. The weights were then applied to the weighted overlay analysis in GIS to obtain the final composite suitability map for new parks. After combining final weights of the criteria from AHP in GIS software, conclusion was made that the most suitable locations for new parks in Bonab City (Sarvar 2011).

These greenway planning and design experiences, such as canopy-road greenway restoration, connecting a fragmented city wall, and the Inner-Qinhuai River greenway can all be applied to Xuchang 's street greenway and Shun River (historic moat) greenway, and are illustrated in the next chapter.

5.4 Lessons and Applicability

Table 6-3 Lessons and applicability of precedent case study, created by author.

Precedent Case	Lessons	Applicability to Xuchang
Nanjing Comprehensive Green Space Planning	**1. Different scale approaches**: metropolis scale, city scale and neighborhood scale.	To apply the multi-scale approach, the study of Xuchang urban green infrastructure planning will be at city scale, neighborhood scale and site design scale.
	2. Multi-functional urban green infrastructure planning: green field acquisition, recreational functions, wildlife habitats and environmental benefits.	Multi-functional green infrastructure planning strategy will be applied to Xuchang and is also recommended for other study cities.
	3. Landscape ecology principles: use green wedges, greenways and green extensions to improve the connectivity of urban green infrastructure.	Landscape ecology principles will be used as the fundation for planning principles to create efficient connections and landscape mosaic for wildlife.
	4. Greenway design: greenway as river corridor and greenway as canopy road.	In compact Chiese cities greenway as river corridor and greenway as canopy road are two types usually used in urban areas and will be applied to Xuchang.
	5. Neighborhood greening: riparian linkage, pedestrian route, street greening, new parks, green walls and green roofs.	Nanjing and Xuchang has similar traditional neighborhood spatial features. These neighborhood greening methods can be applied to Xuchang at neighborhood greening scale.
	6. Critique This project was well structured based on landscape ecology concepts. The drawbacks would be that the plan does not include the clear consideration of wildlife preservation and conservation, and the selection of greenway locations was experience-based and lacked supporting methods and techniques.	

Table 6-3 Lessons and applicability of precedent case study, created by author (continued)		
Precedent Case	**Lessons**	**Applicability to Xuchang**
Kunming Greenways	**1. Multi-functional urban ecological infrastructure planning**: abiotic process (water management), biotic process (native species /biodiversity conservation), and cultural process (heritage protection and recreation).	Biodiversity conservation and cultural functions (heritage protection and recreation) will be the main focuses of Xuchang Green Infrastructure Planning.
	2. Flood security pattern: use natural landscape elements including wetlands, low-lying grounds and sesonal flood pockets instead of concrete dams and river banks to manage storm-water and protect from flood. 20, 50, and 100 years floods were considered accordingly in the design.	Although the flood security pattern is very successful in Kunming case, however, due to the lack of hydrology data and time and effort limit, some of the methods including storm-water management plan will not be applied in the design chapter. It is recommented to do further research on this subject.
	3. Biodiversity security pattern: identify critical habitats as the primary concerns for the management and design of corridors based on a habitat suitability analysis.	Biodiversity conservation is also one major goals for Xuchang. Critical habitats need to be identified and set conservation priorities, and new suitable habitat locations will be proposed for Xuchang based on suitability analysis.
	4. Cultural secuity pattern: protect existing culrual hetitage sites and create linkages between them as greenway extensions including waterside pathways, pedestrian streets and bicycle lanes.	These approaches are very suitable to be applied to Xuchang and other study cities. In addition, the opportunities and need for new parks should also be included.
	5. Pan Long River corridor design: use greenway extensions to connect parks and linking cultural amenities; apply riverbank stabilization method to strengthen soil structure, prevent water flow erosion, avoid concrete dams and riverbanks and create soft banks; incorporate pedestrian and bicycle path; design riverside hubs.	The pre-development condition of Pan Long River is very similar to rivers in Xuchang. The design strategies for Pan Long River can be applied to planning and design strategies for Qingyi River, Qingni River and Shun River.
	6. Critique The Kunming Greenway project is a comprehensive GIS based greenway planning project in China that is under construction. However, due to the lack of detailed analysis information, the results are not very solid in the regional scale, especially for the biodiversity and cultural heritage aspects.	

Table 6-3 Lessons and applicability of precedent case study, created by author (continued)

Precedent Case	Lessons	Applicability to Xuchang
Bonab City Neighborhood Parks Planning	**1. Multi-criteria approach**: identify important elements relating to suitable park locations; set up criteria for each element on how the different attributes within the element influence the suitablity of certain spatial location for new parks; make thematic maps for each criterion element.	To realize multi-functional green infrastructure planning for both human and wildlife, multi-criteria approach should be applied. In addition to the elements selected in the Bonab City case, which mainly focus on recreational functions of parks, habitat suitability should also be incorporated in Xuchang.
	2. Analytic Hierarchy Process (AHP): use pair-wise comparison matrix to measure relative importance between each pair of elements; obtain the final weighting scores for each element through calculation based on pair-wise comparison; get the quantified importance of each element to optimum locations for new parks.	The method of AHP simplifies the weighting process by dividing elements into pairs, and only two elements need to be compaired at one time. It will be applied to the suitability analysis for green space as hubs in Xuchang. However, in Bonab city case, the results came from questionaires and literature reviews. For Xuchang, there was not enough time for a questionaire survey, and the results will base on literatures and judgement by arthur.
	3. GIS-based weighted overlay: use thematic maps for each element as input for weighted overlay and convert to raster layers; use weighting scores assigned in AHP as input weighting values for each raster layer; generate composite suitability map for new parks using weighted overlay tool.	GIS-based weighted overlay is a very useful tool for suitability analysis that simplify the calculation and provide more solid results. It will be applied to the suitability analysis for hubs in Xuchang, and it is also suggested for other study cities.
	4. Critique The Bonab project is a well-structured and systematic park planning project based-on suitability analysis and AHP. The results were more solid than the previous two projects while the coverage of types of green infrastructure was limited. The results of the suitability analysis did not show a clear conclusion on future park planning.	

CHAPTER 6

DESIGN IMPLEMENTATION IN XUCHANG

The goals for this chapter are to provide solutions for existing urban green spaces of Xuchang. The main issues that need to be addressed are the loss of wildlife habitat within urban built-up areas; the uneven distribution of and poor accessibility of parks; the fragmentation and disconnection of urban green spaces; and the lack of green space in compactly developed traditional neighborhoods.

The theory of green infrastructure proposes that urban green space components are connected to form a system of “hubs” and “linkages” (Lafortezza et al. 2013). Hubs serve as origins and destinations for wildlife and people, and include wildlife habitat and urban parks. Linkages are linear features connecting hubs that enable green infrastructures to form a network and avoid fragmentation, such as greenways and conservation corridors (Lafortezza et al. 2013). Green infrastructure approaches provide a variety of methods to tackle existing issues and to retrofit urban green spaces in cities like Xuchang.

The organization of this chapter is based on the physical components of green infrastructure at the city scale and neighborhood scale; this includes “hubs” and “linkages” at the city scale, and “neighborhood greenings” at the neighborhood scale. Hubs consist of habitat hubs, urban parks and multifunctional hubs that serve as both habitat hubs and urban parks. A GIS-based suitability analysis and Analytic Hierarchy Process (AHP) are used to identify optimum locations for each type of hubs and their priorities. Design guidelines for each type of hub are developed and Chunqiu Square serves as a design example a multifunctional hub. Both of these efforts strive to ensure ecosystem functions and ecosystem services provision in future landscape design processes. Under the “linkage” category, planning and design principles for river corridors in Xuchang are proposed based on landscape ecology principles and precedent case studies. These linkages improve connectivity of urban green spaces, avoid habitat isolation for wildlife, and enhance accessibility for people. Under the “neighborhood greening” category, the spatial evolution of traditional residential neighborhoods in the Xuchang urban area is discussed, and appropriate green infrastructure elements and design strategies are proposed based on the study in Chapter Four of this paper. Precedent case studies to harvest ecosystem services at the neighborhood scale are also discussed.

6.1 Hubs

Hubs provide and protect critical ecosystems functions such as wildlife habitat, air filtering, microclimate regulation, noise reduction, stormwater control, recreation, aesthetically pleasing and educational services, a sense of place and cultural heritage (Bolund and Hunhammar 1999). In urban area, hubs are mainly in the form of urban parks and landscape patches (Lafortezza et al. 2013).

In this section of the design chapter, the goals are to assess existing landscape hubs within the urban built-up area of Xuchang, and propose suitable land areas for future hub development based on a GIS-based suitability analysis using weighted overlay informed by Analytical Hierarchy Process (AHP). These efforts tackle two challenging issues of existing urban green spaces of Xuchang: the loss of wildlife habitat within urban built-up area and the uneven distribution and poor accessibility of parks. Because the needs of ecosystem functions and ecosystem services are different for humans and wildlife, two sets of suitability analyses are prepared for hubs as wildlife habitat and hubs as urban parks. The results are then discussed, and the overlapping areas are proposed to be multifunctional hubs, which serve as both habitat hubs and urban parks. Then a design was prepared that illustrated context and site responses at a smaller scale.

Methodology

There are six major steps in the GIS-based suitability analysis of this design section .These include: data collection, existing hubs analysis, identification of factors, criteria and thematic maps, assigning weights using Analytical Hierarchy Process, and data integration and analysis using Geographic Information Systems (GIS).

(1) Data Collection

Spatial data used in this analysis is primarily from Urban Planning and Design Institute of Xuchang. Data from the Urban Planning and Design Institute of Xuchang includes the Inventory Report of the Xuchang Urban Development (2010), an overall Master Plan of Xuchang (2005-2020), and the existing land use map of Xuchang. The maps of existing public parks, water bodies, cultural features, schools, and residential neighborhood density are derived from these resources.

Google Earth aerial satellite image (Google 2014) was used to produce the land cover map for Xuchang, and a land use map from city government and field survey photos were used as references and were based on the methods used in the study of influence on ecosystem service from urbanization and land cover change in Panyu, China

(Yu, 2011). The land cover types identified are urban forest, grassland, cropland, barren land, low-density built-up area, high-density built-up area, street, and water bodies

(2) Existing Hubs Analysis

Hubs as Habitat Patches

Species are affected differently by landscape fragmentation in urban areas, and native species with large habitats suffer more from urbanization (Csorba 2011). Species with relatively large habitats, such as birds and small terrestrial mammals, should be considered preferentially in habitat preservation in urban areas (Teng et al. 2011). Based on the inventory of wildlife species in Henan Province and Xuchang region in Chapter Three, two species assemblages are identified as focal targets: forest-breeding birds (magpies, sparrows, vinous-throated Parrot bill, northern lapwing, siskins, Kentish plovers, long-tailed shrike, etc.) and small terrestrial mammals (including hedgehog, raccoon, macaque, grass hare, yellow weasel, etc.).

Precise data of species distribution in urban areas are often lacking (Teng et al. 2011). In this situation, "land cover and vegetation information can reliably be used as a surrogate of the habitat value (Cook, 2002)." A study of Wuhan greenway planning demonstrated a good example of how to identify birds and small mammals' habitat in urban areas (Teng et al. 2011). Xuchang and Wuhan are both on the Huaihai Plain and in the same ecoregion as Xuchang (Global Energy of Network Institute, "Geographic Location of Ecoregions"). A set of criteria is adopted from this study to identify existing habitat hubs, including: the type of hub is urban forest; the minimum area of habitat hubs (four hectares for local generic forest-breeding birds and eight hectares for local small terrestrial mammals, according to their habitat requirements) (Teng et al. 2011).

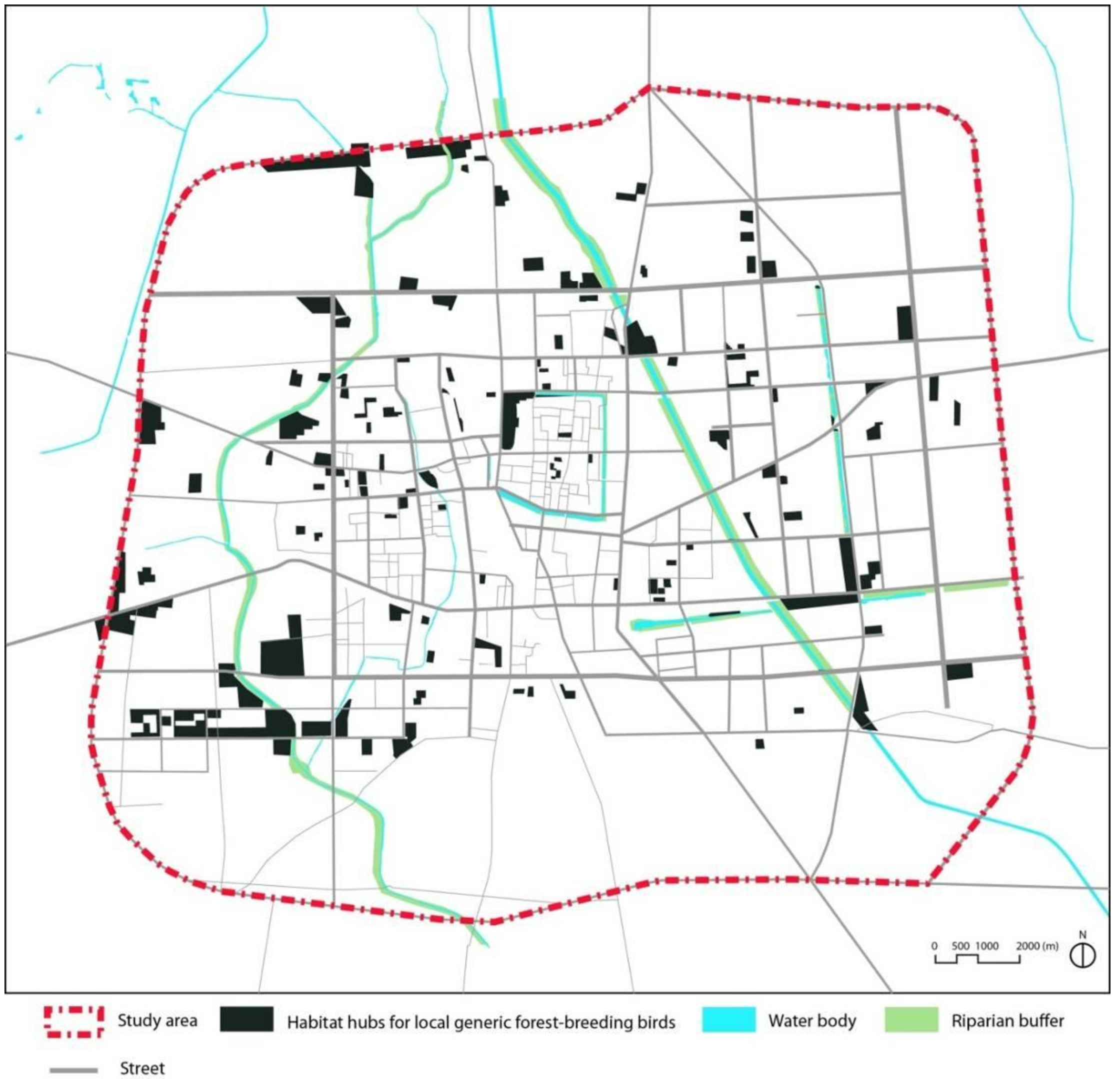

Figure 6-1 Existing habitat hubs of local generic forest-breeding birds, map created by author June 2014.

Here, urban forest lands are classified as zero-to-four-hectare hubs, four-to-eight-hectare hubs and above eight hectare hubs. The existing habitat hubs of local generic forest-breeding birds (Figure 6-1) are urban forest lands above four hectares. One hundred and thirty-six landscape hubs are identified as habitats for local generic forest-breeding birds in the study area, which is1,088 hectares total. Thirty-two of these hubs are connected with river corridors and riparian buffers. One hundred and six hubs are adjacent to streets.

The existing habitat hubs of local small terrestrial mammals (Figure 6-2) are urban forest lands above eight hectares. Twenty-five landscape hubs are identified as habitat hubs of local small terrestrial mammals, which total 642 hectares. Seventeen of them are along river corridors and riparian buffers, and eight of them are along streets.

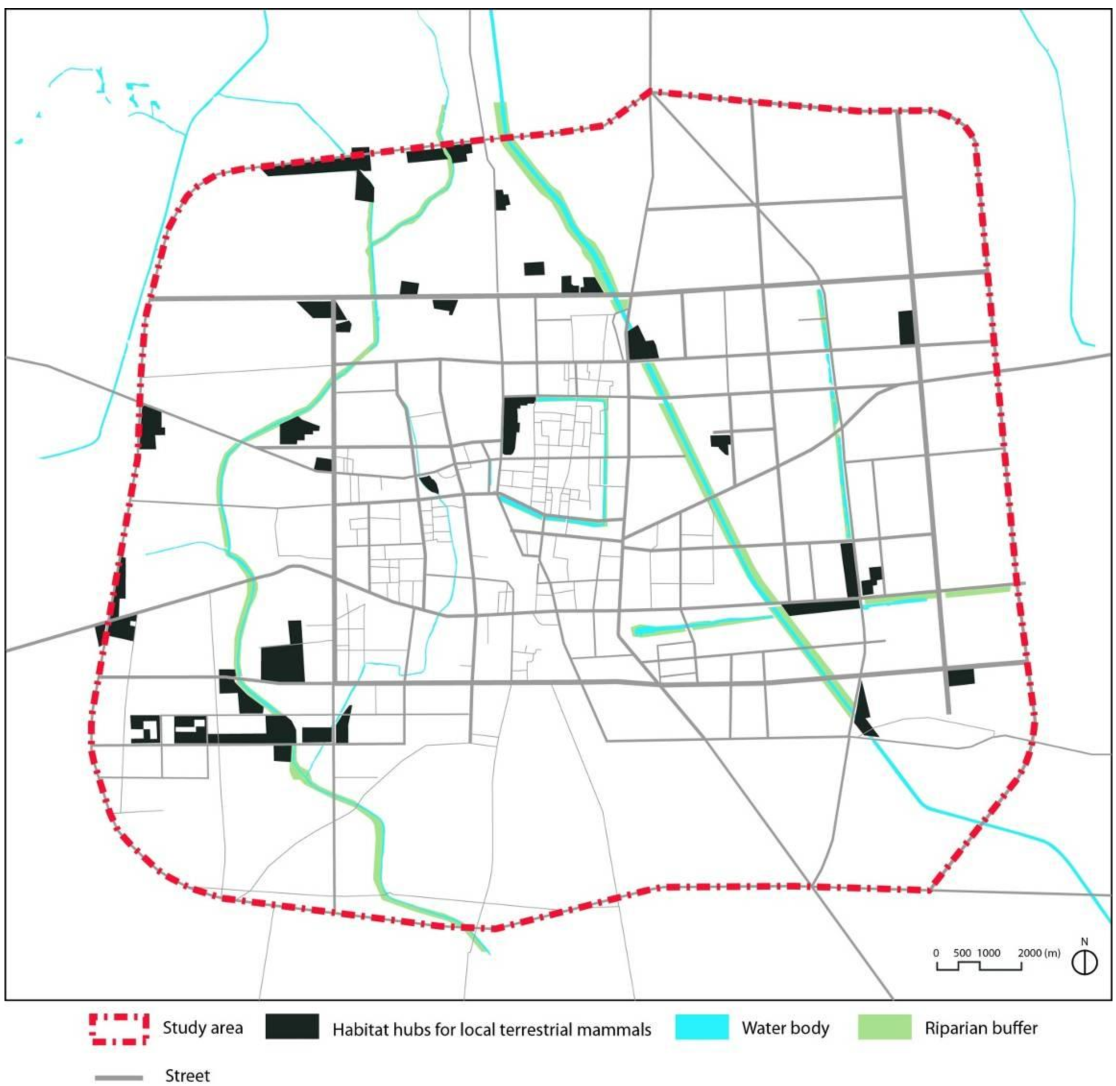

Figure 6-2 Existing habitat hubs of local small terrestrial mammals (>8h), map created by author 2014.

Hubs as Urban Parks

As discussed in Chapter Two, two major issues of urban parks in Xuchang include unevenly distributed parks in Xuchang’s built-up area and central districts and densely developed neighborhoods lack access to public parks; the second major issue is that existing parks have poor accessibility and are disconnected from other public services and facilities.

According to the Urban Rural Planning Law of People's Republic of China (2006), park land per capita should be at least eight square meters. According to the China City Development Statistical Yearbook 2012, the park land per capita in Xuchang built-up area was 8.5 square meters in 2012. However, the value is calculated citywide, and most of the public park area is distributed along river corridors and in several large parks. Also, they are beyond walking distance for many residential neighborhoods.

In Chinese cities, the suitable walking distance is usually considered less than 500 meters, which is about 1500 feet (Ziyu and Wowo 2011). Using the Buffer Tool in GIS to generate a 500m buffer for each existing urban park, the result shows that only 19.5% of study area is within walking distance from existing urban parks (Figure 6-3).

