Ecological Infrastructure as a Powerful Instrument for Smart Conservation: A case study of Beijing

1 Introduction

In 2008, 3.3 billion people will be living in urban areas. By 2030, this is expected to swell to almost 5 billion (Martin, 2007). Fast urbanization cause natural ecosystems and the integrity of landscapes damaged. This is an event that will significantly impact the earth and our future generations. Thus, there is an urgent need for smart conservation, which is able to effectively protect lands with predominantly ecological functions under the enormous pressure of social and economic development.

There is a long history for exploring the approach of urban nature conservation in planning theories and practices. As early as in the late 19th century, parks and green spaces have served as fundamental infrastructure to solve urban problems such as congestion and sanitations in the US. The well cited examples include the Boston's Emerald Necklace by Olmsted brothers and other open space systems in Minneapolis, Kansas City, Cleveland and so on. In England in the same period, Ebenezer Howard(1898) developed the "garden city" and "greenbelt" concept, meant to regulate the urban sprawl of London and other urbanizing areas in England by surrounding the inner city with parks (Zube, 1995; Ahern, 1995).

In the last decades of 20th century, with land use change and landscape fragmentation, nature conservation has changed from site protection to conservation of ecological networks. Landscape ecological principles have also been integrated into nature conservation and landscape planning. New initiatives, including ecological networks, greenways, green infrastructure and ecological infrastructure are emerging. They all emphasize the concept of spatial connectivity, of an integrated functional network, managed for multiple purposes, linking rural and urban environments (Walmsley, 2006; Ryan, 2004; Benedict, McMahon, 2001; Jongman, et al., 2004).

Among those emerging concepts, Ecological Infrastructure gathers the most comprehensive meaning and is further related to be explored in the context of this paper. It firstly appeared in MAB program (Man and Biosphere) of UNESCO. In the 1984 report of MAB, "Ecological Infrastructure" was put forward as one of the five principles. The principle of Ecological Infrastructure is referred to the natural landscape and hinterland of the city but is not clearly defined and overlaps with other concepts such as Ecological Conservation. In biological conservation study, the term was firstly used to represent the habitat network and emphasized the biodiversity conservation function of landscape components such as core zone and corridors (Mander, Jagonaegi, et al., 1988; Selm, J. Van , 1988). From practical perspectives, the practices on EI in Netherlands have shown to be good examples, such as the Dutch Ecological Main Infrastructure, which is made up of: (a) natural core areas; (b) natural development areas; (c) corridors or connections; (d) buffer zones (Bohemen, 2002).

In this research, Ecological Infrastructure (EI) is defined as the structural landscape network of which essential landscape elements are conformed. Both existing and potential spatial patterns are of strategic significance in preserving natural, biological and cultural processes, which are critical in securing the integrity and identity of the natural and cultural landscapes, as well as securing natural capital that supports sustainable ecosystem services.

This paper take Beijing as a case study to establish the research framework for urban ecological security pattern and identify overall ecological infrastructure to safeguard urban long-term ecology security.

2 Methods

There are two major kinds of approaches to identify ecological pattern. The first approach is landscape-suitability approach, which was first systematically proposed by Ian McHarg in his book *Design with Nature*. This approach relies on the natural features of the landscape to estimate landscape suitability. However, there are often barriers to this kind of approach, such as neglecting the material and energy flows in landscapes and the relationship between landscape pattern and its functions.

The second one is applied landscape ecology approach. This approach emphasizes the relationship between spatial and ecological processes and recognizes changes as a fundamental landscape quality. Landscape ecology is still developing and several concepts have been developed, such as the patch-corridor-matrix framework (Forman, Godron, 1986) and security patterns(Yu, 1996).

Security patterns (SPs) approach, the processes oriented model of spatial analysis, might be useful to the identification and planning of ecological pattern or ecological infrastructure. Security patterns are composed of strategic portions and positions of the landscape that have critical significance in safeguarding and controlling certain ecological processes. Components of the security patterns have the quality of initiative, co-ordination and efficiency, and are, therefore, strategically important in controlling ecological processes and landscape change. SPs can be identified according to the properties on a general surface model of flows and processes. Potential surfaces (accessibility surfaces) are developed using landscape resistance to represent the dynamics of horizontal ecological processes (e.g species movement, the spread of urban development and water flow). The security pattern approach has been applied in multiple cases in China and is considered as an effective method to identify the ecological spatial pattern(Yu et al., 1998; Yu et al., 2005; Yu et al., 2008).

The specific method to identify SPs is as following:

(1)Identifying sources: sources are the points of origins for different processes. For example, the existing native habitats that act as origins of species dispersal are sources for biological process. They are commonly identified by survey and landscape suitability analysis.