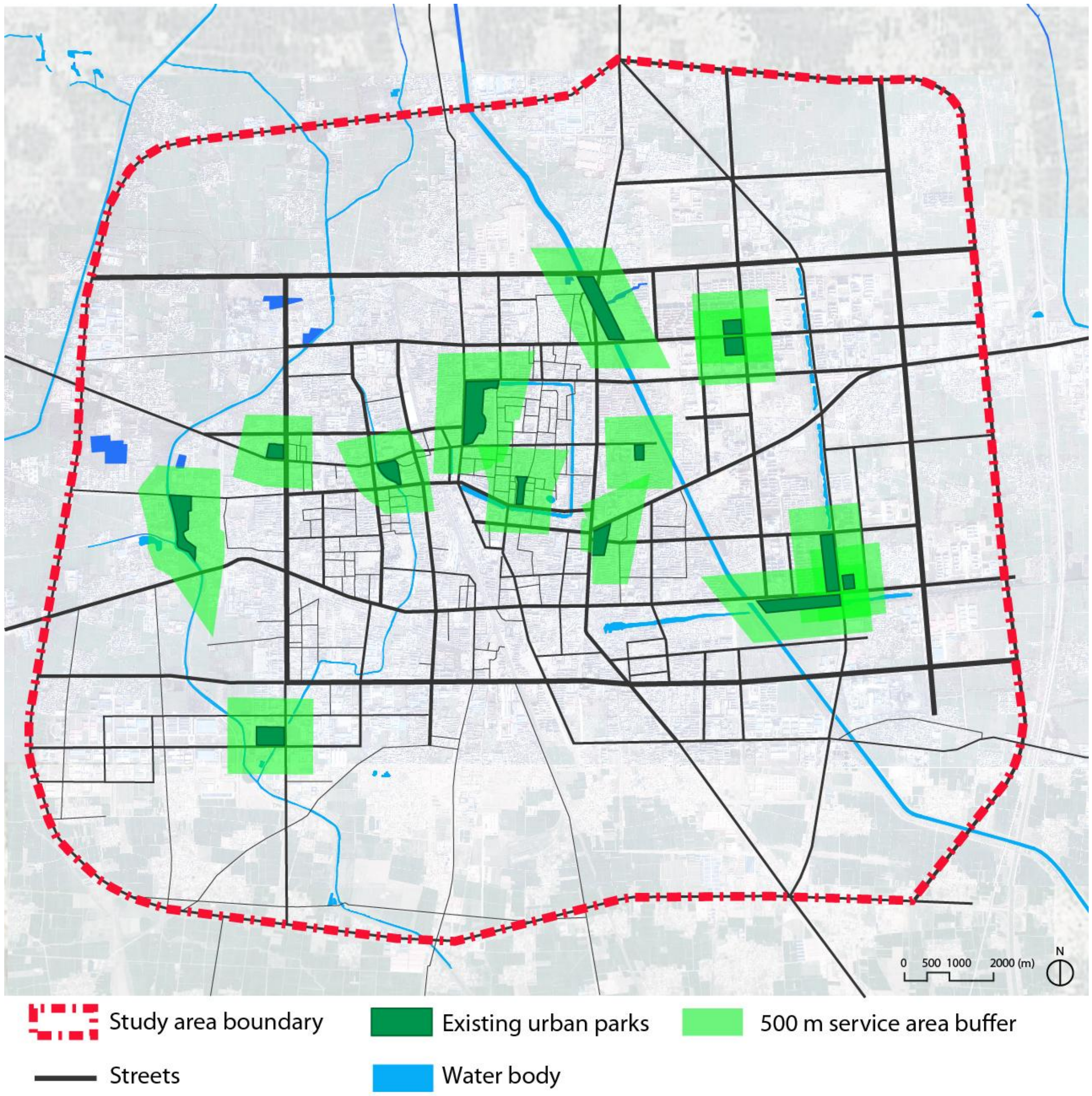

Figure 6-3 Existing urban parks and service areas in Xuchang, map created by author June 2014.

(3) Identification of Factors

Factors indicate a group of attributes, such as habitat size, land cover, compatibility with adjacent uses, etc. They support fundamental processes or function features related to current land-use (Miller et al. 1998). In this paper, factors are identified based on previous inventory of Xuchang's green spaces and a literature review.

Hubs as Habitat Patches

Important features that affect the bird and small mammal diversity in urban habitats are habitat size, habitat connectivity, habitat structure and human disturbance (Fern´ndez-Juricic and Jokimäki 2001). The sizes of habitat hubs is very important because larger hubs may hold higher urban bird populations and provide a larger diversity of habitats necessary to hold different species with different habitat requirements (Fern´ndez-Juricic and Jokimäki 2001). Also, the loss of habitat size shows a clear negative effect on the biodiversity of small terrestrial mammals and is "unlikely to be mitigated by the spatial configuration of that habitat (Garden, 2010)." Thus, habitat size is the key to the preservation and restoration of both birds and small terrestrial mammal species' richness.

The urban matrix may greatly restrain bird movement and so we must consider alternatives that might support a functioning environment. Vegetation strips can act as corridors for many birds (Fernández-Juricic 2000). Functional connectivity is very important for suitable habitat hubs of small terrestrial mammals in urban areas, which need to be a low-risk conduit for facilitating essential species, dispersals between habitat hubs (Garden 2010). A habitat hub that is closer to other hubs is beneficial for wildlife dispersal, habitat connectivity and biodiversity, especially for birds (Wang et al. 2014). River corridors and their riparian buffers in Xuchang are important landscape corridors, serving as green infrastructure linkages that connect with hubs to form a functional ecological network. Thus, in the Xuchang case, the connectivity of potential locations for future habitat hubs can be represented by two factors– proximity to river corridors and proximity to existing habitat hubs identified earlier in this chapter.

Canopy trees of different ages are essential for providing food, shelter and breeding substrates for birds (Leedy and Adams 1984). The growth form and dense lower foliage of grass trees can be used to provide important nesting and shelter niches for small mammals (Marchesan and Carthew 2004). In addition, soft soils and mulch are crucial for small terrestrial mammal species' diversity in urban habitat hubs (Garden 2007). These habitat structure features can be represented by land cover factor.

Urban wildlife species can be affected by human disturbance, especially heavy traffic areas (Blair 1996). Here, proximity to streets will be used to represent the degree of human disturbances.

Table 6-1 Important factors for suitable habitat hubs (table made by author)

Habitat feature	Factor
Habitat size	Land area
Habitat connectivity	Proximity to river corridors
	Proximity to existing habitat hubs
Habitat structure	Land cover

Hubs as Urban Parks

For urban parks in Xuchang, crucial issues include uneven distribution and accessibility according to previous study in Chapter Three. Suitable sizes of urban parks and their distribution are complemented with park accessibility. In a survey of the park visitors habits in Chinese cities (Zhang et al. 2013) , 95% of respondents ranked "proximity to residence and school" as the most important factor to them when choosing which park to go visit. Urban parks are considered adequate when the human population is in harmony with parks' spatial distribution; parks are "accessible" if they provide adequate services to the demand of the population using the services (Lee and Hong

2013). Thus, population density in residential neighborhoods and proximity to schools should be considered as important factors in planning urban parks.

Public transportation also contributes to the accessibility of nearby parks. In addition, existing parks can serve a certain area while new urban parks can serve areas that are outside service areas of existing parks. Because suitable walking distance in China is usually considered 500 meters, this distance serves as the suitable park service radius (Ziyu and Wowo 2011). Existing parks and service areas should also be a factor in determining suitable locations for new parks.

Urban streams and river corridors are essential landscape features of Xuchang. They provide accessibility for pedestrians and bike greenways, and add to the attractions of nearby parks (Zhong-xuan, Hui, and Zhi-yong 2010). Cultural features also enrich hubs, help create a sense of place, and bring more people to the parks (Chiesura 2004). Cultural features in Xuchang include historic heritage sites and districts and recreational land use. For parks to be effective, proximity to existing river corridors and cultural features are important. In the following suitability analysis for new park locations both of these factors are addressed.

Table 6-2 Important factors for suitable hubs as urban parks (table made by author)

Park feature	Factor
Park accessibility	Proximity to schools
	Proximity to bus stops
Park distribution	Residential neighborhood density
	Existing parks service area
Park attraction	Land cover
	Proximity to river corridors
	Proximity to historic heritage site and district
	Proximity to recreational land use

(4) Criteria and Thematic Maps

A set of criteria is used to refine the desirable location associated with a geographical space for a specified function in suitability analysis (Imtiaz Ahmed et al. 2011). Criteria need to be satisfied in order to ensure the potential spaces have the ability to maximize beneficial features and minimize undesirable features. For each factor, the degree of contribution of attributes within the factor to successful wildlife habitat and urban parks is called suitability. The degree of contribution is quantified by assigning numerical values, which are usually called suitability scores in suitability analysis (Miller et al. 1998). Numbers one to five are used as suitability scores in this paper, and their meanings are shown in Table 6-3. A suitability score is assigned to each attribute within each factor, and the results forms the criteria of this suitability analysis.

Table 6-3 Suitability scores and meanings (table adapted from Sarvar 2011)

Suitability scores	1	2	3	4	5
Meanings	Most suitable	Suitable	Moderately Suitable	Least suitable	Not suitable

The spatial distribution of attributes for each factor is converted in GIS 10.1 from vector layers. Spatial analysis tools are used to process these data and generate thematic maps for each factor. For the land area factor, the block size is used to represent the possible habitat size. Larger block size is considered more suitable for wildlife habitat expansion. The streets data is derived from the Inventory Report of Xuchang Urban Development (2010) and converted from a vector layer. The area of each block is calculated in the attribute table, and then classified using natural break method into five groups. For the proximity thematic maps, vector layers of existing habitat hubs, streets, schools, bus stops, historic heritage sites and districts, recreational places are first derived from land cover and land use maps. These vector layers are then converted to raster layers using the Polygon-to-Raster Tool with a cell size of 10 meters. The Euclidean Distance Tool is used to calculate the distance between each cell within the study area boundary and the nearest cell that contains the attribute of a certain factor element. The results are then classified into five groups using an interval of 250 meters (half of the suitable walking distance) to represent criteria for each factor and to display. For residential neighborhood population density factor, the residential neighborhood locations and shapes are derived from the land use map into ARC GIS as a polygon layer. Populations of residential neighborhoods information is obtained from the Inventory Report of Xuchang Urban Development (2010) and then put into an attribute table of the polygon layer. The areas of neighborhoods are obtained in the attribute table. Population density of each neighborhood is then calculated by dividing the population by areas in attribute table. For the existing parks service area factor, the data of existing parks is derived from the land use map. Five hundred meter buffers from existing parks are then generated using the Buffer Tool in ARC GIS, as the service areas of existing parks, and the lands outside of the services areas are generated by erasing existing parks and service areas from study area boundary using the Erase Tool. The three vector layers are then merged together and converted to a raster image using the Merge Tool and the Polygon-to-Raster Tool. The areas within existing parks service area will have a lower suitability score, while the areas outside existing parks service area will have a higher suitability score. The result thematic maps and criteria are shown in Table 6-4, Table 6-5, and Figure 6-4 to Figure 6-15.

Table 6-4 Criteria for suitability analysis of habitat hubs (table made by author)

Factor	1-Most suitable	2-Suitable	3-Moderate suitable	4-Least suitable	5-Not suitable
Land area	0 - 36 ha	36 - 116 ha	116 - 298 ha	298 - 463 ha	> 463 ha
Proximity to river corridors	0 - 250m	250 - 500 m	500 - 750 m	750 - 1000 m	> 1000 m
Proximity to existing habitat hubs	0 - 250m	205 - 500 m	500 - 750 m	750 - 1000 m	> 1000 m
Land cover	Wooded	Grassland	Barren land	Water body	Developed land
Proximity to streets	> 500 m	200 - 500 m	100 - 200 m	50 - 100 m	0 - 50 m

Table 6-5 Criteria for suitability analysis of urban parks (table made by author)

Factor	1-Most suitable	2-Suitable	3-Moderate suitable	4-Least suitable	5-Not suitable
Proximity to bus stops	0 - 250m	250 - 500 m	500 - 750 m	750 - 1000 m	> 1000 m
Proximity to schools	0 - 250m	250 - 500 m	500 - 750 m	750 - 1000 m	> 1000 m
Residential neighborhood population density (people/ha)	0 - 100	100 - 200	200 - 500	500 - 1000	> 1000 m
Land cover	Wooded	Grassland Cropland	Barren land	Water body	Developed land Street
Proximity to historic heritage site and district	0 - 250m	250 - 500 m	500 - 750 m	750 - 1000 m	> 1000 m
Proximity to recreational land use	0 - 250m	250 - 500 m	500 - 750 m	750 - 1000 m	> 1000 m
Proximity to water body	0 - 250m	250 - 500 m	500 - 750 m	750 - 1000 m	> 1000 m

(5) Assigning Weights Using Analytical Hierarchy Process

Weight values indicate the relative importance of factors affecting the suitability of potential locations as future green infrastructure hubs. Weighting is "one of the fundamental steps in suitability analysis, as it particularly impacts the output (Mahmoud and El-Sayed 2011)." Weight values are numbers from 0 to 1, and the sum of all weight values for each factor should be 1 (Liu Tie 2013).

The Analytic Hierarchy Process (AHP) is an efficient method to extract weights of different factors (Saaty 1990). It is a multi-criteria decision-making (MCDM) process that is usually used to examine complex matters by applying "a pair-wise comparison procedure to arrive at a scale of preference" among a set of factors (Saaty 1990). The methods of constructing the comparisons within the matrix is based on Saaty's method (1990). The matrix contains intensity of importance from 1/9 to 9, which means the importance of one element against another in the pair (Table 6-6). The intensity of importance value is given to each pair of factors identified before, and the comparison matrix of habitat hubs and hubs as urban parks are shown in Table 6-7 and Table 6-10. The sum of each column in the matrix is then calculated. The intensity of importance value cells are divided by the sum of their columns to get the normalized comparison matrix (Table 6-8 and Table 6-11**)**. The average of each row is then calculated, and the results are the average weighting values of each factor (Table 6-9 and Table 6-12).

Table 6-6 Importance value definition and explanation ,adapted from Saaty 1990.

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Moderate importance of on over another	Experience and judgement strongly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If factor A has one of the above numbers assigned to it when compared with factor B, then B has the reciprocal value when compared with A	

Table 6-7 Pair-wise comparison matrix of habitat hubs factors (table made by author)

	Land area	Proximity to river corridors	Proximity to existing habitat hubs	Land cover	Proximity to streets
Land area	1	1/3	1/3	1/5	1
Proximity to river corridors	3	1	1/2	1/5	1/3
Proximity to existing habitat	3	2	1	1/5	3
Land cover	5	5	5	1	3
Proximity to streets	1	3	1/3	1/3	1
Sum of columns	13.00	11.33	7.17	1.93	8.33

Table 6-8 Normalized Pair-wise comparison matrix of habitat hubs factors (table made by author)

	Land area	Proximity to river corridors	Proximity to existing habitat hubs	Land cover	Proximity to streets	Average of rows
Land area	0.077	0.029	0.047	0.103	0.120	0.075
Proximity to river corridors	0.231	0.088	0.070	0.103	0.040	0.106
Proximity to existing habitat	0.231	0.176	0.140	0.103	0.360	0.202
Land cover	0.385	0.441	0.698	0.517	0.360	0.480
Proximity to streets	0.077	0.265	0.047	0.172	0.120	0.136

Table 6-9 Average weight values based on AHP for habitat hubs factors (table made by author)

Factor	Land area	Proximity to river	Proximity to existing habitat	Land cover	Proximity to streets
Weight values	0.079	0.128	0.251	0.394	0.148

Table 6-10 Pair-wise comparison matrix of hubs as urban parks (table made by author)

	Proximity to schools	Proximity to bus stops	Residential neighborhood population density	Existing parks service area	Land cover	Proximity to river corridors	Proximity to historic heritage site and district	Proximity to recreational places
Proximity to schools	1	5	3	1/3	1/3	3	2	2
Proximity to bus stops	1/5	1	1/3	1/7	1/9	1/3	1/5	1/3
Residential neighborhood population density	1/3	3	1	1/3	1/5	3	3	1
Existing parks service area	3	7	3	1	1/2	4	2	6
Land cover	3	9	5	2	1	3	3	4
Proximity to river corridors	1/3	3	1/3	1/4	1/3	1	1/3	1/3
Proximity to historic heritage site and district	1/2	5	1/3	1/2	1/3	3	1	2
Proximity to recreational places	1/2	3	1	1/6	1/4	3	1/2	1
Sum of columns	8.867	36.000	14.000	4.726	3.061	20.333	12.033	16.667

Table 6-11 Normalized Pair-wise comparison matrix of hubs as urban parks (table made by author)

	Proximity to schools	Proximity to bus stops	Residential neighborhood population density	Existing parks service area	Land cover	Proximity to river corridors	Proximity to historic heritage site and district	Proximity to recreational places	Average of rows
Proximity to schools	0.113	0.139	0.214	0.071	0.109	0.148	0.166	0.120	0.135
Proximity to bus stops	0.023	0.028	0.024	0.030	0.036	0.016	0.017	0.020	0.024
Residential neighborhood population density	0.038	0.083	0.071	0.071	0.065	0.148	0.249	0.060	0.098
Existing parks service area	0.338	0.194	0.214	0.212	0.163	0.197	0.166	0.360	0.231
Land cover	0.338	0.250	0.357	0.423	0.327	0.148	0.249	0.240	0.292
Proximity to river corridors	0.038	0.083	0.024	0.053	0.109	0.049	0.028	0.020	0.050
Proximity to historic heritage site and district	0.056	0.139	0.024	0.106	0.109	0.148	0.083	0.120	0.098
Proximity to recreational places	0.056	0.083	0.071	0.035	0.082	0.148	0.042	0.060	0.072

Table 6-12 Average weight values based on AHP for hubs as urban parks factors (table made by author)

Factor	Proximity to schools	Proximity to bus stops	Residential neighborhood population density	Existing parks service area	Land cover	Proximity to river corridors	Proximity to historic heritage site and district	Proximity to recreational places
Weight values	0.135	0.024	0.098	0.231	0.292	0.05	0.098	0.072

(6) Weighted Overlay in ARC GIS

After all the factors are displayed as raster layers in ARC GIS, and the final weighting values are assigned to each factor based on AHP, the Weighted Overlay Tool in ARC GIS is used to generate composite suitability maps for hubs as wildlife habitats and hubs as urban parks. The raster layers of each factor are used as input rasters with their reclassified suitability scores in the scale from 1 to 5. The suitability score of each cell is multiplied by the raster’ weight of importance. The resulting cell values for all factors are added together to produce the output raster (ArcGIS Resource Center). The output rasters for hubs as habitats and hubs as urban parks are shown in Figure 6-15 and Figure 6-17.

To generate the suitability map for multi-purpose hubs as both habitats and urban parks, the Weighted Sum Tool is used to add the suitability values of output rasters for hubs as habitats and hubs as urban parks together. The weight value of both raster layers are set as 0.5, which means that they are equally important in determining suitable land for multi-functional hubs. The scale of suitability values is from 1 to 5. The result is shown in Figure 6-19.

(7) Creation of final maps

Based on the suitability map of habitat hubs, a habitat hubs conservation plan is proposed (Figure 6-16). Hubs that are bigger than 4 ha (smallest suitable habitat size for birds) and have a suitability score bigger than 3 are proposed as potential future habitat hubs for conservation purposes. Hubs with higher priority should be considered first in future conservation and urban greening projects, in the policy making process and ecological protection zone set-ups. The most suitable areas (suitability score of 1) are proposed as future habitat hubs priority 1. The suitable areas (suitability score of 2) are proposed as future habitat hubs priority 2. The modestly suitable areas (suitability score of 3) are proposed as future habitat hubs priority 3.

Based on the suitability map of urban parks (Figure 6-17), the most suitable areas (suitability score of 1) are proposed to have priority 1 for future public parks development, and the suitable areas (suitability score of 2) are proposed to have priority 2 for future public parks development. In areas that are not covered by these proposed parks' service area, moderately suitable lands (suitability score of 3) are proposed as priority 3 for future park development. The results are shown in Figure 6-18.

Based on the suitability map of multi-functional hubs, the most suitable areas (suitability score of 1) and suitable areas (suitability score of 2) are proposed to be future multi-functional hubs as both urban parks and wildlife habitats. Combining proposed multi-functional hubs, proposed wildlife habitats and proposed urban parks, the plan of green infrastructure hubs are generated (Figure 6-20).