(2)Identifying landscape pattern: SPs can be identified according to the properties on a general surface model of flows and processes. The security pattern commonly includes four strategic landscape portions and positions: buffer zone, inter-source linkages, radiating routes and strategic points. These components, together with the identified sources, compose the ecological SPs at various security levels. Geographic information system plays a vital role in simulating the process and identifying the security patterns.

Based on the theories of EI and SPs, the research framework of Ecological Security Pattern Research in Beijing was proposed. To address the specific needs and problems of Beijing, this study focus on flood and stormwater SP, geological disaster SP, biodiversity SP, cultural heritage SP and recreation SP. These individual SPs were then integrated to comprehensive ecological SP, namely, the overall ecological infrastructure of Beijing.

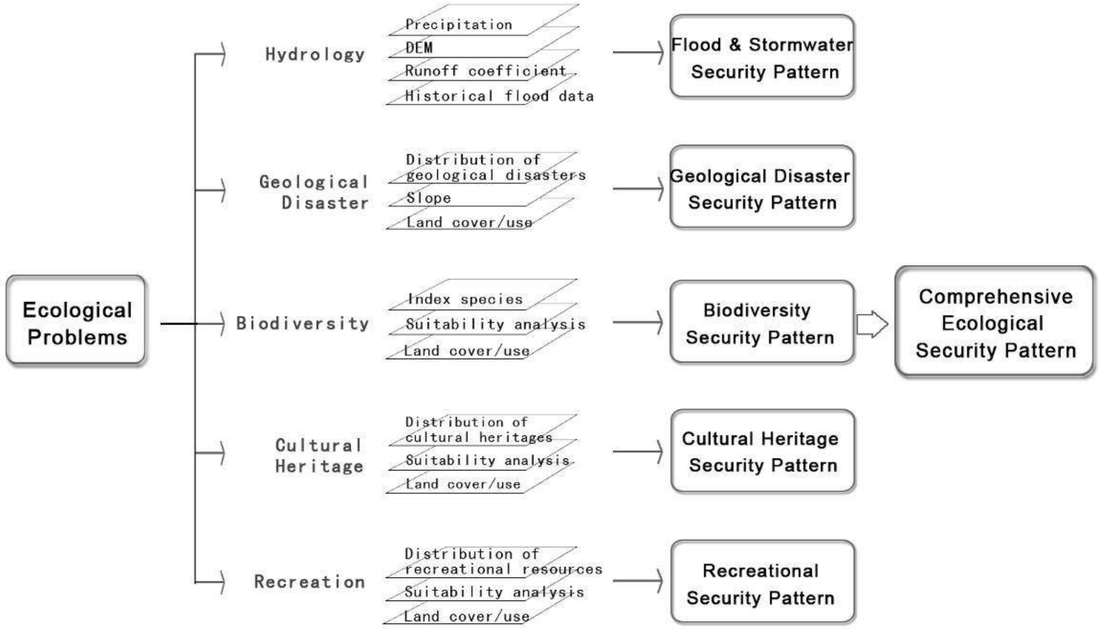

Fig.1 Research Framework of Ecological Security Pattern Research in Beijing

3 Study area

3.1 Backgrounds

Beijing, the capital of China, situated in the northern part of North China Plain (39º38'–41º05'N), covers 16,410 km^2 of land. The northwestern part is mountainous area which covers 10,418 km^2, while the southeastern part is plain. Beijing lies in the continental monsoon region in the warm temperature zone and the average temperature throughout a year is 11.7□. The average annual rainfall is 585 mm, and the average water resources is only 280 m^3 per person. Major rivers flowing through Beijing include Yongding River, Chaobai River, North Canal and Juma River. These rivers flow through rugged mountains towards southeastern plain of Beijing and in the end join the Bohai Sea. The original natural vegetation was deciduous broadleaf and evergreen coniferous forest.

Fig.2 Location of study area

Beijing municipality has 16 subordinate districts and 2 counties. The metropolitan is home to approximately 16 million inhabitants, which has an average density of 963 people per square kilometer (2006). The gross domestic production (GDP) reached 772.03 billion Yuan in 2006 and the average GDP per capita was 49,505 Yuan.

3.2 Challenges

Beijing is a microcosm of major shifts and challenges that Chinese mega-cities are experiencing. Due to the rapid growth of population and urbanization during the last 30 years, there are several challenges to the sustainable development of Beijing. The most obvious evident is the notable "scrambled egg" urban sprawl. The urban area of Beijing was 183.184km^2 in 1973 and increased to 1209.197km^2 in 2005. It was increased by 1026.113km^2 during the past 32 years and expanded 32.107km^2 per year (Mu, et al., 2007). The built-up area was expanded around the old area along ring roads with a relatively low density (Fig. 3).

Such unwise urban growth has resulted in the fragmentation of landscape and the fundamental change of ecological processes.

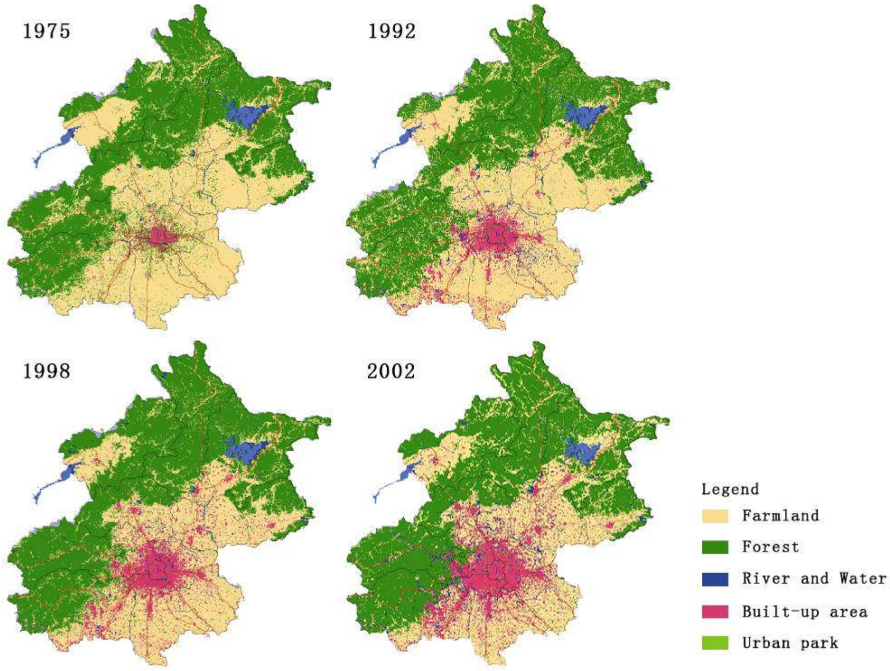

Fig.3 Land use change of Beijing (1972-2002)
Source: Beijing Municipal Bureau of State Land and Resources

First, rapid urbanization and single-function engineering have brought fundamental changes of urban hydrological process and functions. River channelizing and damming markedly decreased the ecosystem services of water network. Growth in paved surfaces makes stormwater runoff and peak flow increase. There is more than 400million m^3 storm water unutilized and drained each year. The city is more likely to have water logging even during regular rainfall events. Second, vital habitats, including rivers, wetlands and forests, decreased and were isolated by urban sprawl. Additional, high quality farmlands in the plain area were also occupied by urban development. Finally, the landscape character is disappearing and inhabitants gradually lost their spiritual connection to the land (Zhou, et al., 2006; Niu and Ding, 2006; Zhou and Wang, 2005).

Although municipal government tried to introduce greenbelts to stop urban sprawl and keep good landscape structure, it has more or less failed to form an optimal network and optimize urban spatial structure. The two greenbelts of Beijing were planned artificially and lack of the intrinsic relationship between the green elements and the living earth system. It also lacked integration of various functions. Therefore, the greenbelts became vulnerable to land use change and have already been fragmented by extensions of settlement areas (Han, 2004; Liu, Kang, 2001).

4 Defining Regional Ecological Security Pattern

4.1 Security pattern for floods and stormwater

The research targets recovering natural hydrological process and avoiding flood disaster. GIS is used to analyze and simulate flood and runoff processes, and identify the strategically important spatial pattern. Based on the analysis and simulations, define the security patterns for floods and stormwater.

(1) Security Pattern for Floods

Simulation of flood process and analysis of devastating floods in history were used to define security pattern for flood. Firstly, based on terrain data, identified current water bodies with flood regulation function, which include rivers, lakes, reservoirs, ponds and lower lands. Secondly, according to simulation of hydrological process, determined the strategic points to control surface flow. Thirdly, according to rainfall data of different frequencies(once in 20 years ,100 years and 200 years), together with DEM(Digital Elevation Model) simulated flood process, and got the floodable areas for different frequencies. Combining with historical flood data of 1939, 1956, 1959, 1963 and 1964, analyzed historical floodable area in Beijing. Areas of three different frequencies- low, medium and high – were defined by overlying the simulated floodable area and the historical floodable area. Finally, by the analysis above, defined the key areas and location for flood control, and so as to establish security pattern for flood at different levels.