Results and Discussion

(1) Thematic Maps

Figure 6-4 Land area map created by author June 2014

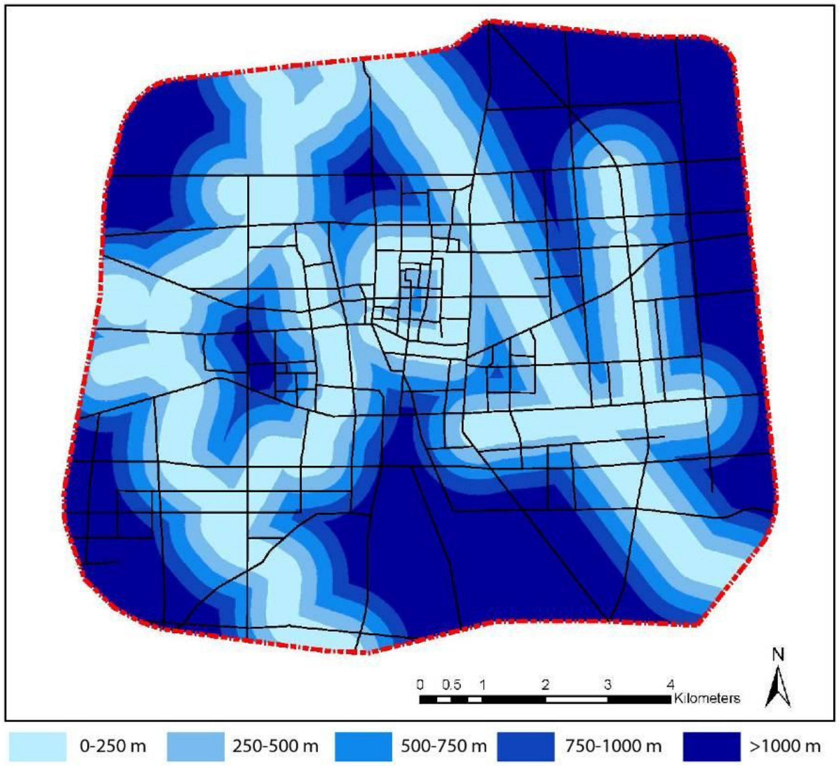

Figure 6-5 Proximity to river corridors map created by author June 2014

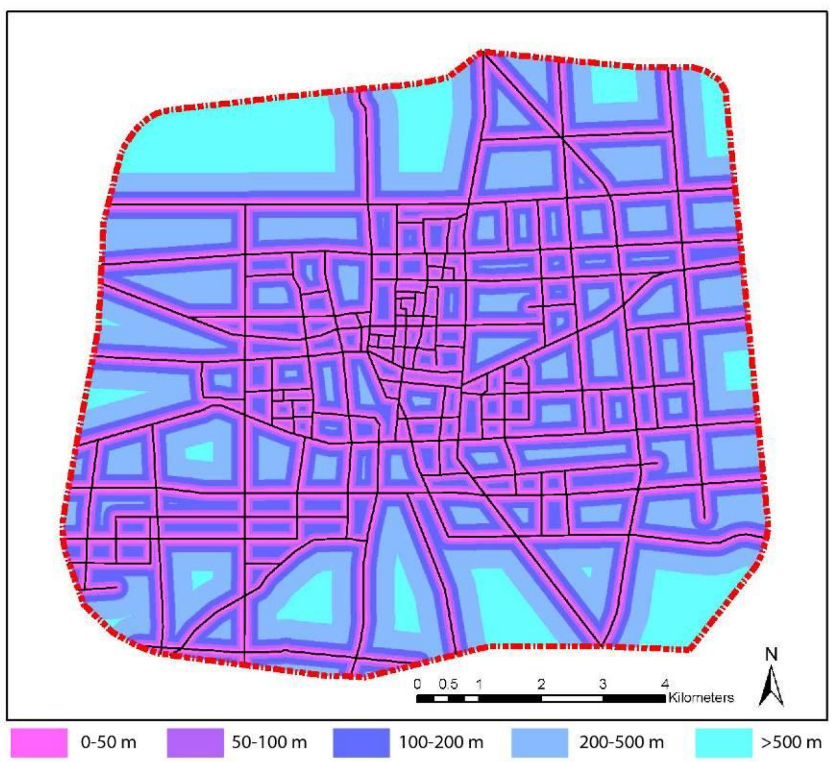

Figure 6-6 Proximity to streets map created by author June 2014

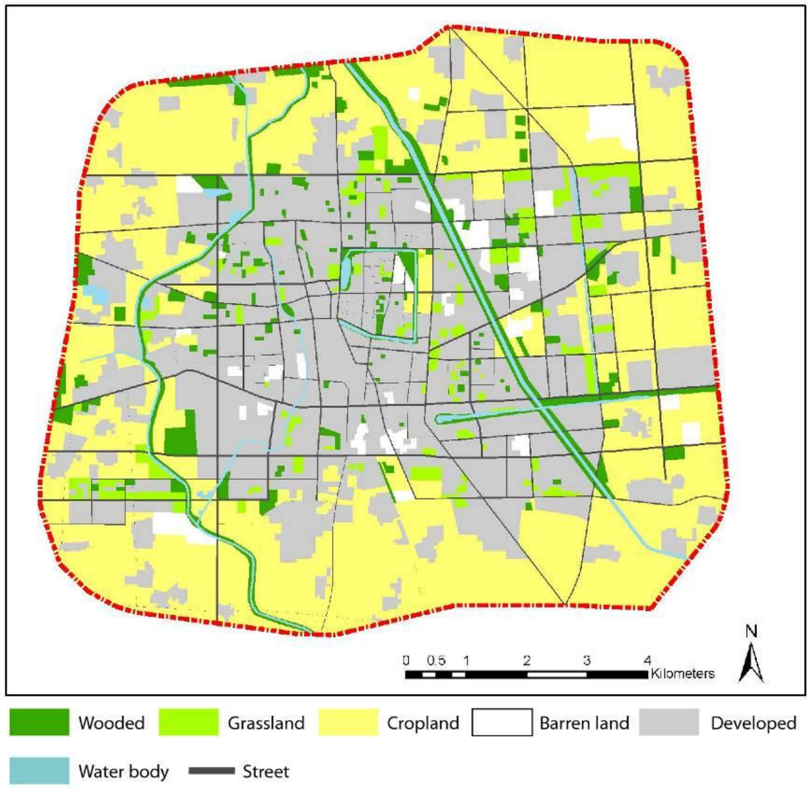

Figure 6-7 Land cover map created by author June 2014

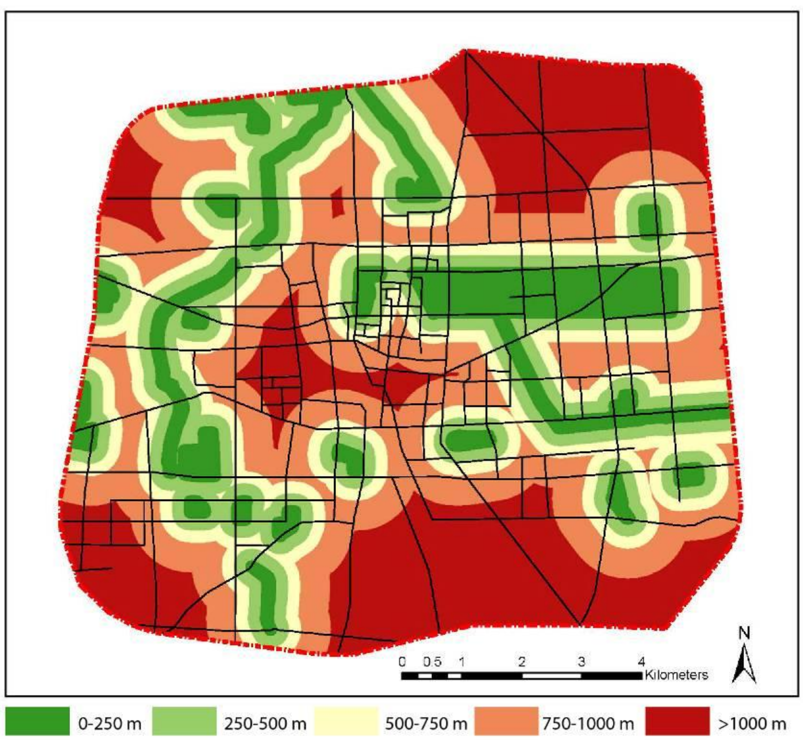

Figure 6-8 Proximity to existing habitat hubs map created by author June 2014

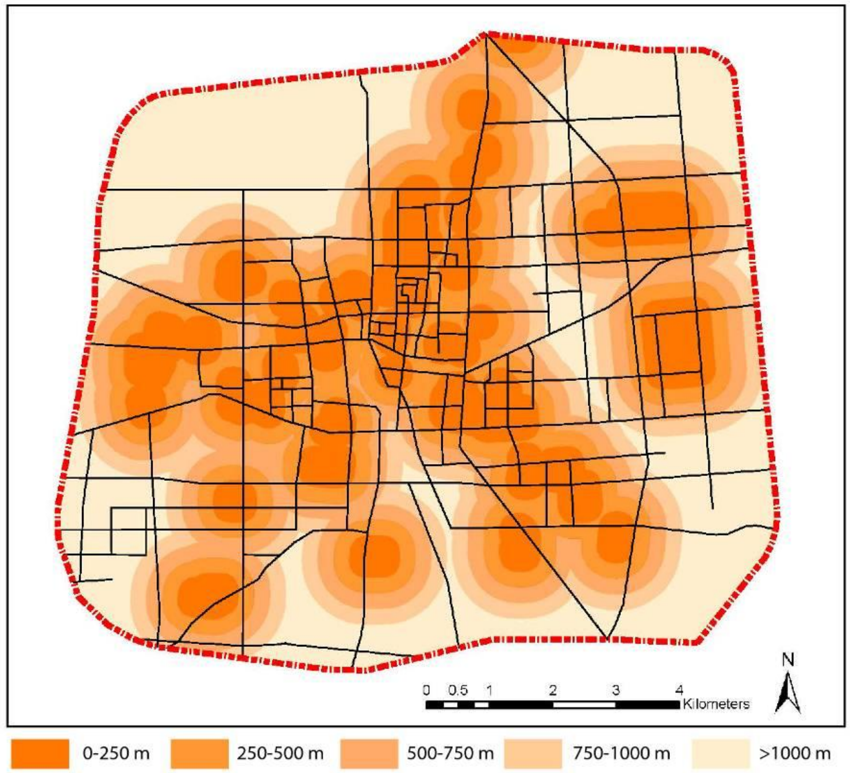

Figure 6-9 Proximity to schools map created by author June 2014

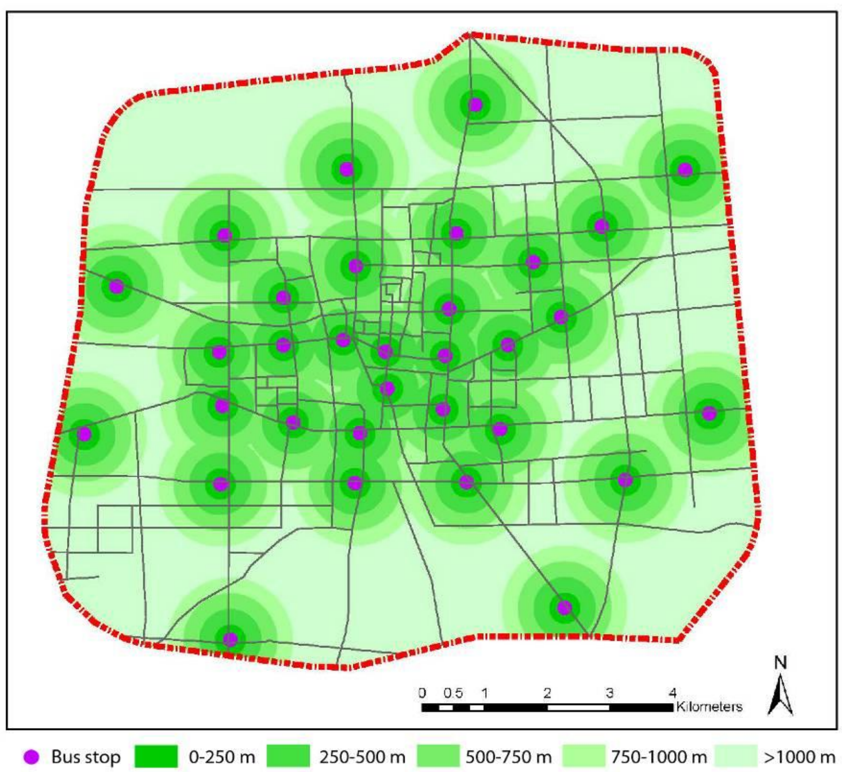

Figure 6-10 Proximity to bus stops map created by author June 2014

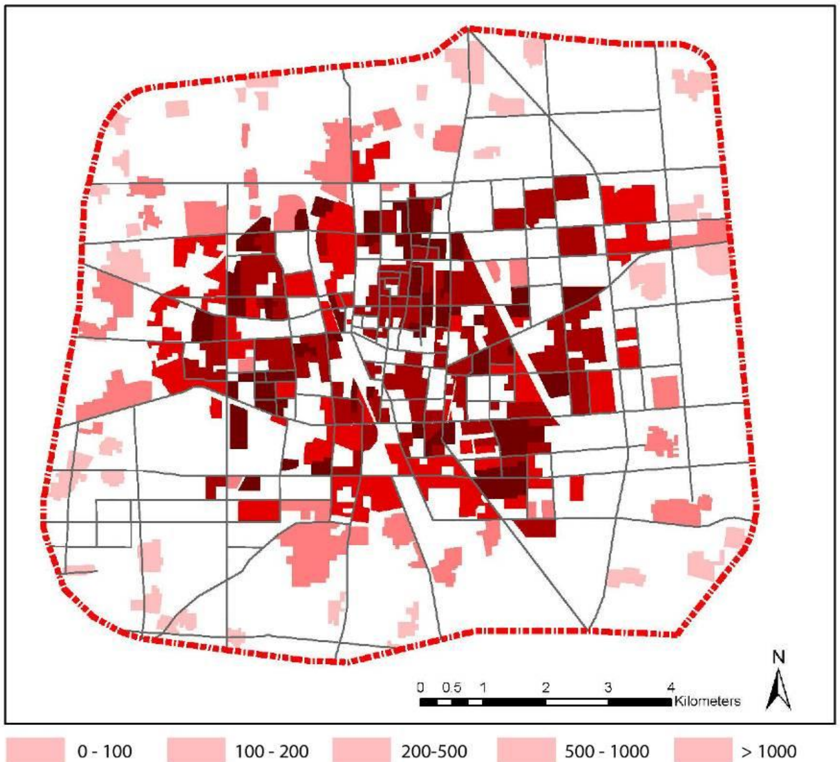

Figure 6-11 Residential neighborhood population density map created by author June 2014

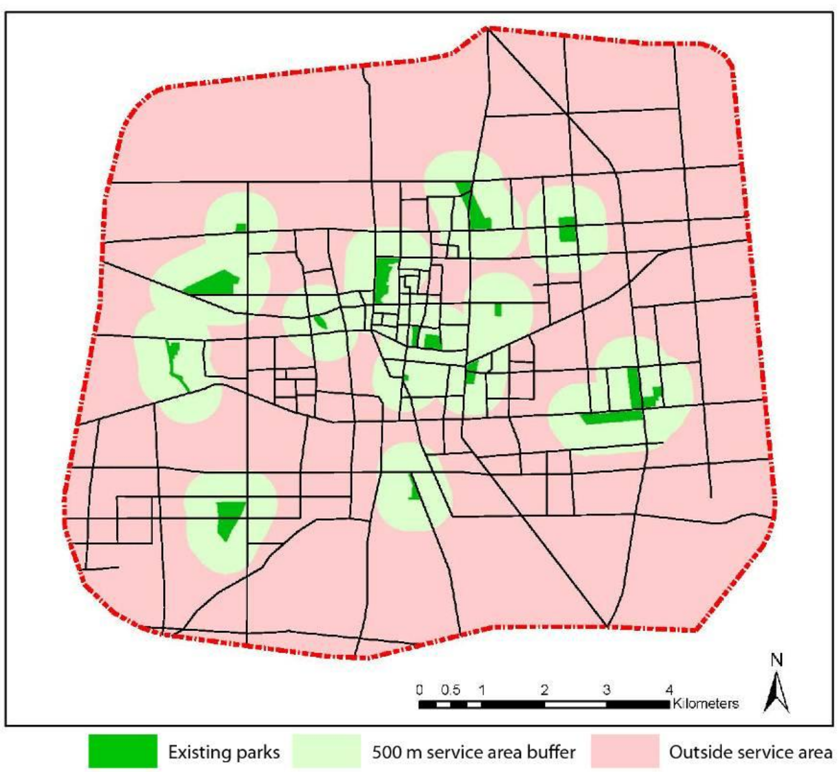

Figure 6-12 Existing parks services areas map created by author June 2014

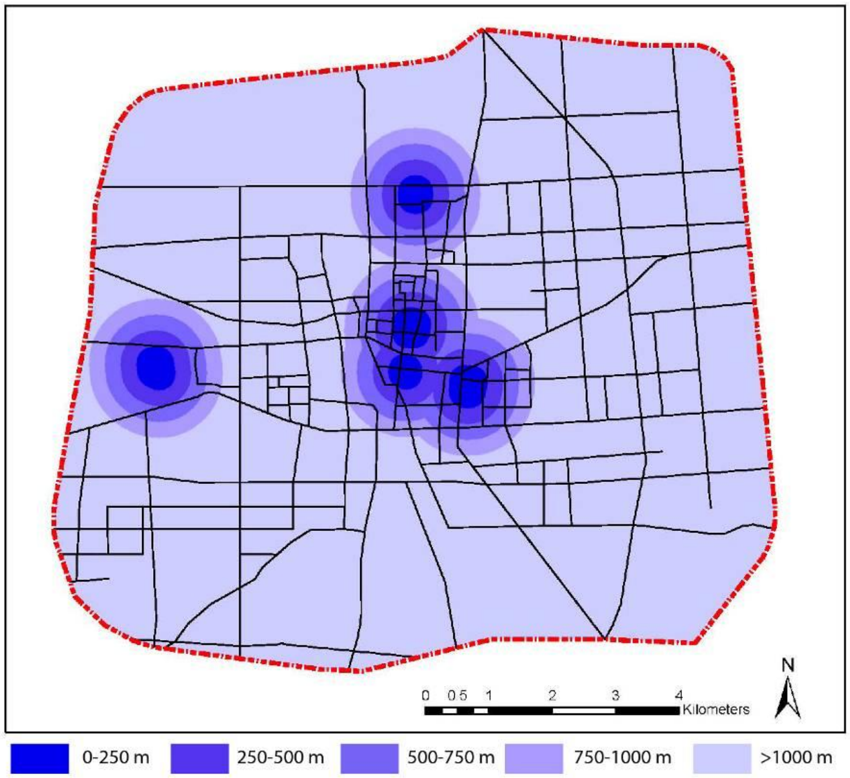

Figure 6-13 Proximity to historic heritage sites and districts map created by author June 2014