(2) Security Pattern for Stormwater

By analysis of groundwater recharge, groundwater overdraft and soil erosion, defined key spatial patterns for stormwater (eg. alluvial-pluvial fan, etc.), formulated stormwater management measurements based on land use types, and identified Beijing's security pattern for stormwater.

Based on security pattern for flood and for stormwater, taking protection of surface and groundwater resources into consideration, overlaid the above two security patterns and formed the comprehensive security pattern for water (Fig. 3). According to different security levels, construction limitation and requirements and measures for aquatic ecosystem recovery were suggested.

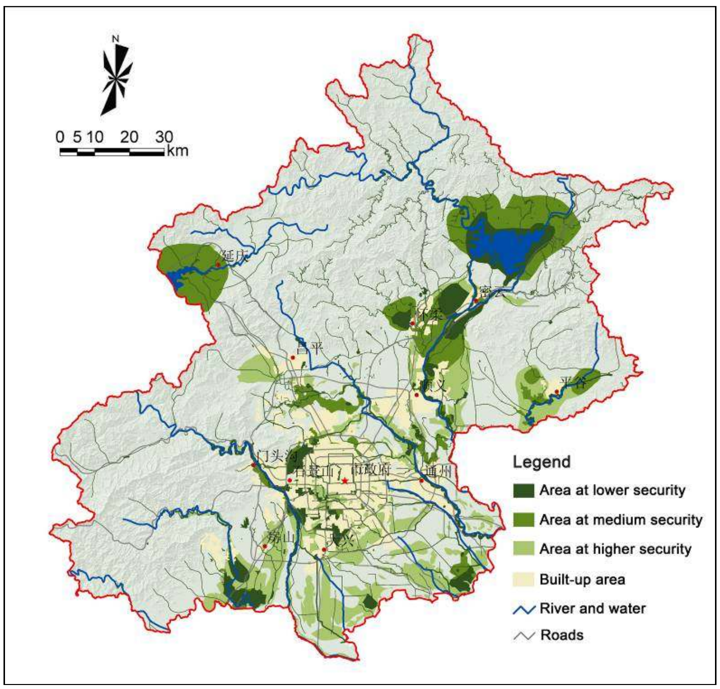

Fig.4 Security Pattern for Floods and Stormwater

4.2 Security Pattern for Geological Disasters

The research located geological disasters elements such as debris flow, landslide, slumping, mine ground-subsidence, surface subsidence, ground crack and soil erosion, and made them the sources for analysis of geological disasters.

According to cause analysis of kinds of geological disasters and the analysis of land use patterns in geological hazard area, defined the key areas for countermeasures, which took the origin points of geological disasters as the core, and defined the buffer zone. The extent of buffer zone was affected by the types of disasters, distribution, geological and topographical conditions, climate and precipitation, and intensity of human activity, etc. Referring to relevant research achievements, this paper determined the levels and boundaries of the geological disasters buffers, and accordingly defined the security pattern for geological disasters at low, medium and high security levels, and different construction limitation and requirements and measures for controlling disasters were suggested (Fig. 5).

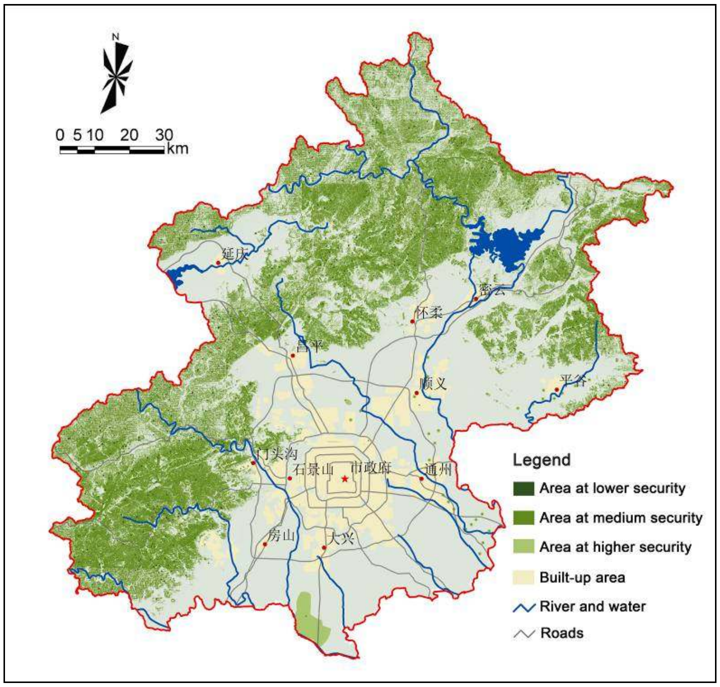

Fig.5 Geological Disaster Security Pattern

4.3 Security Pattern for Biodiversity Conservation

The research aims to form a habitat network at regional scale to protect biodiversity, by defining the key spatial pattern for various focus species.

By literature study and communication with experts in biodiversity conservation, the standards for selection of focal species were determined: (1) which can indicate the current situation of Beijing's ecological condition, and also can indicate other species and kinds of habitats; (2) common and favored by the masses. According to the standards, the conclusion was drawn: it was appropriate to choose representative resident and migrant birds as the focal species for the regional biodiversity. Through further analysis and experiment of focal species candidates, finally *Egretta alba, Anas Platyrhynehso, and Phasianus colchicus* were chosen to be focal species.

Based on focal species' habitats, analyzed the suitability to species' activities of lands with different kinds of land cover and land use types, and identified current and potential core habitats. Used a minimum cumulative resistance (MCR) model to simulate the process of a species traveling across a type of landscape(land cover and land use), and developed the MCR surface. The surface revealed the accessibility from the source (habitat) to a cell, thus can be used to simulate species horizontal dispersal. By analyzing the MCR of the targeted species, identified the buffer zone, linkage, radiating routes and strategic points, so as to define the security pattern for each focal species (Yu, 1996; Yu, 1999). Finally, overlaid the three security patterns for the three species and the security pattern for biodiversity of Beijing was defined (Fig.6).

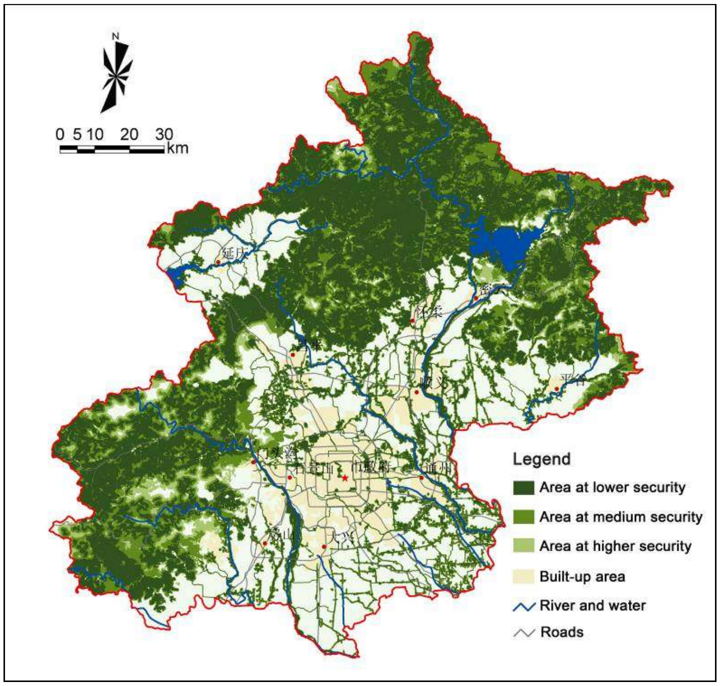

Fig.6 Security Pattern for Biodiversity Conservation

4.4 Security Pattern for Cultural Heritages

The research aims to establish a cultural heritage network, so as to further protect the historical and cultural character of landscapes in Beijing.

Through literature review, components of security patterns for cultural heritages can be concluded as following (Yu et al., 2005):

(1) Culture heritage sites: all registered heritage sites (including ancient buildings, ancient sites, ancient tombs, etc.), historical districts and historic villages are defined as the source.

(2) Potential landscape elements which link these heritages and form corridors: according to expert's advice and literature study, historical rivers and lakes and historical cultural routes are defined as the most important linear cultural heritages. Besides, linear landscape elements with recreational value, such as water system, country roads, etc, as well as those landscape elements without recreation value at present but a part of heritage corridors due to their spatial relation, are also of value to the planning of heritage network.

According to the data of cultural heritages from Beijing Municipal Cultural Heritage Bureau and relevant documents, the specific information of heritage sites and potential cultural heritage corridors were put into the GIS database. Secondly, based on resistance disperse of different land cover and land use, using MCR simulates the spatial disperse and accordingly analyzed and defined the area suitable to establish corridors. Based on the suitability analysis of corridors, formed security pattern for cultural heritages at regional scale (Fig.7).