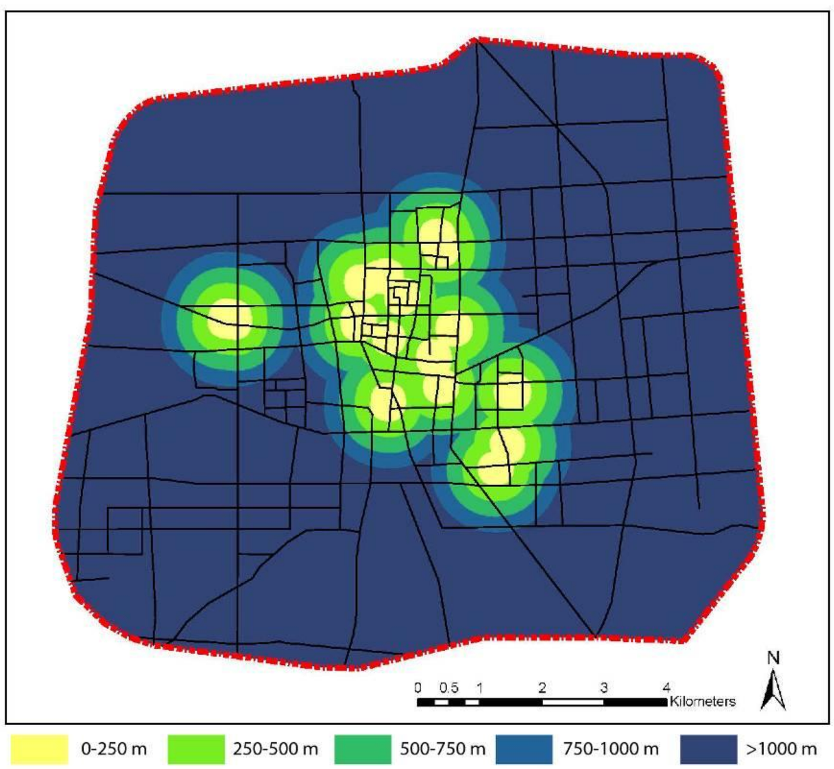

Figure 6-14 Proximity to recreational places map created by author June 2014

(2) Hubs for Wildlife Habitats

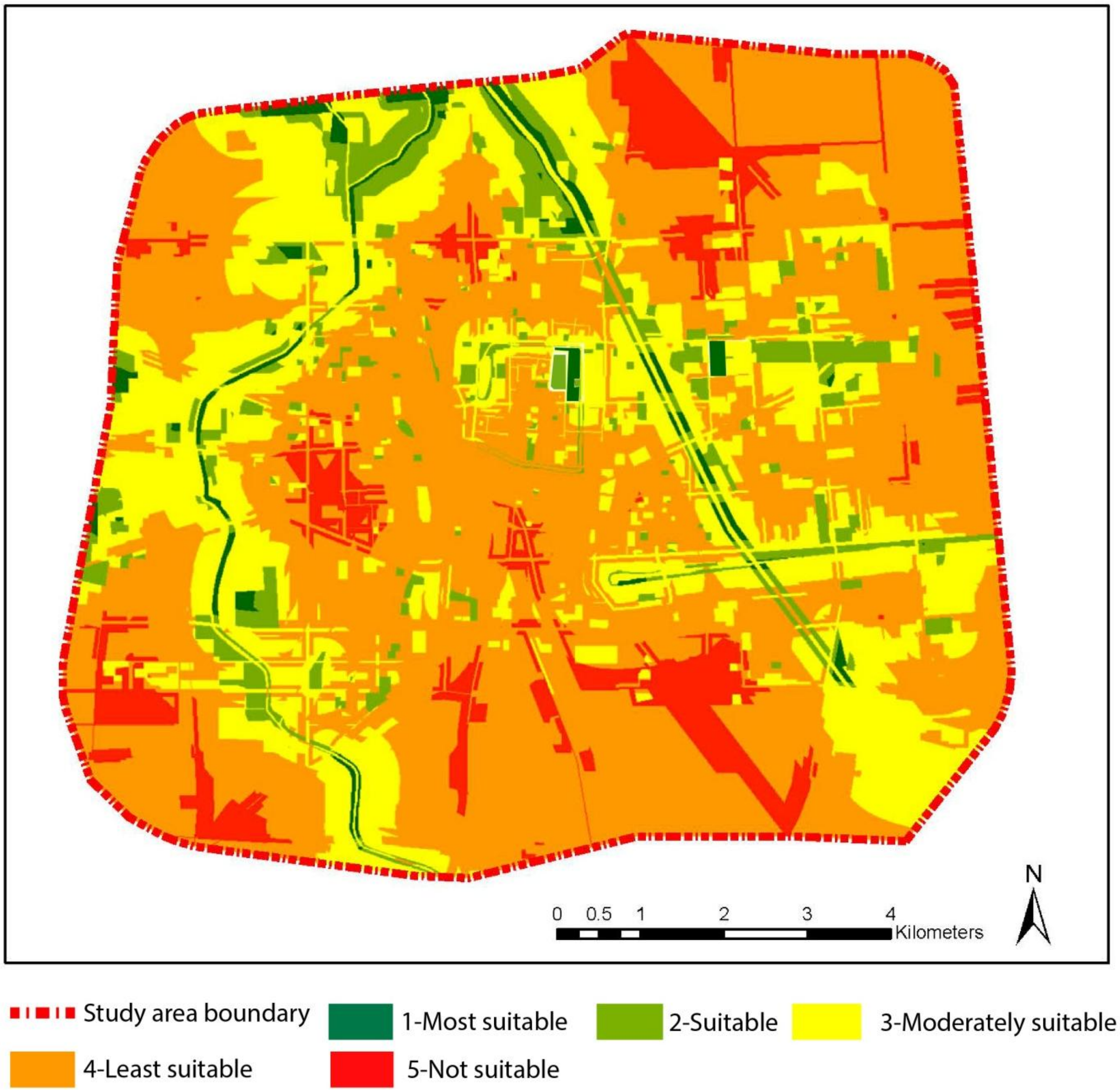

Figure 6-15 Suitability map for hubs as wildlife habitat, created by author June 2014

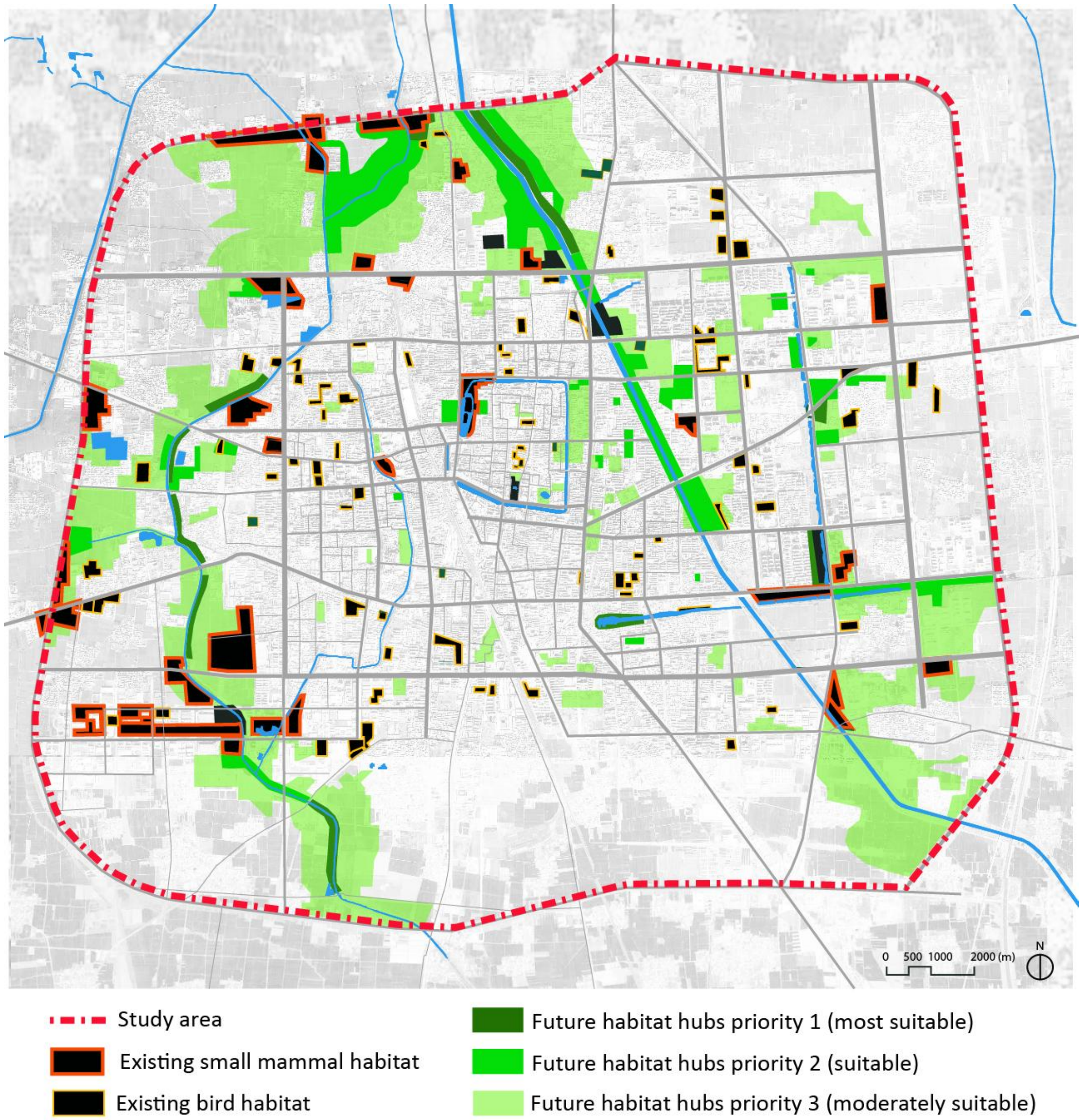

Figure 6-16 Proposed future habitat hubs priority map created by author June 2014

In the suitability map for habitat hubs (Figure 6-15), the total area of most suitable lands (suitability score of 1) for habitat hubs is 596 hectares, and the total area of suitable lands (suitability score of 2) is 1,672 hectares. The majority of most suitable lands (suitability score of 1) are already existing habitat hubs. The most suitable areas that are not covered by existing habitat hubs include a few hubs along river corridors and include enlargement from existing habitat hubs, which in total is 112 hectares. Larger suitable hubs are located mostly along river corridors and at the urban fringe area, where there is better vegetation coverage and are close to existing habitat hubs with less traffic disturbances and bigger block size for future habitat expansion.

In the proposed future habitat hubs priority map (Figure 6-16), assuming that all the proposed future hubs are restored to wooded lands, the habitats for local generic forest-breeding birds increases from 1,088 hectares to 4,930 hectares and the habitats for small terrestrial mammals increases from 642 hectares to 3,021 hectares. Large areas of proposed habitat hubs are connected by river corridors and their riparian buffers. However, 40 % of habitat hubs are still isolated, and the majority of them are located mostly in more compactly developed urban core area with smaller hub sizes. Connectivity should be provided, which may include using canopy trees on streets as linkages, parks as “stepping stones,” and other types of green infrastructures such as green roofs and green walls that can also provide access.

(2) Hubs as Public Parks

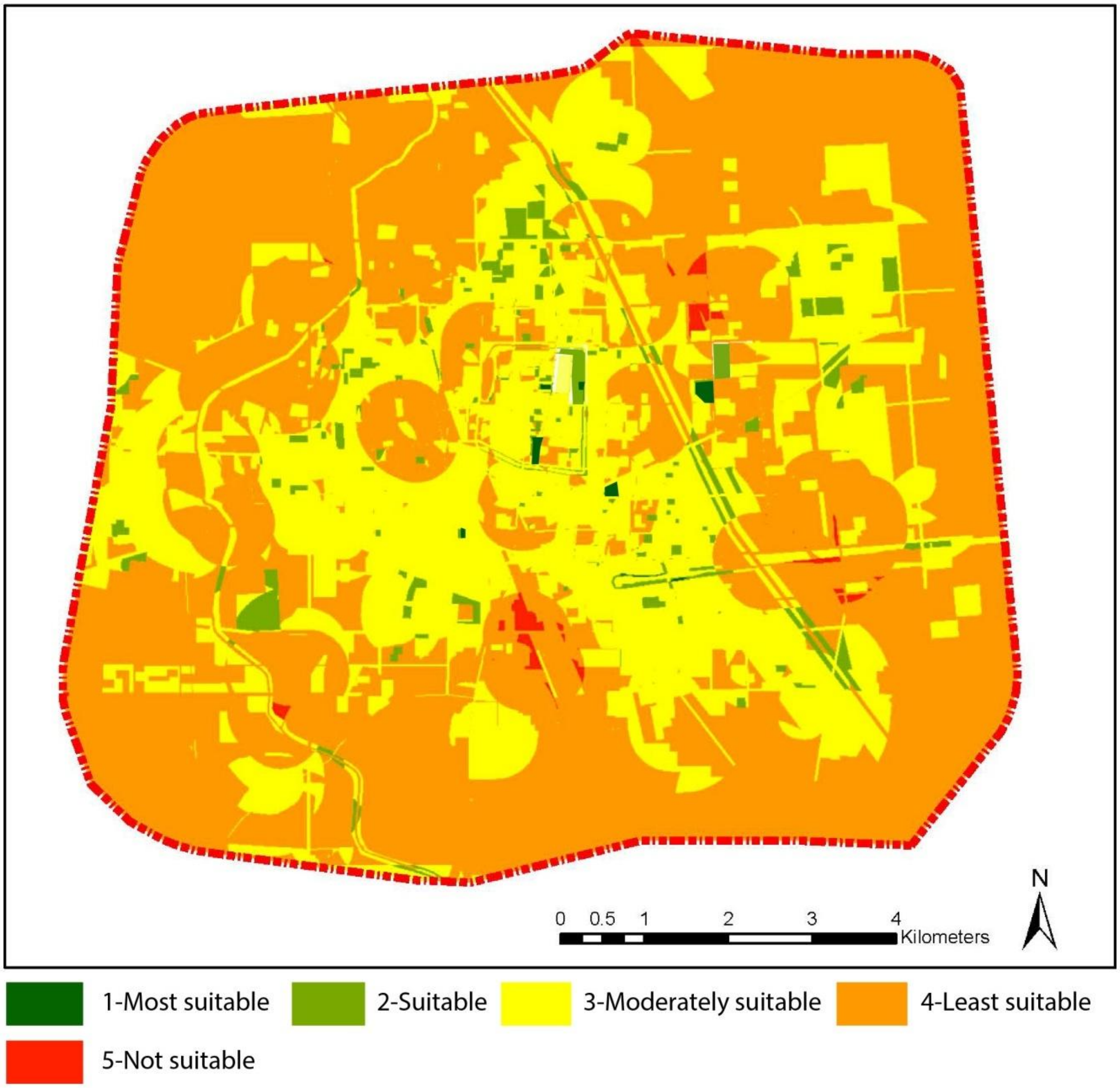

Figure 6-17 Suitability map for urban parks, created by author June 2014

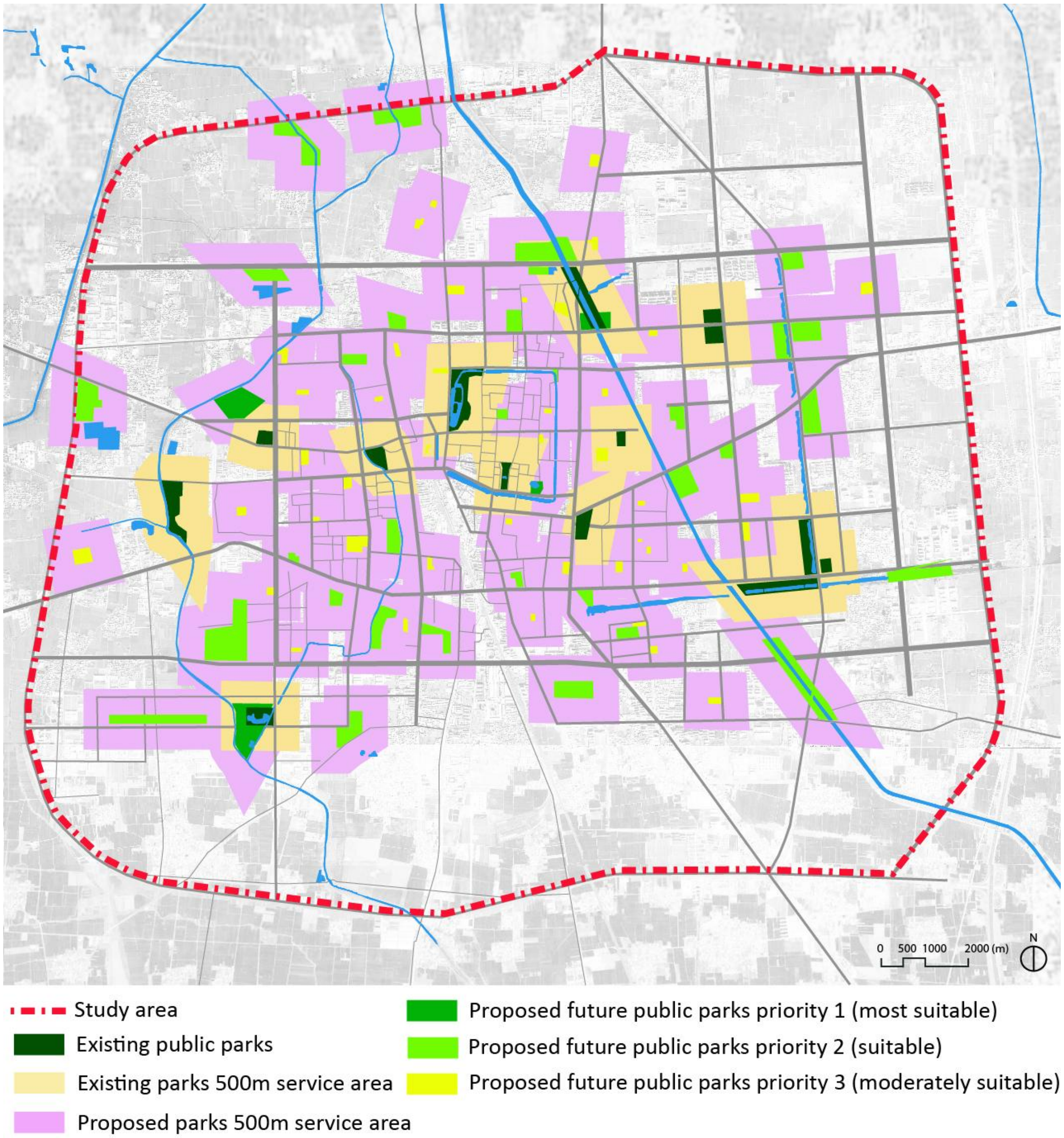

Figure 6-18 Proposed future urban parks map created by author June 2014

In the suitability map for urban parks (Figure 6-17), the total area of most suitable lands (suitability score of 1) for future urban park development is 67 hectares, and the total area of suitable lands (suitability score of 2) is 1,274 hectares. These hubs are distributed mostly near developed areas that are close to other urban public service facilities and attractions such as schools, bus stops, recreational places, historic sites and districts, high population density neighborhoods, river corridors, outside existing park service areas, and have better vegetation coverage.

In the proposed future public parks map (Figure 6-18), all proposed future urban parks increased total park service area coverage from 19.5% to 56.5% of study area. The master plan of proposed hubs as an urban park system mitigates the issues of park distribution and accessibility. How to design these parks at site scale to provide better ecosystem services and connect them with linkages to form a green infrastructure network will be discussed in the design guidelines and linkages sections.

(3) Multifunctional Hubs

Multi-functional hubs are the overlapped areas of the two main functions of green infrastructure hubs -- urban parks and wildlife habitats. Multi-functional hubs provide more types of ecosystem services than single function hubs, including regulating services, cultural services and wildlife habitat. They utilize the lands and green infrastructure more efficiently in compactly developed urban areas (Tzoulas et al. 2007). The design of multi-functional hubs needs to meet requirements of both wildlife needs and citizens' daily use functions, which will be discussed further in design guidelines section.

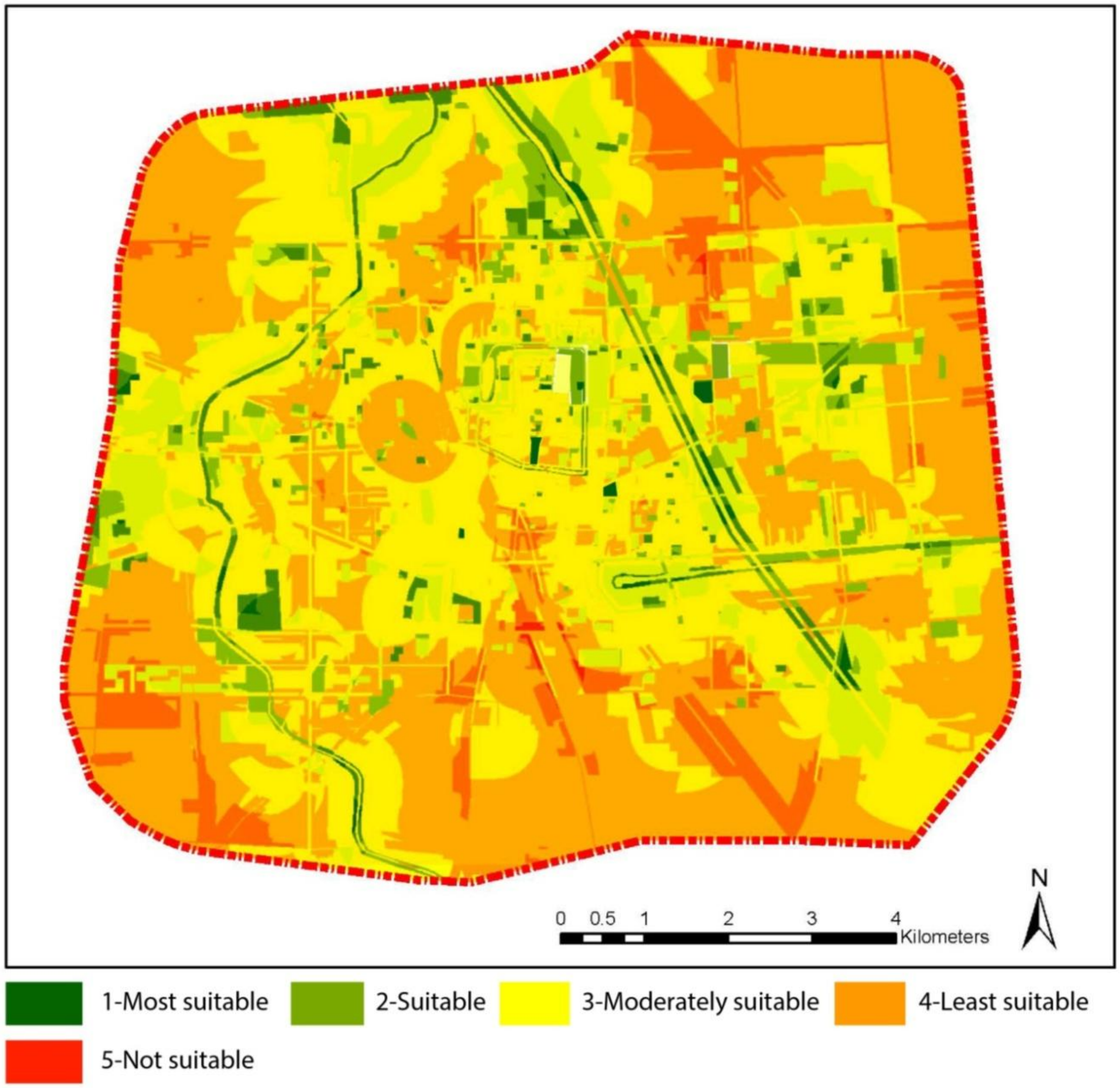

Figure 6-19 Suitability map for multi-functional hubs, map created by author June 2014

In the suitability map for multi-functional hubs (Figure 6-19). The most suitable land for multi-functional hubs is 1,154 hectares in total, and the suitable land for multi-functional hubs is 3,420 hectares in total. The most suitable and suitable lands are proposed for future multi-functional hub development. Combining habitat hubs, urban park hubs and multi-functional hubs, the proposed plan of green infrastructure hubs is generated (Figure 6-20).