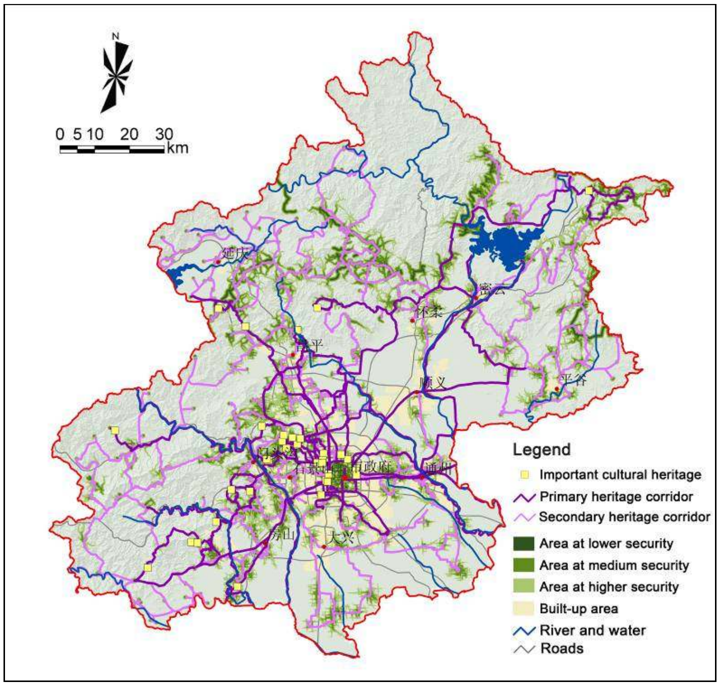

Fig.7 Security Pattern for Cultural Heritage

4.5 Security Pattern for Recreation

The research overlays the above cultural heritage network, green and blue network, which are with different recreational values, and defines the security pattern for recreation by spatial and function integration.

Urban parks, scenic resort and historic sites, vernacular landscapes as well as natural landscape such as mountains, woodlands and water systems are with great recreational value in Beijing. They were defined as the source of recreation process in the study. According to suitability analysis of land cover types to recreation activities, using MCR model, recreation resistance surface was established. Together with the resistance surface and other security patterns, a regional network for recreation was finally defined (Fig.8).

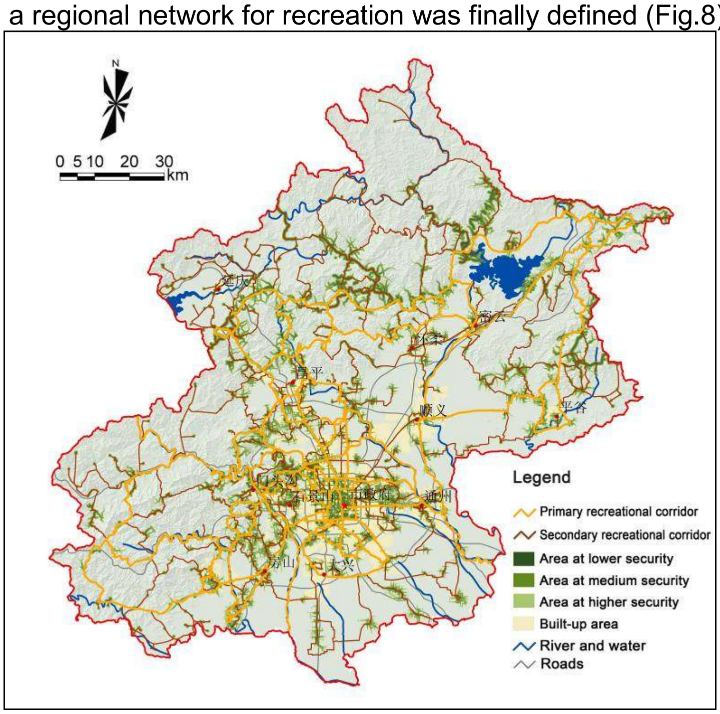

Fig.8 Security Pattern for Recreation

4.6 Comprehensive ecological security pattern

The regional ecological infrastructure was an integration of security patterns for flood and stormwater, geological disasters, biodiversity conservation, cultural heritage and recreation. Three alternatives of ecological infrastructure were developed corresponding to high, medium and low security levels (Fig.9). They were used to guide and frame regional urban growth pattern.

The area at lower security level is the most important and irreplaceable ecological network for Beijing, which should be strictly protected and not be taken up by urbanized area. Area at medium security level should be protected, restricting land use to human activities that are considered not harmful for the environment. Area at higher security level is helpful to the continuity and integrity of ecological network, where people minimize the disturbance to environment as much as possible, but stimulate recreational use and development of tourist facilities.

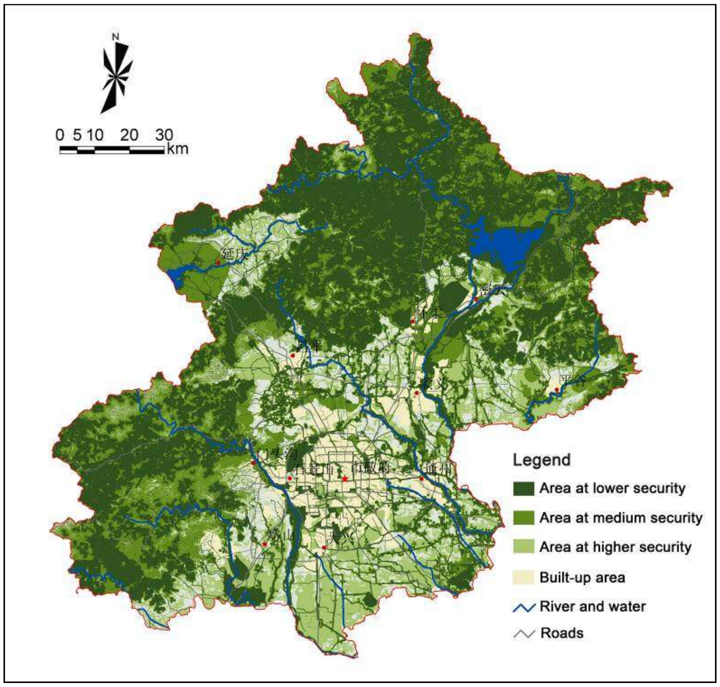

Fig.9 Comprehensive Ecological Security Pattern for Beijing

5 Scenarios of Urban Growth Pattern Based on Regional Ecological Security Pattern

Using the three regional Ecological SP alternatives as frame structure, this study chose some towns as sources of growth, setup the growth resistance and designed the urban growth pattern of Beijing: Urban Growth Pattern without Ecological SP, Urban Growth Pattern Based on Lower Level Ecological SP, Urban Growth Pattern Based on Medium Level Ecological SP, and Urban Growth Pattern Based on Higher Level Ecological SP (Fig.10-13). The size of construction land was chosen as the index of urban growth levels and thresholds.