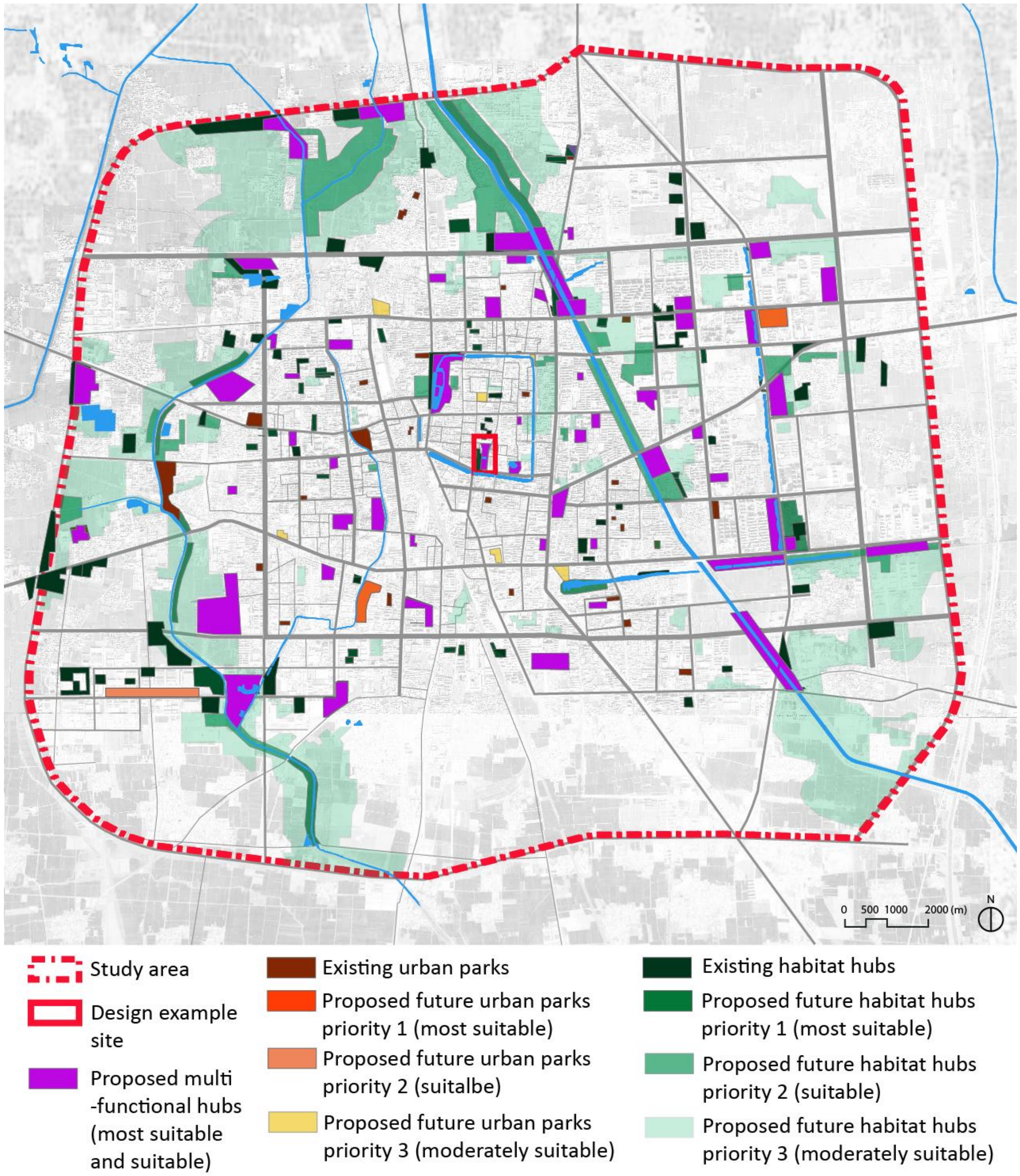

Figure 6-20 Proposed plan of green infrastructure hubs, map created by author June 2014

In the proposed plan of green infrastructure hubs (Figure 6-20), Chunqiu Square (marked by the red square in the map) is chosen to be further studied and designed in the design example section of this chapter. Chunqiu Square is located within historic downtown area, and next to the historic Shun River. It is identified as most suitable location for urban parks, suitable location for wildlife habitat, and most suitable location for multi-functional hub location.

Design Guidelines

(1) Design Guidelines for Hubs as Public Parks

This listing needs an introductory sentence such as: Design guidelines for hubs as public parks will need to address several key components to be effective. Among these components are:

- **Cultural landscape**: Preserve existing cultural landscape parks including Chunqiu Square, West Lake Park, Baling Bridge Park, Wenfeng Tower Square, Dragon Park and Grande Dragon Park. Their property boundaries should be the boundary of urban development in the Comprehensive Overall Plan of Xuchang.
- **Physical health**: For peoples' physical health, public parks need to provide a variety of settings and infrastructure for various levels of formal and informal sport and recreation, including trails, fields, courts, playgrounds, picnic areas, dog parks, etc.
- **Social health**: For social health, public parks should provide settings to enhance community communication and interaction. Common social activities in Xuchang parks include walking, group chatting, traditional opera band playing (usually by older people), group exercise dance, roller skating, etc. Facilities suggested are pavilions, moveable tables and chairs, gathering spaces, plazas, lawns, etc.

- **Sense of place**: For spiritual satisfaction, a sense of place should be attained by creating quiet tree-lined spaces, water features, culturally pristine spaces, woods and traditional Chinese gardens.
- **Public participation**: Social surveys and public opinions on expectations of proposed parks should be collected and studied before park design, and design alternatives should be evaluated by citizens before the construction of a park.
- **Regulating services**: Other ecosystem services can also be provided by urban parks and need to be considered in park design. Bio-retention ponds, rain gardens and pervious surfaces should be encouraged in park design for storm water management purpose. Canopy trees should be planted to provide shade and for air filtration and microclimate regulation.

(2) Design Guidelines for Hubs as Wildlife Habitats

Below are some considerations for creating effective guidelines for using hubs as wildlife habitats.

- **Ecological protection area**: Define habitat patches as ecological protection areas in Comprehensive Overall Plan of Xuchang. A buffer zone should be kept where construction is limited, and the width can be determined site specifically. Sound barrier is needed to isolate noise disturbance to major bird habitat.
- **Vegetation structure**: Preserve existing mature trees and healthy plant communities. Choose native plant species and create tight plant communities with canopy trees, understory trees, shrubs, and groundcovers.

- **Pervious paving**: Impervious surfaces should be removed and replaced by pervious pavements, plants, and mulch to facilitate storm water infiltration.
- **Human activity**: Activities with few disturbance and pollution such as science education and passive recreational activities are allowed. Building construction and usage must be strictly controlled.
- **Management**: Ecosystems should be managed to achieve or maintain a stable state based on adaptive management strategies, which is a structured and interactive process that is suitable for decision making process in the face of the uncertainty of ecosystems (Allan and Stankey 2009).

(3) Design Guidelines for Multifunctional Hubs

Suggested design guidelines for multifunctional hubs as both urban parks and wildlife habitats are shown below:

- Multipurpose hubs should be wooded with at least 80% tree coverage to provide bird habitat.
- Zones such as active recreation areas, passive recreation areas and habitat conservation areas can be set up in large parks to provide recreational spaces as well as protect habitat.
- Recreational areas, especially active recreational facilities such as sports field, plazas and gathering spaces should be compactly developed in one or a few zones with the least disturbance to habitat conservation areas possible.
- Pedestrian paths, benches and pavilions can be built in habitat conservation zones for walking and leisure purposes. Soft surfaces such as mulch

and plants should always be used in habitat conservation areas, and necessary accessible pervious pavement is recommended for pedestrian paths.

Multi-functional Hub Design Example: Chunqiu Square

Chunqiu square is located within the historic downtown area of Xuchang, connecting historic Chunqiu Temples and the moat – Shun River. The Chunqiu Temples have a history of over 1500 years, and the existing Chunqiu Square was designed and constructed at 1990s.

It was proposed as a multipurpose hub in the previous section, which means that the design must meet both human recreational needs and wildlife habitat needs. Being one of the most important public square/parks in Xuchang, Chunqiu square serves as a cultural landscape which provides enrichment services. It is also an important urban forest and habitat patch which provides regulating services.

The context and existing conditions are analyzed and shown in Figure 6-21. A new renovation design is proposed following “multipurpose hubs design guidelines,” and the goal is to enhance the park’s ability to provide better cultural and regulating services. The design is shown in Figure 6-22, Figure 6-23. In Table 6-13 and Table 6-14, the usage, facilities and ecosystem services provided in existing condition and proposed design are compared and evaluated.

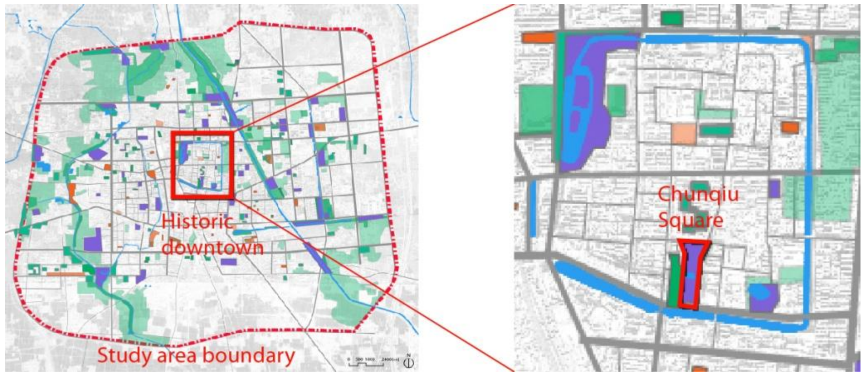

Figure 6-21 Chunqiu Square context map created by author June 2014

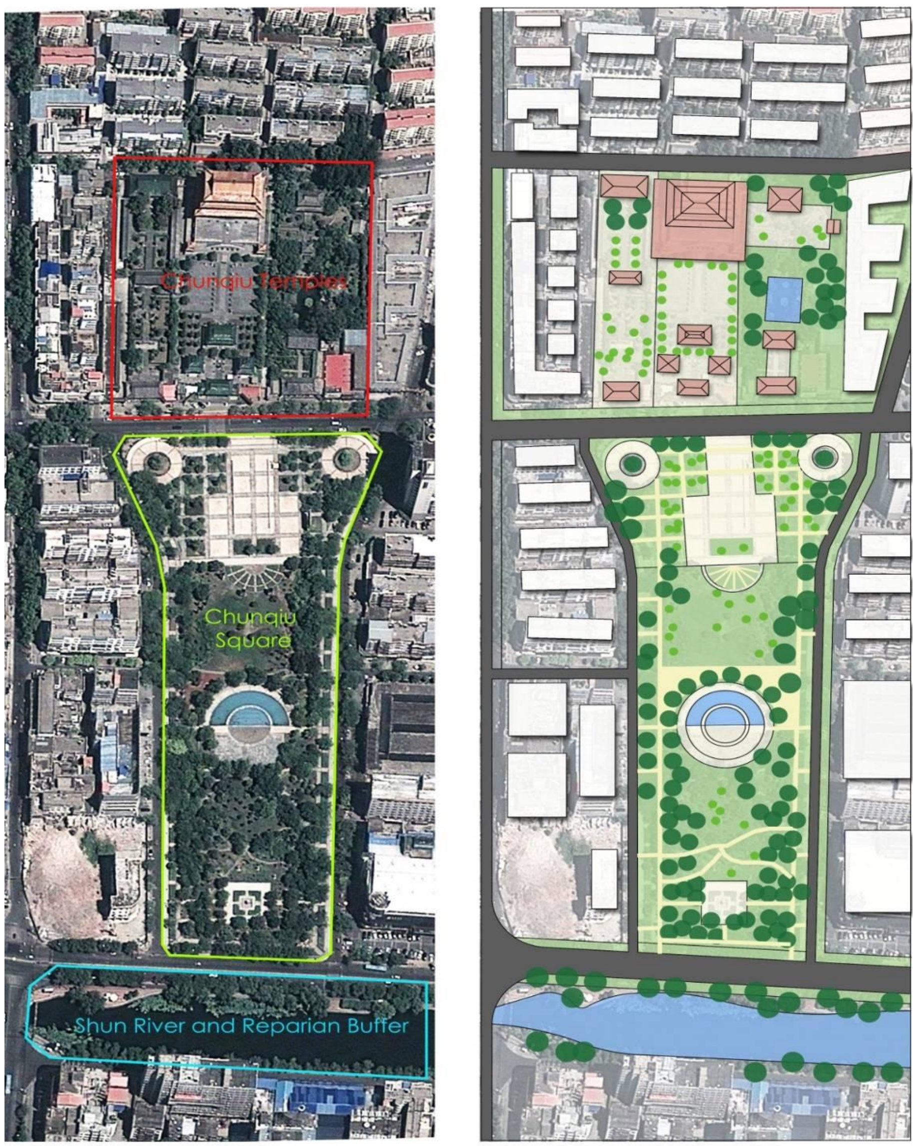

Figure 6-22 Chunqiu Square existing condition maps created by author June 2014

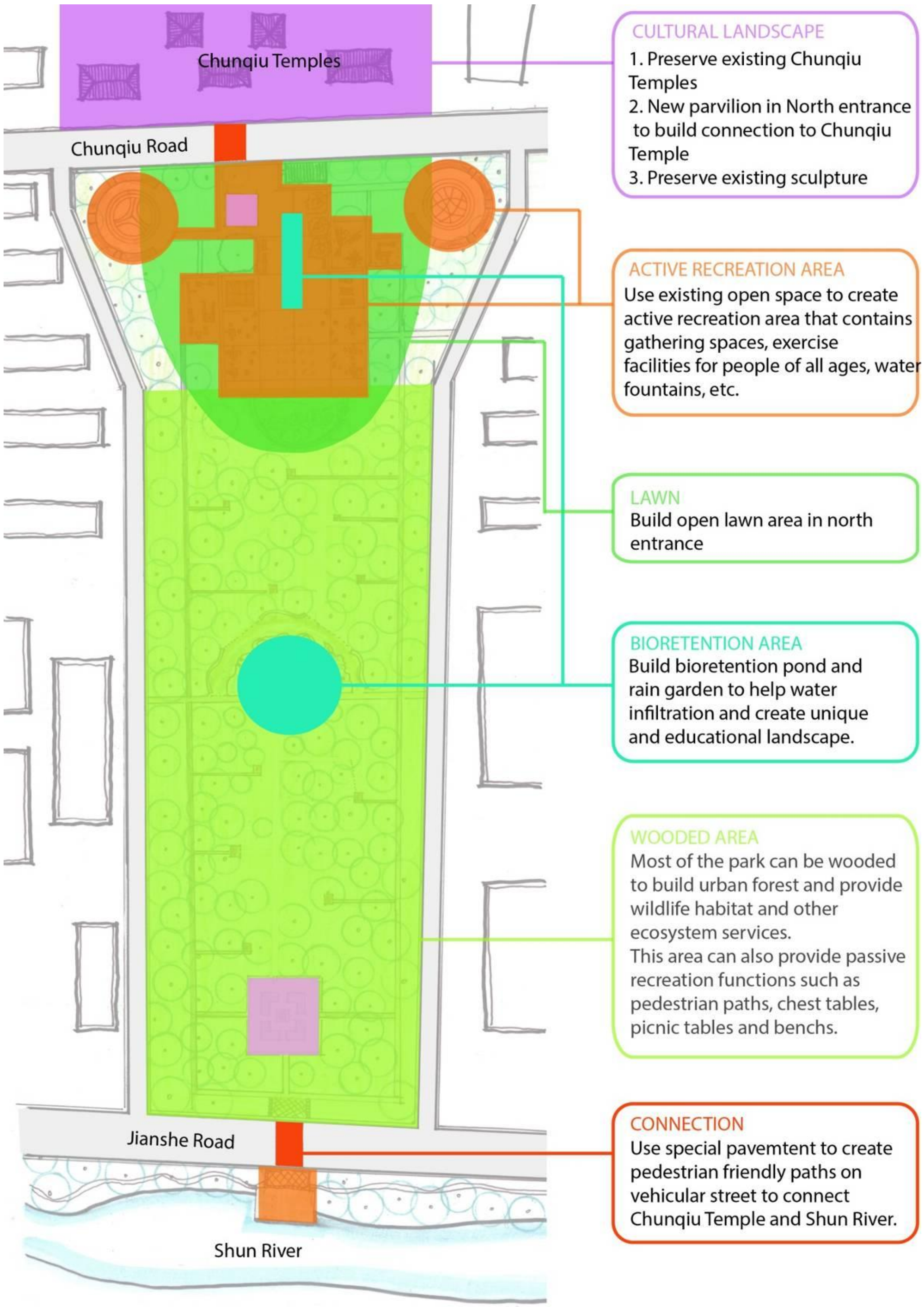

Figure 6-23 Chunqiu Square renovation strategies map created by author June 2014

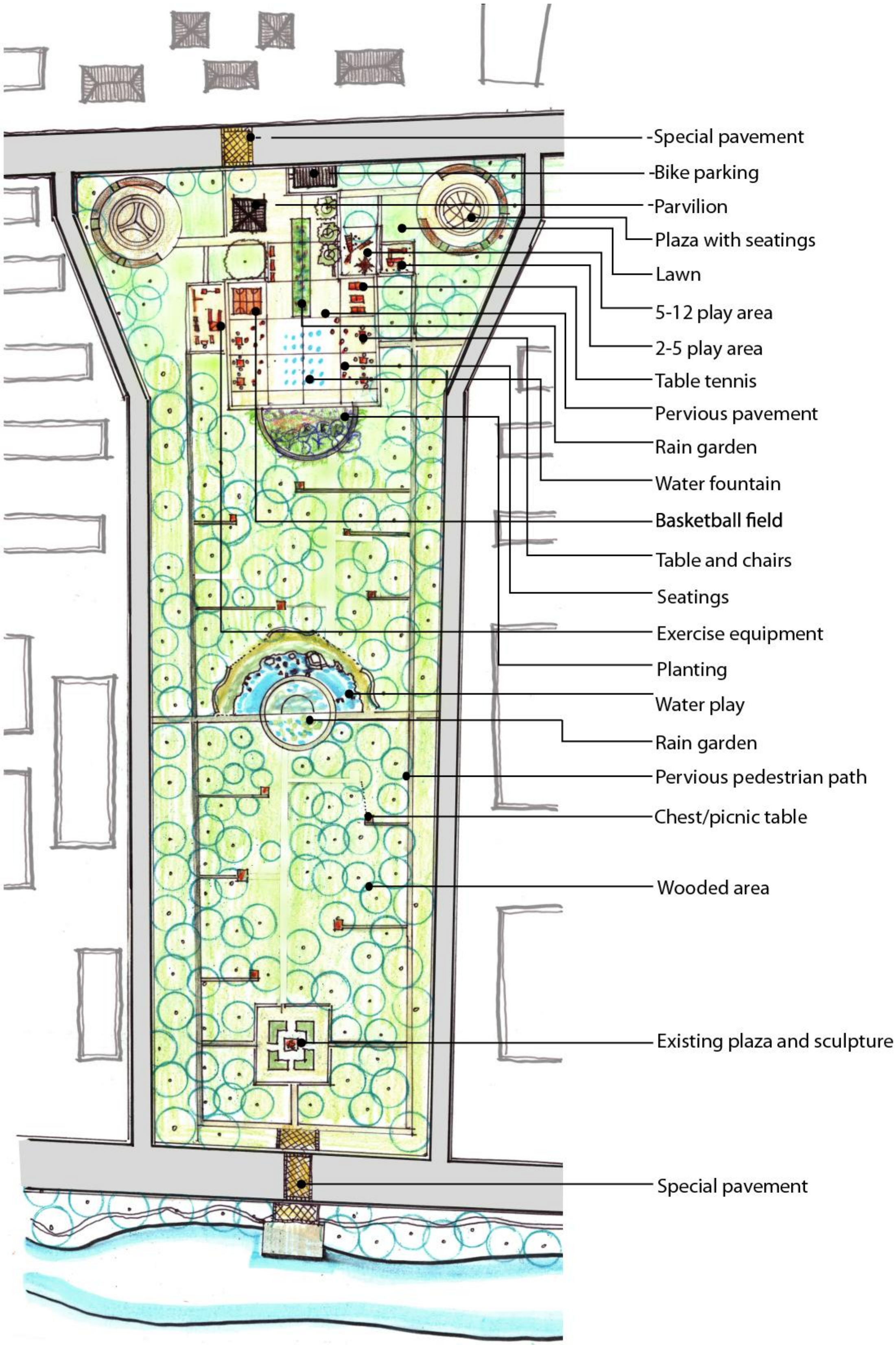

Figure 6-24 Proposed Chunqiu Square master plan map created by author June 2014

Table 6-13 Existing and proposed cultural services of Chunqiu Square

Cultural services	Existing facilities analysis	Proposed facilities	Existing programs / activites	Proposed programs / activities
Recreation	**Plazas** 1. Provide space for activities 2. No facilities **Pedestrian path** Provide passive recreation/relaxing	Parvilion Plaza with seatings and gallery 2-5 play area 5-12 play area Table tennis Basketball field Table and chairs Infinite water fountain Seatings Exercise equipment Water play area Chess/picnic table in the woods Pedestrian path	Dancing Tai Chi Walking Gathering	Dancing Exercising 2-5 play 5-12 play Sports Tai Chi Gathering Play chess Walking Picnic Music practice and performance Water play at water fountain Water play in the woods
Aesthetic Pleasing	**Water fountain** 1.The waterfountain attracts some people 2. lack of seattings around and no interactive facilities 3. The fountain is oftenly off. **Plaza** 1. Scale is too huge 2. Lack of variation of space **Sculpture** Sculpture in morth plaza represents historic charactors **Planting** 1. Too rigid 2. Lack mature canapy trees	Parvilion Plaza Infinite water fountain Rain garden Sculpture Open lawn	N/A	N/A
Educational	There is no existing educational service	Rain garden Wooded area	N/A	Outdoor classes for plant identification, birds, rain garden,etc.
Sense of place	Lacking activities and the ridid and simple space hardly create the sense of place	Historical:Parvilion and sculpture Ecological: Woods, habitat, rain garden Recreational: activities and events	N/A	Sense of history Sense of ecology Sense of gathering
Cultural heritage	1. The design does not speak enouph to the spacial pattern and building style of Chunqiu temples 2. Sculpture in morth plaza represents historic charactors which can provide cultural heritage 3. Some mature trees in wooded area have place in the memories of old residents	1. Existing Chunqiu temples 2. New parvilion in north entrance to build connection to Chunqiu temple 3. Preserve existing sculpture	Visiting temple	Guided tour from Chunqiu temples to Chunqiu square and Shun River

Table 6-14 Strategies for imporving regulating services of Chunqiu Square

Regulating services	Strategies
Habitat and corridor provision	Habitat are mainly wooded area.Existing canopy tree coverage is 35%, which can be improved by utilizing lawn in south part. Wooded area is 65% in proposed design, which can provide more habitat area in the center of the urban area.
Air Filtering Microclimate regulation	Air filtering and microclimate regulation are primarily depending on total leaf area. It can be improved by adding broad leaf canopy trees.
Noise reduction	There is a loose buffer of trees around the park, which can eliminate some noise from street.
Water flow regulation and runoff mitigation	Existing wooded area is 37%, grass land is 32%, and impervious paving area is 31%. Since that wooded land can infiltrate more water than grass and paving, impervious paving need to be reduced and turn into pervious paving, mulch, grass and wooded land.
Overall	The site has a lot of green space. The points that need to be improved are: a. enhance plant community structure; b. reduce impervious surface; c. add more broad leaf canopy trees; d. make the buffer around the site thicker

6.2 Linkages as Greenways

The concept of "linkage" in green infrastructure theory is similar to the "corridor" concept in landscape ecology. In this discussion, the word "linkage" will be used to refer to linear green infrastructure features that provide connectivity to hubs. The focus will be on the greenways along river corridors within the study area of Xuchang. River corridors and riparian buffers provide important linkages for wildlife, store groundwater, filter waste and runoff, and provide access to water and water features for urban dwellers. To successfully design urban streams, landscape ecology principles should be applied to ensure the effectiveness as habitat linkages. In addition, as studied in Chapter Four, the residents’ expectations should also be considered, including their recreational use, participation, interactions with nature and scenery, sanitary maintenance and water safety, etc.

In this section, design principles basing on landscape ecology principles will be used to develop a set of spatial planning and design strategies for Xuchang.

Landscape Ecology Principles

In Chapter Four, the study of strategies based on landscape ecology principles for Xuchang proposed four principles for landscape edges, five for corridors, and six for mosaics (Table 4-4). The principles related to river corridors and riparian buffers are:

1. Use soft edges and small patch outreaches if applicable, especially in water banks.
2. Preserve the width of river corridors which enrich its vegetation structure with native plants.
3. Small patches should be provided along corridors.
4. Stepping stones should be used to maintain or create connectivity. Utilize neighborhood greening, pocket parks and street parks.
5. Intersections of corridors have high species richness and should be treated carefully.
6. Fragmented and isolated patches should be connected to corridors as much as possible.
7. Increase diversity of edge shapes, incorporating coves, lobes and fingers (Forman 1995).

To apply these principles to spatial design, several design strategies for greenways as river corridors are proposed. They include: connecting corridors with existing habitat hubs and other greenways; designing greenways into neighborhoods; designing small patches along corridors, especially at intersections of greenways; design “soft” edges and stable banks.

Connect with Hubs and Other Greenways

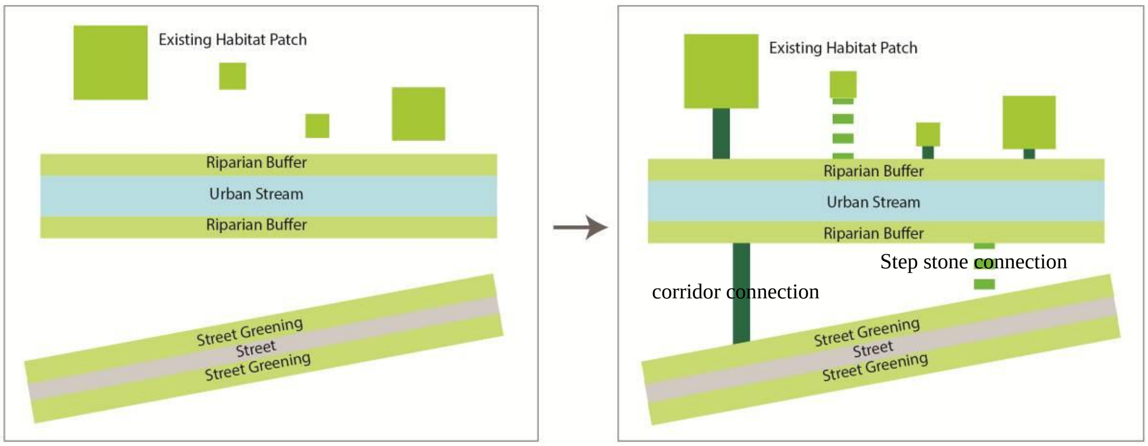

Figure 6-25 Connect with hubs and street greenings, graphic created by author June 2014

Habitat isolation is one of the major reasons of habitat loss and reduction of biodiversity (Dramstad, Olson et al. 1996). Corridors for wildlife movement and stepping stones are important forms in helping providing linkages between habitat patches and landscape connectivity (Dramstad, Olson et al. 1996). Based on the previous section in this chapter, hubs as habitat patches proposed need to be connected to corridors to enhance connectivity and avoid habitat isolation. In addition, connected greenways form networks that provide high circuitry and more alternative routes, thus improve the efficiency of movement of focal species (Dramstad, Olson et al. 1996). The connection can be in forms of street greening (green street method with storm water treatment can be applied), green corridors within neighborhoods, or step stone connections including pocket parks, private gardens, community gardens, green roofs, etc.

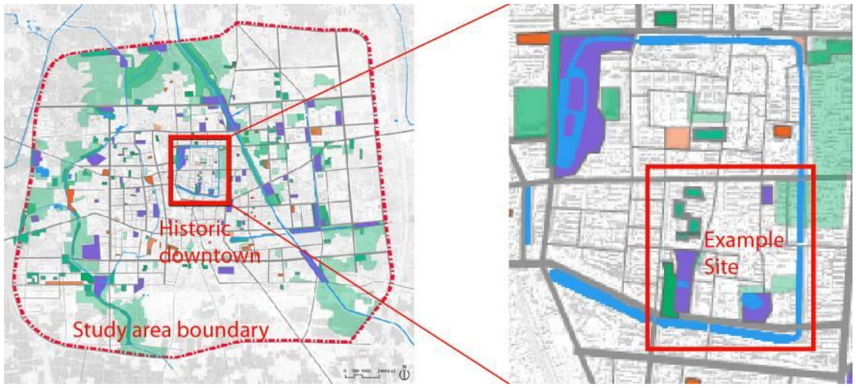

Figure 6-26 Context of example site, graphic created by author June 2014

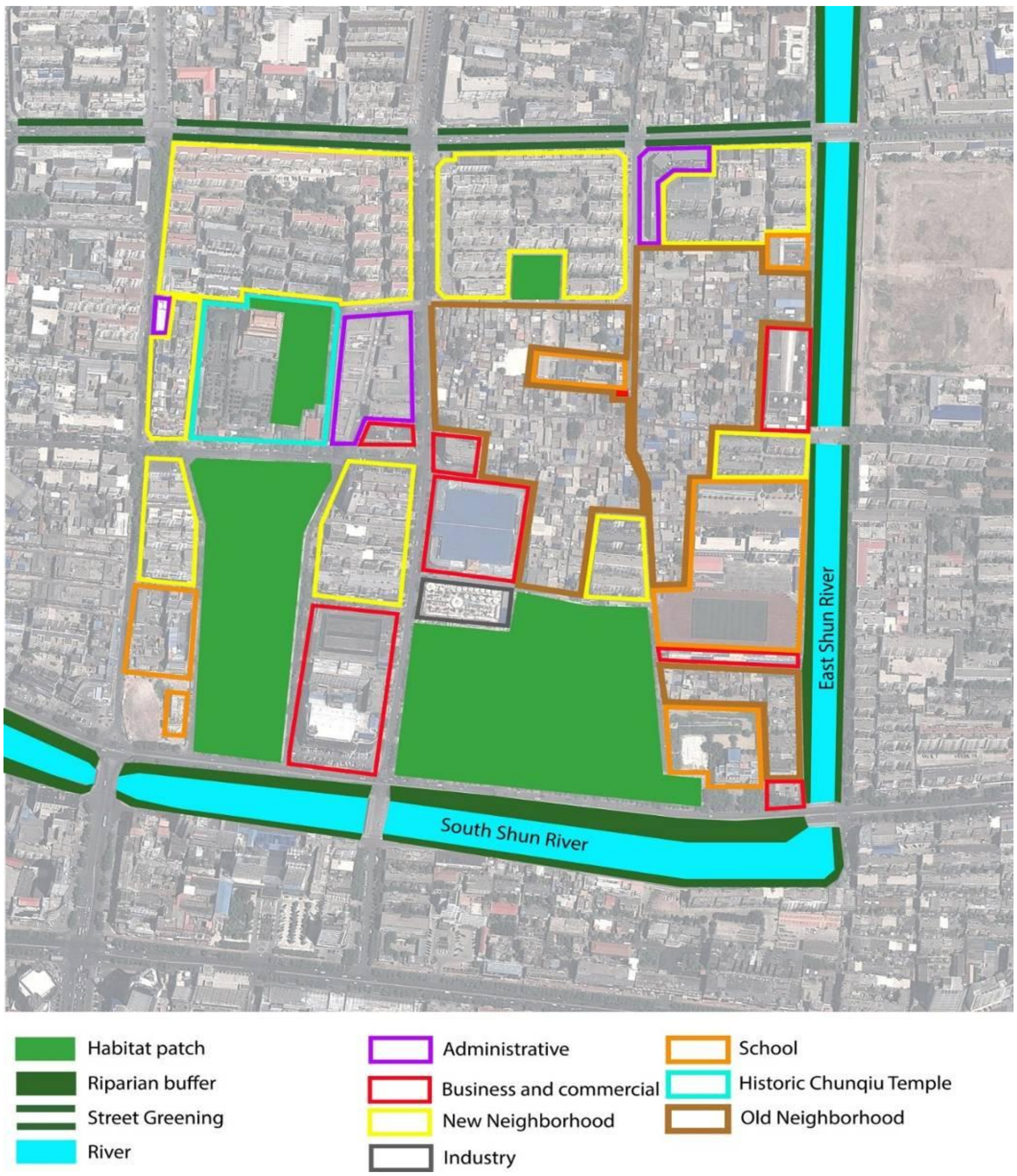

Figure 6-27 Existing land use and green infrastructure, graphic created by author June 2014

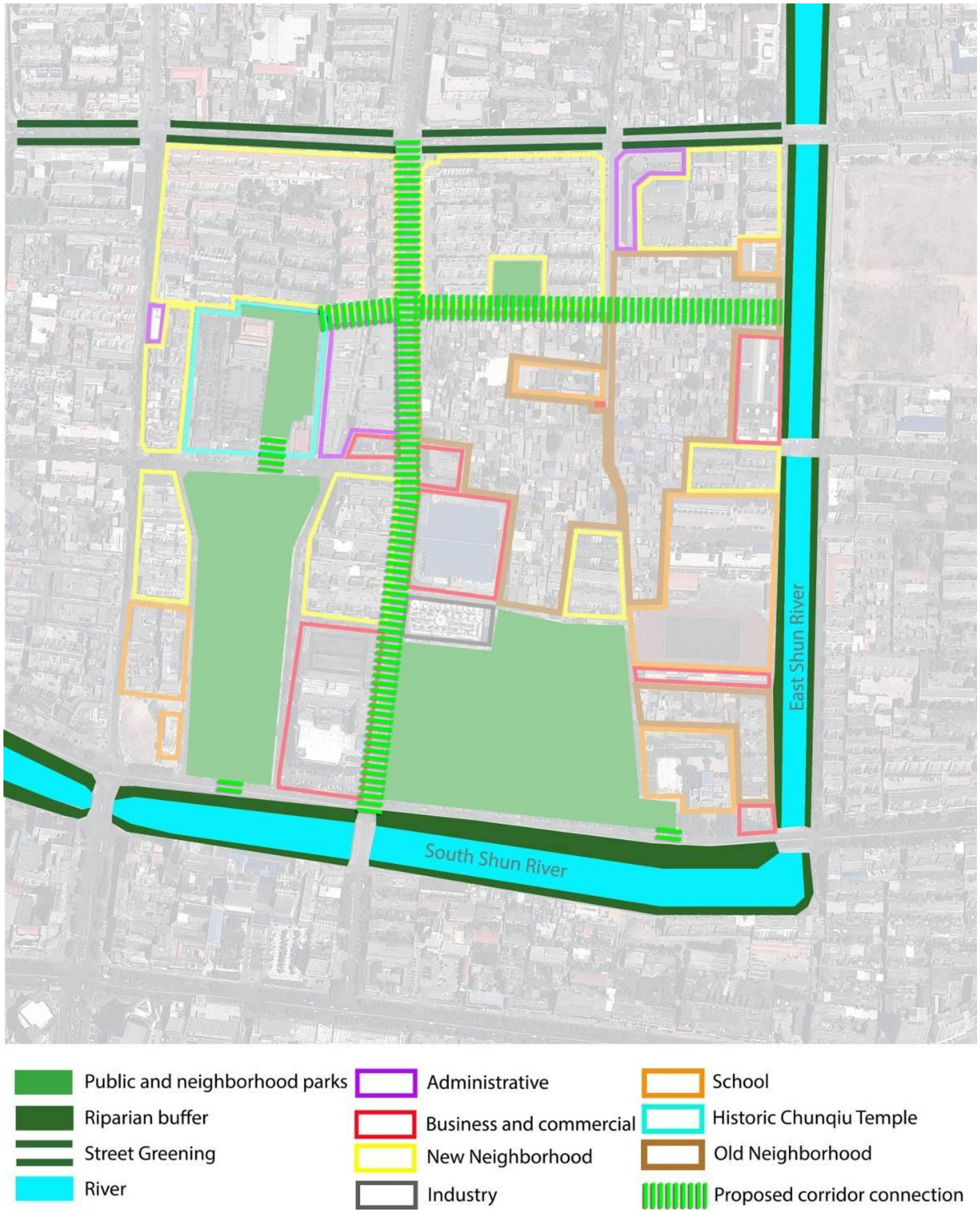

Figure 6-28 Proposed corridor connection, map created by author May 2014

<u>Neighborhood Connectivity</u>

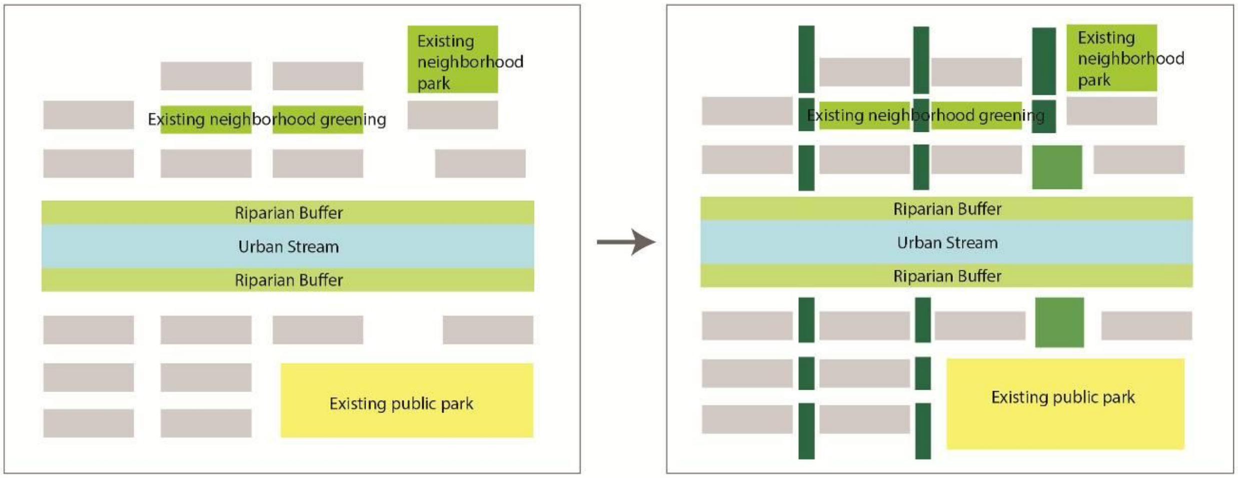

Figure 6-29 Neighborhood connectivity, graphic created by author May 2014

Except for habitat corridors, urban stream greenways also provide important recreational use and access to water for urban residents (Asakawa, Yoshida et al. 2004). Urban streams are also essential spatial elements that create a sense of place for communities. Therefore, penetrating river corridors into nearby neighborhood is very significant.

Other factors important for effective connections and creating active neighborhoods include continuation of pedestrian, bicycle and public transportation access; visual openings for views and feelings of connection; connectivity to public facilities such as libraries, schools, markets, etc.; connectivity to public parks, neighborhood parks, squares, etc. A neighborhood connectivity layout example is proposed in Figure-30 and Figure-31, using the same site in "hubs and greenway connectivity".