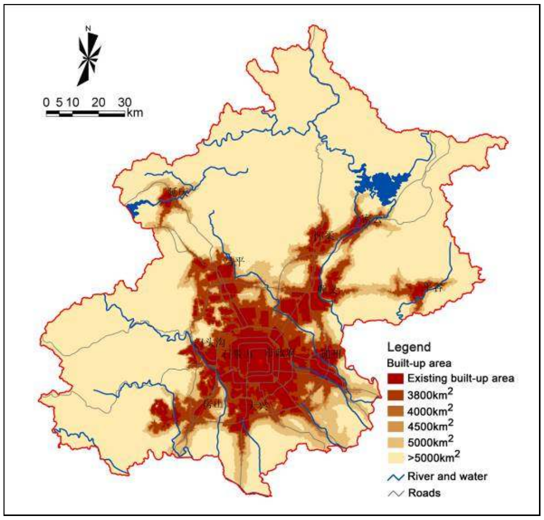

Fig.10 Urban Growth Pattern without Ecological Security Pattern

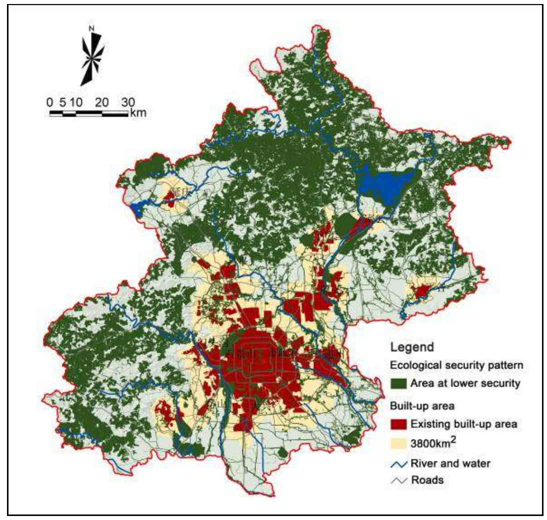

Fig.11 Urban Growth Pattern Based on Lower Level Ecological Security Pattern

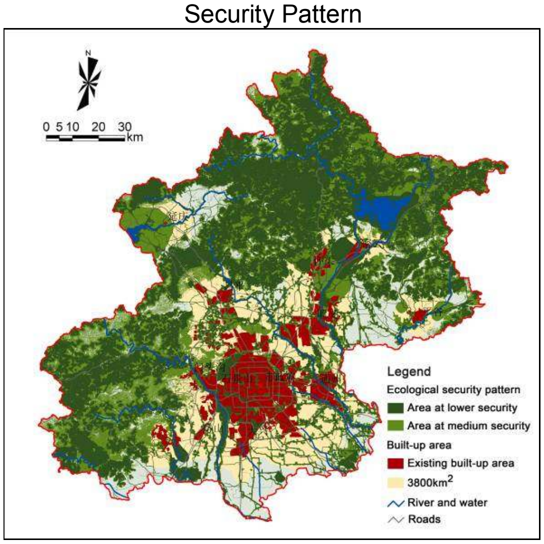

Fig.12 Urban Growth Pattern Based on Medium Level Ecological Security Pattern

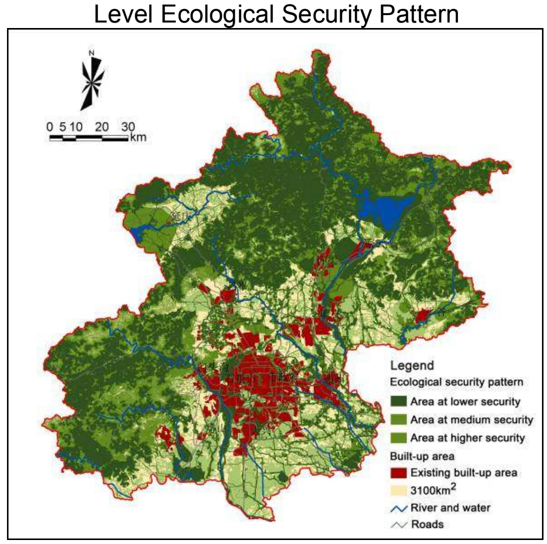

Fig.13 Urban Growth Pattern Based on Higher Level Ecological Security Pattern

Comparative impact evaluations were made for these scenarios by qualitative and quantitative methods, in terms of urban growth pattern, protection of ecological resources and land use allocation. The results are shown in Tab. 1.

Tab.1 comprehensive comparison of the four scenarios

Scenario	Urban Growth Pattern without Ecological Security Pattern	Urban Growth Pattern Based on Lower Level Ecological Security Pattern	Urban Growth Pattern Based on Middle Level Ecological Security Pattern	Urban Growth Pattern Based on Higher Level Ecological Security Pattern
Urban Growth Pattern	The downtown area and surrounding clusters are combining as a whole. Construction land will mainly develop along main	The downtown area and surrounding clusters with little open space between them. The new towns develop faster.	The downtown area and surrounding clusters are separated by open space. The new towns develop faster.	Urban area will be scattered by EI. Construction lands will be surrounded by open space and the scale of individual cluster is

	roads. The new towns develop slower.			small.
Ecological Resources Protection	Ecological resources will be taken up by construction land.	Critical ecological resources will be protected, but the ecological network is frail.	Ecological resources will be protected and form a whole ecological network.	Ecological resources will be protected to the maximum extent and form a whole ecological network.
Land use Allocation	The amount and allocation of land uses are difficult to predict and manage.	The competing demands of different land uses can be fulfilled. Provide a total area of 9237km^2 for construction and agriculture.	The competing demands of different land uses can be fulfilled. Provide a total area of 5450km^2 for construction and agriculture.	The ecological resources and agricultural lands will be strictly protected and the demand for construction will not fully fulfilled. Provide a total area of 3100km^2 for construction.

6 Conclusions

This study proposes the research framework of ecological security pattern for Beijing, based on the theories of ecological infrastructure and landscape security pattern. Supported by GIS, ecological processes (including abiotic, biotic and cultural process) are analyzed vertically and horizontally. Key landscape patterns are then identified and integrated into regional ecological infrastructure.

Ecological security pattern proposed by this study is different from the traditional plans for greenbelt or land out of urban constructing in content and spatial pattern. Ecological security pattern emphasizes on spatial integrity and comprehensive ecosystem services of the regional ecosystem, and forms a completed ecological network. It not only plans land out of urban constructing based on current land use, but also identifies potential key corridors and patches needed to be protected and ecological recovered.

The scenarios of urban growth pattern based on EI emphasize on establishing a key landscape pattern in advance to guide urban development. Results show that they not only allow the city to accommodate enough construction land for its future development, but also keep a critical landscape structure and provide multiple ecosystem services. In other words, ecological infrastructure is a tool to achieve smart conservation and smart growth.

Ecological security patterns and ecological infrastructure could provide scientific basis for relevant planning of Beijing, including urban master planning, land use planning and urban green-line planning. In order to realize ecological infrastructure plan, the measures regarding legal, economic, institutional, social and technological aspects need further research.

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- All the graphics in this paper were drawn by authors (except Fig.3).

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