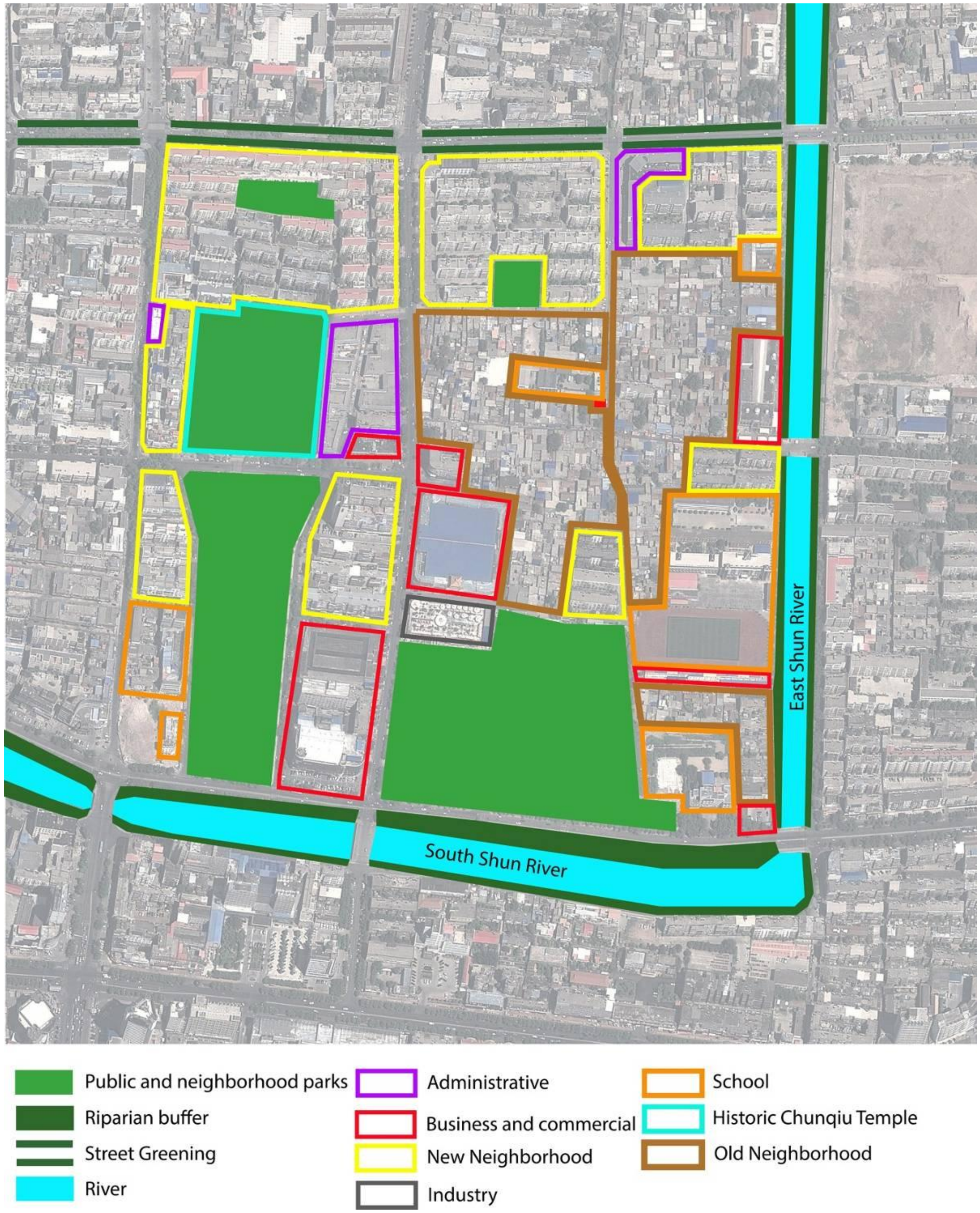

Figure 6-30 Existing land use and parks, map created by author June 2014

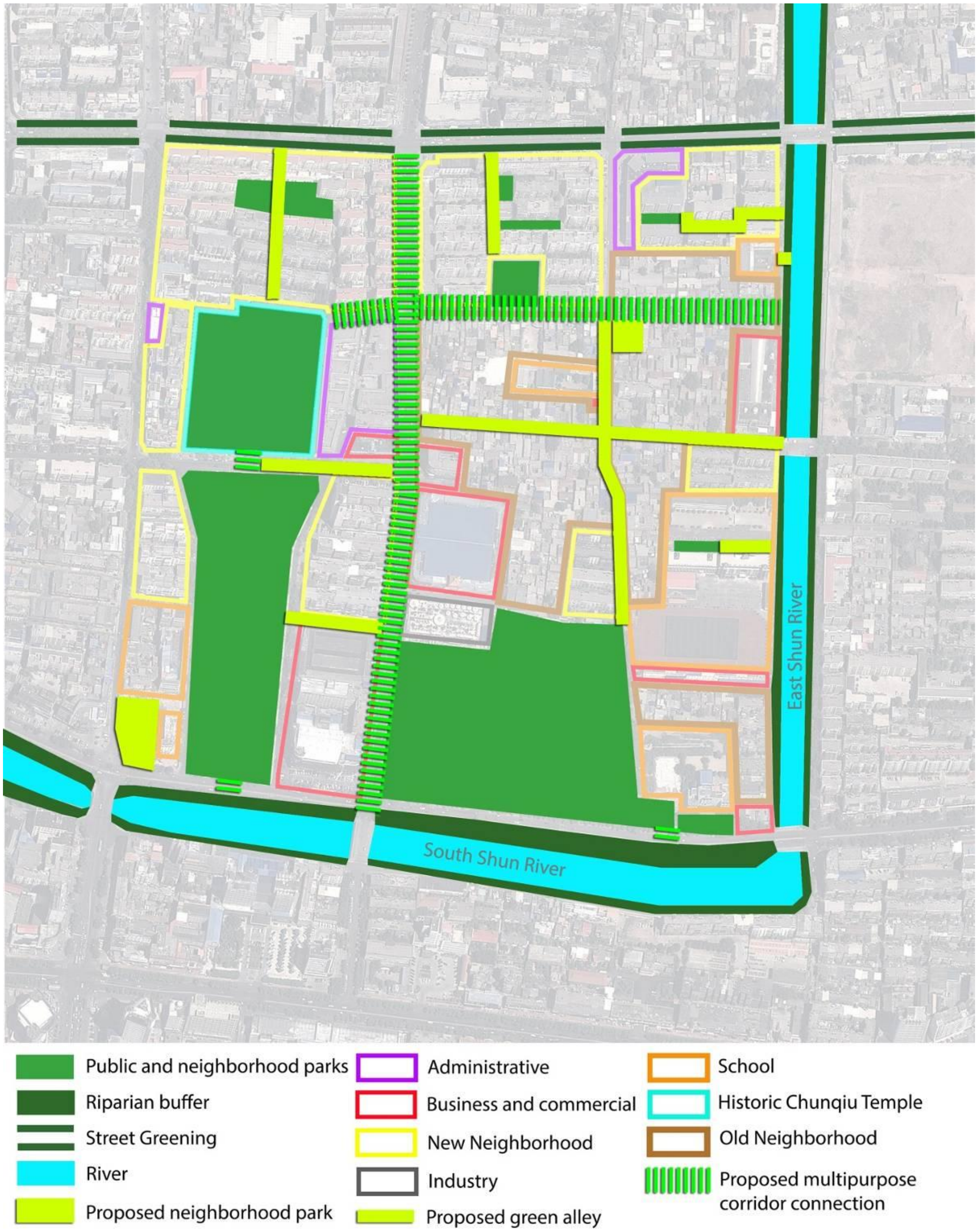

Figure 6-31 Proposed neighborhood connectivity, map created by author June 2014

Small Hubs Along Corridors And At Intersections

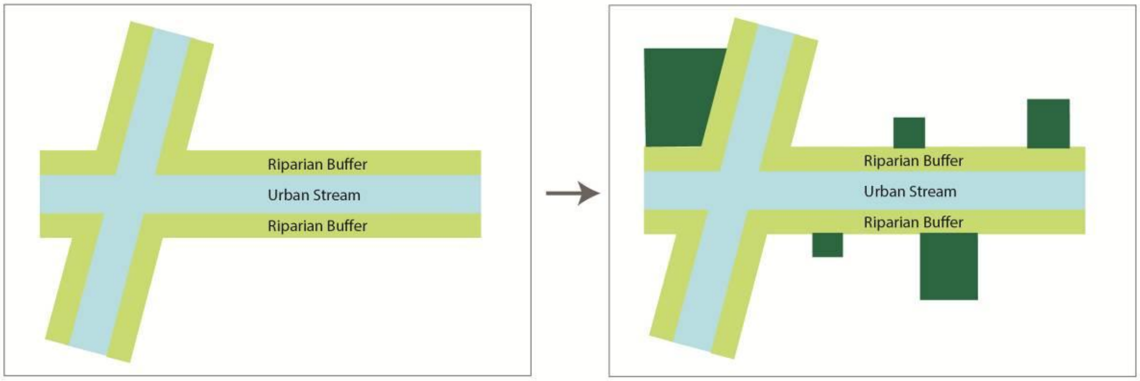

Figure 6-32 Small hubs along corridors and at intersections, graphic created by author May 2014

From a landscape ecology point of view, a series of small patches or nodes along a corridor or network are important for species' breading within the network and with the dispersal of these species. Also, the intersection effect usually occurs at the intersection of corridors where some interior species exist and species richness is higher than elsewhere in a network (Dramstad, Olson et al. 1996). Therefore, patches along river corridors and enlargement at corridor intersections are beneficial to enhancing biodiversity.

In addition, patches along corridors and at corridor intersections can serve as riverside parks and platforms to provide recreational services for residents. Three types of hubs along river corridors are proposed in the following section.

Figure 6-33 Type A: wooded hub, graphics created by author June 2014

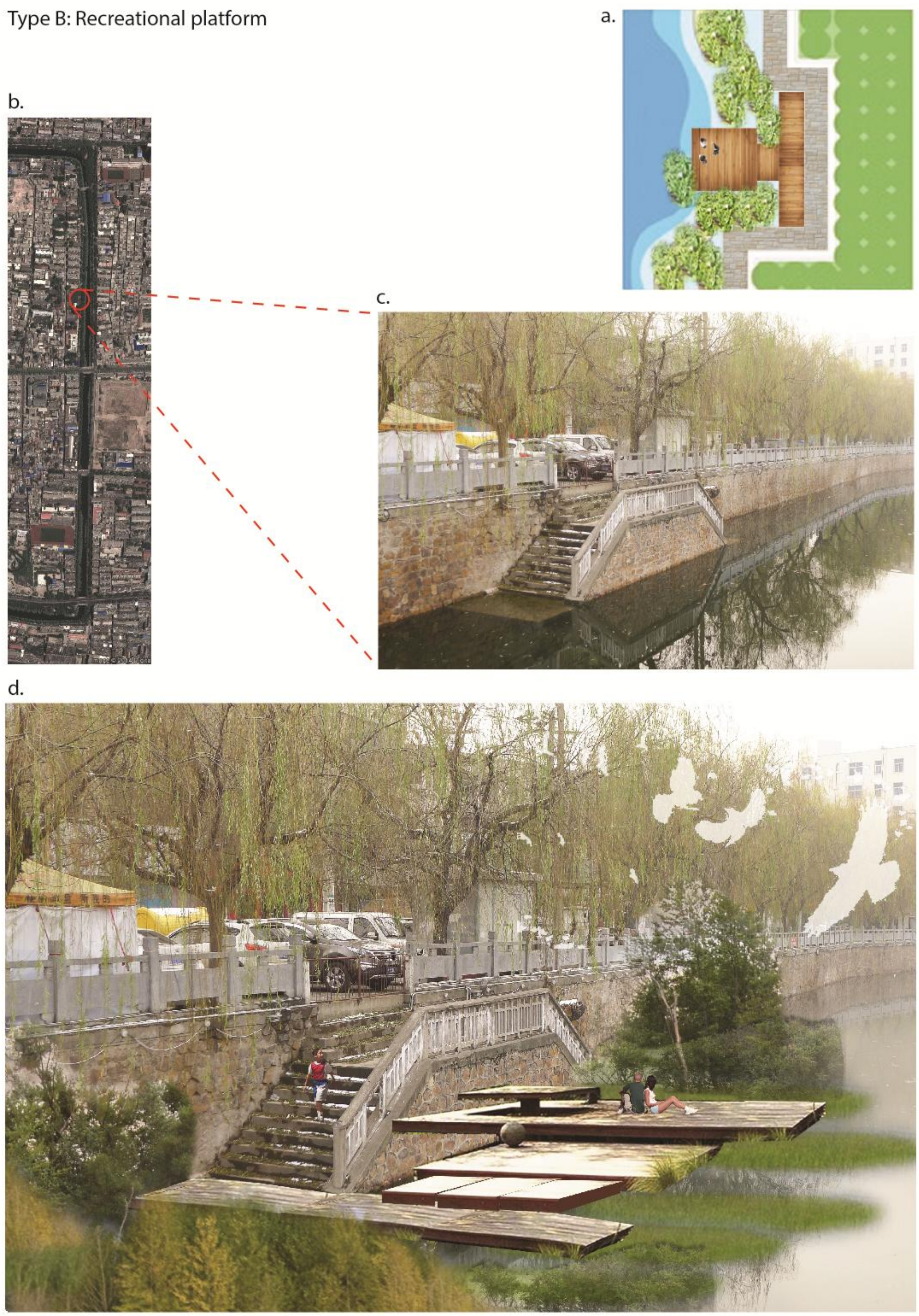

Figure 6-34 Type B: Recreational platform, graphic created by author June 2014

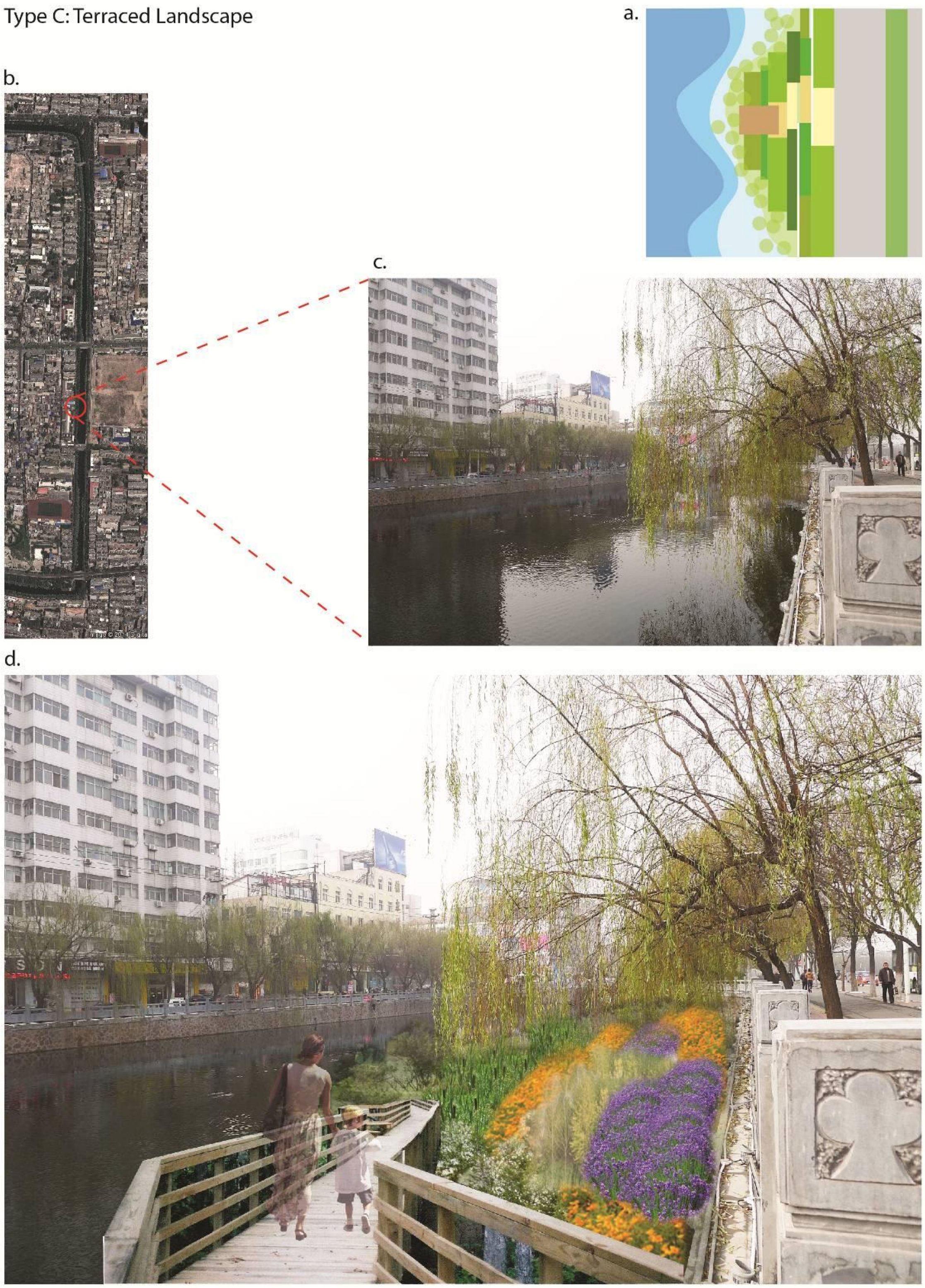

Figure 6-35 Type C: Terraced landscape, graphics created by author June 2014

Soft Stream Edge And Bank

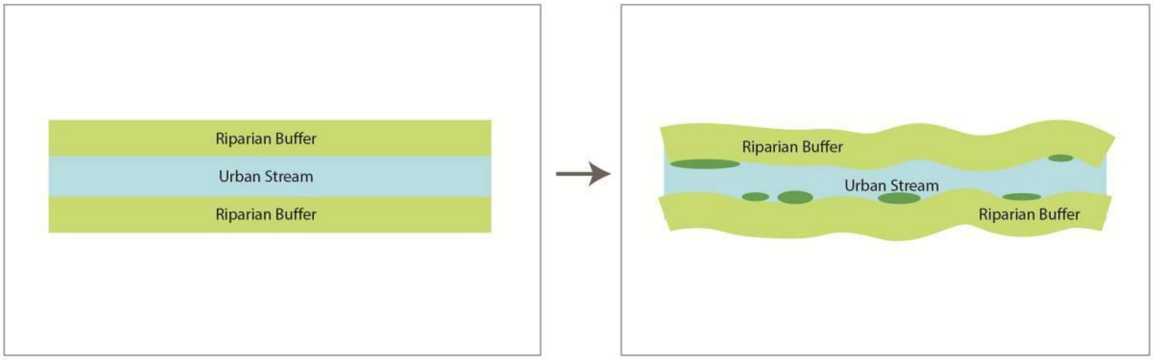

Figure 6-36 Soft stream edge and bank, graphic created by author June 2014

The edge effect lends landscape edges a distinctive character that supports species composition and abundance. Usually, coves and lobes along an edge, curvilinear "tiny-patch" boundaries and edges with high structural diversity will have more species, greater habitat diversity, less soil erosion and more overall ecological benefits (Dramstad, Olson et al. 1996). Also, soft river banks like wetlands help water quality management, provide special habitat and add to visual quality and diversity.

Suggested design guidelines for river banks include:

- To protect animal habitat, mitigate the damaging effects of flooding from storms, and filter pollutants from overland flow, a minimum of seven meters of unmanaged forest riparian buffer and a minimum of 10 meters managed forest riparian buffer zone should be set up on both sides of rivers.
- Use compact plant community structure and canopy trees to provide and enhance bird habitat. Non-native invasive plant species should be eliminated from corridors by management teams. Mast producing trees

and shrubs with non-toxic berries should be considered as food sources for wildlife when possible.

- Incorporate wetland plants for fluctuating water levels and water quality improvement.
- For water-related species, natural stream banks must be maintained (Jongman 2004). Stabilize riverbank by maintaining stable width-to-depth ratio and installing rock wires and log structures.
- Maintain fish passage at all flows and improve fish habitat. If Tunnels are necessary, they must consist of both a dry and a wet passage for fauna where roads cross rivers.

The two major urban streams in the Xuchang built-up area, Shun River and Qingni River, both have concrete banks (Figure 6-37-a). Using them as an example, the suggested bank and riparian buffer design is proposed in Figure 6-37-b.

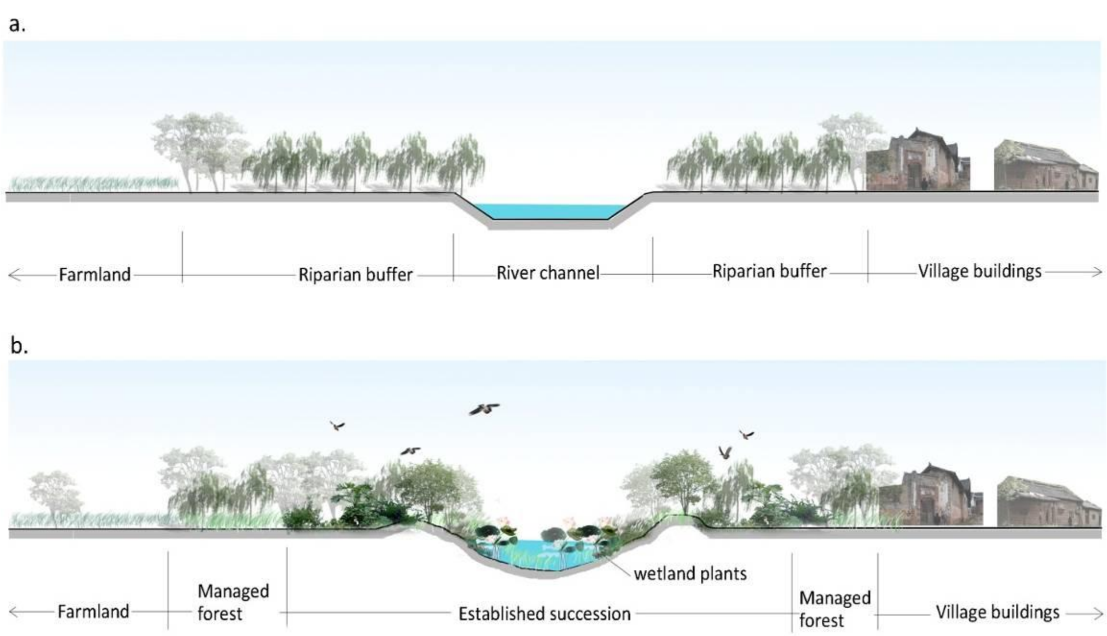

Figure 6-37 River corridor conservation strategy: a. typical existing condition (Qingni River and Shun River); b. Suggested design solution. Graphic created by author October 2013.

6.3 Neighborhood Greening

In China, the conflicts between high density development and limited land have led to crowded residential communities with inadequate open and green spaces (Feng, 2005). Newly built neighborhoods need to meet the "Residential Neighborhood Design Standard", which indicates that public green space needs to be 7.5%-18% of the total neighborhood area. Many other design factors are recommended to insure adequate sunlight, air circulation, fire exit, public facilities, access to green and open space, etc. In Xuchang and other study cities with higher green coverage rate, these design standards were implemented in most of the newly built neighborhoods after the 1980s. However, old neighborhoods built before the standards came out remain in bad living conditions and lack basic accessibility, open space and green infrastructure.

As discussed in Chapter Three, in Xuchang, especially in the historic downtown and East-Railway Old Town, earliest communities built during the urbanization period have severe safety and public health issues. This section of the design chapter tries to propose possible solutions for these traditional neighborhoods and urban villages using green infrastructure elements at a neighborhood scale to improve public health and safety, and engender a living environment with adequate ecosystem services.

<u>The Evolution of Old Neighborhoods and Urban Village</u>

Old neighborhoods in Xuchang were built during the earliest urbanization period at the beginning of 20th century. Urban villages are villages encroached upon by the city during the urbanization process. Residents in old neighborhoods are mostly certified urban residents and work in the city, and in urban villages the residents are mostly former farmers who lost their farmland during urban development. Most have transitioned to small retail businesses, and rent their house for a living (Zhong 2010).

The original spatial pattern of old neighborhoods and urban villages are very similar, which is traditional in the middle and northern Chinese neighborhood style. Figure 6-38-a and Figure 6-38-b show the typical spatial pattern of traditional neighborhoods.

Figure 6-38 Evolution of traditional neighborhood: a. original spatial pattern (aerial); b. original spatial pattern; c. spatial pattern nowadays (aerial); d. spatial pattern nowadays. Graphics made by author.

The aerial map shows a well preserved village in the Xuchang sub-urban area, which has the typical spatial pattern of middle-northern Chinese traditional neighborhoods. The spatial characteristics include main building facing south; some east-west secondary rooms that form informal quadrangle courtyards with north-south main buildings; some private yards, and some shared by several families. There are public wooded open spaces within about 100 meter radius and larger roads are accessible by cars. Most of the roads within the neighborhood are too narrow for cars and can only be used by pedestrians only.

The increasing land value in the city core area encouraged residents in old neighborhoods to build upper stories onto the existing houses as well as in between them, utilizing open spaces. The same thing happened in urban villages: triggered by the increasing rent price, living pressure and the increasing migration population who need low-rent housings development went unchecked. Figure 6-38-c and Figure 6-38-d show the existing conditions of an old neighborhood next to East Shun River, which can represent the existing typical conditions of old neighborhoods and urban villages. The changes of spatial characteristics from original traditional neighborhood are that public open and green spaces are used to build more buildings; newly built buildings are taking off roadways; additional stories are added to existing one- and two- story buildings; and courtyard space is transformed for adding rooms to existing buildings.

Green Infrastructure for Traditional Neighborhoods

Green infrastructure at the neighborhood scale can provide social functions that encourage informal community meetings, provide access to nature near home and create a sense of place or hometown, as well as provide ecological benefits such as intercepting pollutants, attenuating noise, and reducing building energy consumption (Jim and Chen 2003).

Green infrastructure elements at neighborhood scale including community garden, green roof and vertical greening are reviewed in Chapter Four. Their application strategies will be explored, using the neighborhood next to East Shun River in Figure 6-38-c as an example.

The community gardens are proposed in three types, including quadrangle shared community garden, cluster shared community garden, and neighborhood shared community garden. Quadrangle shared community gardens are designed within traditional enclosed courtyards owned by one or two families for growing vegetables and fruits. This type of community garden mainly provide the pleasure of growing their own food , family gathering opportunities as well as provide food supply. Cluster shared community gardens are designed within building clusters within 4 to 6 main buildings and side rooms shared by multiple families. This type of community gardens are shared by more people, therefore creates opportunities of gathering and cooperating for a larger group of community members. Existing open space can be used to build neighborhood shared gardens that are more public and shared by the entire neighborhood. More activities can be incorporated in these community gardens like teaching children knowledge of plants and how to grow food.

Because that in these compactly developed neighborhoods, the streets are extremely narrow and hardly allow cars to go through. The retail shops and restaurants take additional street space. These streets are usually crowded during breakfast, lunch and supper times. There are hardly any apace for regular street streets or planters. In this case, green walls and green roofs are proposed to add visual pleasure to the landscape, filter the air, and reduce the cooling and heating cost within buildings. These green infrastructure can also provide habitat and food for some bird species. In addition, green alley approaches can be applied on these narrow streets to mitigate the flooding issues after rainfall by using permeable paving and reduce the cost by using recycled materials.

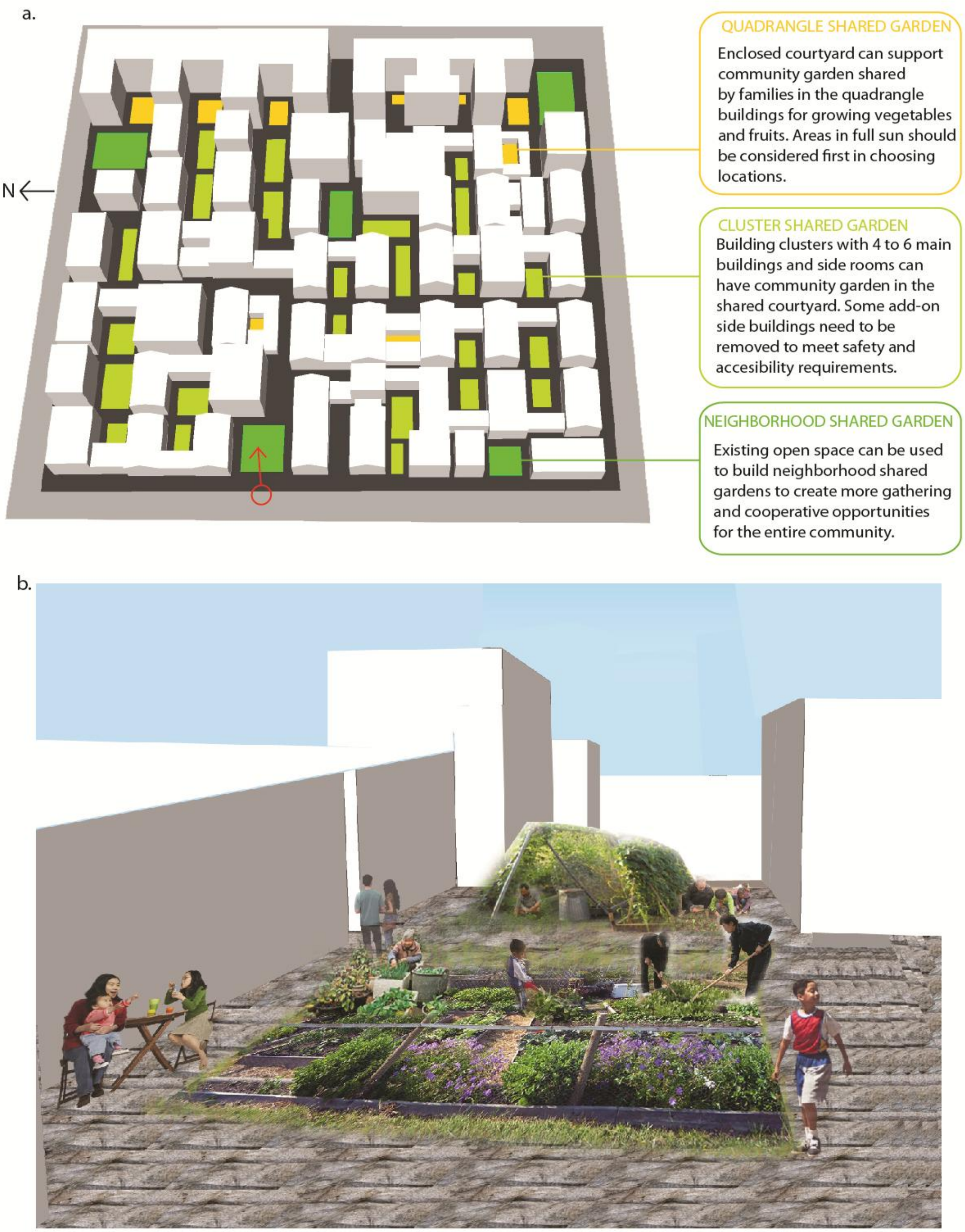

Figure 6-39 Community garden strategies, by author.

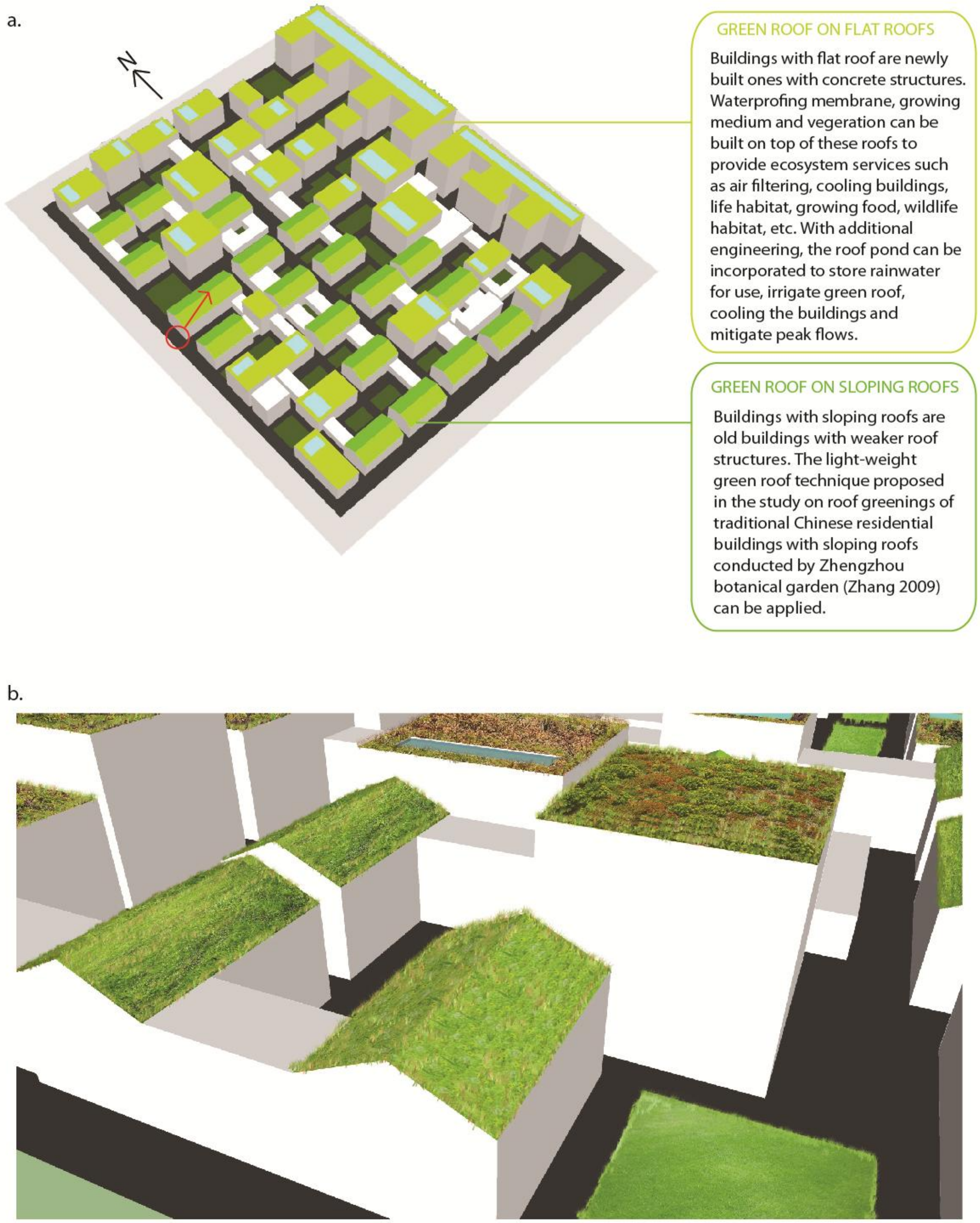

Figure 6-40 Green and blue roof strategies, by author.

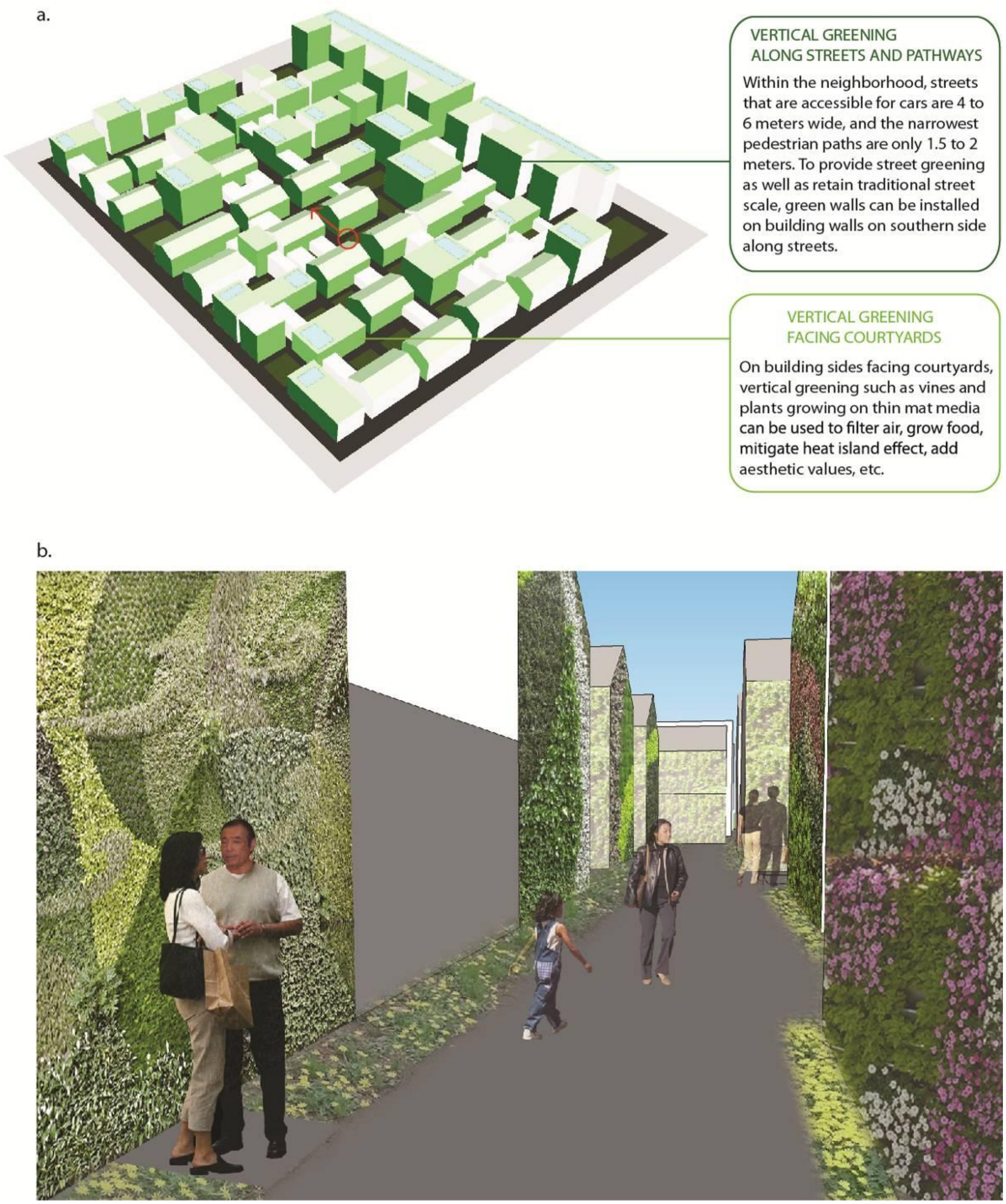

Figure 6-41 Vertical greening strategies, by author.

CHAPTER 7

SUMMARY AND CONCLUSION

Urban green spaces can provide a range of ecosystem services such as air filtering, micro-climate regulation, stormwater treatment, recreational and cultural services, and wildlife habitat (Alcamo and Bennett 2003). Green infrastructure is defined as interconnected networks of green spaces that conserve ecosystem functions and provide ecosystem services and benefit both humans and wildlife (Benedict and McMahon 2002). In China, natural ecosystems are being lost to increased development and rapid urbanization. Preserving and restoring green spaces as semi-natural areas within cities become more important (Ge 2012). Due to policy control, the green coverage rate in urban areas of Chinese cities is increasing (Zhang 2013), but requires planning and design to prioritize opportunities.

This thesis began with an overview of urban greening planning situations in China. Focal cities and a main case study city were chosen based on population density, urban built-up areas and green coverage rate. The problems of urban greenings in focal cities were identified, and an inventory of Xuchang was conducted. Then, green infrastructure approaches for Xuchang were explored. These approaches ranged from city scale to neighborhood and site scale to promote ecosystem services. I also studied practical greenway planning and green infrastructure design elements. Three precedent case studies were incorporated to show how projects with similar purposes and concerns were done in China, the pros and cons of their implementation and the lessons Xuchang could learn from them.

Based on these studies, a comprehensive green infrastructure plan is proposed, which includes "hubs" and "linkages" at city scale, and "neighborhood greenings" at neighborhood scale. A GIS-based suitability analysis and Analytic Hierarchy Process (AHP) identified optimum locations for future urban park and habitat hubs. Under the "linkage" category, planning and design principles for river corridors in Xuchang are proposed based on landscape ecology principles and precedent case studies. Green infrastructure techniques including green walls, community gardens and green roofs are applied to the compactly developed traditional residential neighborhoods of Xuchang. Design guidelines, principles, strategies and examples are illustrated to guide the design of proposed green infrastructure components.

The research reveals how green infrastructure hubs and linkages can fulfill multiple needs and meet a variety of criteria in the urban area of Xuchang. The benefits to wildlife and humans are achieved by blending two suitability mapping efforts and identifying gaps between habitat conservation in urbanized areas and urban greening infrastructure planning and design. The methods used in this thesis are applicable to other cities similar to Xuchang.

The aim of the thesis is to develop a conceptual green infrastructure plan, supporting design guidelines and strategies for Xuchang. The research questions of each chapter are studies and explored inclusively to enlighten the design implementation in Xuchang. Although ome of the problems addressed in Chapter Two weren't solved in the design chapter, such as aesthetic, public participation, policy and management issues. These issues need to be explored further in future research. Similarly, some of the findings in Chapter Three can be used as reference by the city of Xuchang in a green space detailed control plan and construction plan, including the ecosystem service evaluation methods (ecosystem services value unit area of Chinese terrestrial ecosystem, ecosystem services inventory in Xuchang and their indicators), landscape ecology principles for Xuchang, and green infrastructure assets at neighborhood scale.

Several other questions need to be further explored. First, the green infrastructure plan proposed is limited to the urban area of Xuchang, but further planning should expand the study to rural areas and go beyond administrative boundaries to larger ecological regions and ecological networks. This would promote the structural continuity and integrity of regional green infrastructure networks (M'Ikiugu, QianNa, and Kinoshita 2012). Further research should also include other ecosystem services generated by green infrastructure as factors in the GIS-based suitability analysis, such as aesthetic quality, stormwater mitigation, air filtering, noise reduction, etc. The process of choosing factors and criteria should incorporate opinions from more experts and local residents by conducting social surveys and meetings. Similarly, in the Analytical Hierarchy Process (AHP), the comparison matrix needs enrollment from a larger group of people and experts using questionnaires based on their value judgment. In sum, this process illustrates the need to incorporate green infrastructure into the future planning efforts to sustain both human and wildlife.

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