THE IMPACT OF WATER RELATED ECO-PLANNING ON ECOLOGICAL EFFECTIVENESS IN MEGACITY BEIJING, CHINA

Wei FU[1]*
[1]School of Architecture and Urban Planning, Beijing University of Civil Engineering and Architecture, Zhanlanguan Road, Beijing, China - fuwei0807@163.com

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ABSTRACT:

Calls have been made for water and ecological planning and design to tackle the ongoing environmental degradation, yet the gaps are not clear where the implemented water (blue) and ecological (green) infrastructure might help to improve the ecosystem services. We selected mega-city Beijing, the pioneer of the "Ecological Priority" strategy, as the study area. We evaluated the conformance and performance of Beijing's water-related ecological planning implementation on ecological effectiveness from 2000 to 2015. The morphological spatial pattern analysis (MSPA) method was used to extract the blue-green ecological source areas to conform with blue-green plannings. Support, regulation and supply ecosystem services were simulated to integrate ecological effectiveness and its temporal-spatial dynamics. The results show a gradual increase in the proportion of spatial conformance, which remained higher than that of spatial low conformance. The trend of the performance of the implementation based on the analysis of ecosystem services decreased. Our results will help inform upcoming actions related to blue-green planning and management in mega-cities.

1. INTRODUCTION

Megacities all over the world attach more and more importance to ecological planning. Each country has eco-planning adapted to their region (Scudo, 2006; Joss, 2013). Water related eco-planning approach addresses different issues and objectives depending on the blue (water) elements. The spatial pattern of water-related eco-planning includes river corridors, lakes and pond, wetlands systems and other types of blue-green infrastructures that guarantee ecological security (Maruani, 2007), such as parks, greenways, and nature reserves (Ghofrani, 2017; Brears, 2018). However, due to rapid population growth and imperfect regional ecological planning, mega-cities in developing countries have higher population density and lower environmental quality than those in developed countries (Rahman, Alam, 2021; Verani, 2015). Because water and ecological space has positive effects on social and environmental dimensions, those green and blue spaces were planned to reach the high quality of urban development needs strategic evaluation.

In the global scale, there is a gap between theoretical literature and practice on planning implementation study since 1980. On the one hand, planners pay attention to the realization of a given goal, while researchers pay attention to the performance. On the other hand, time constraints force planning practitioners to ignore existing research conclusions and implementation evaluations of similar projects already implemented. Further from the related papers published, it shows that more implementation evaluation based on conformance (Laurian, 2004; Bulti, Sori, 2017; Feitelson, 2017), and few on performance (Pelorosso, 2020; Baker, 2006). In a small number of planning implementation studies have explored the possibility of combining conformance and performance evaluation (Alexander, Faludi, 1989) and their simultaneous application to compare implementation results (Altes, 2006; Baker, 2006). Altes (2006) compared conformance and performance approaches, and took the Netherlands national dense city policy as an example. The results showed that high conformance may correspond to poor performance. Therefore, it is urgent to integrate conformance and performance evaluation practice in planning implementation evaluation research.
It is urgent to evaluate environmental and ecological planning. Planning effectiveness evaluation should comprehensively consider the results and process of planning implementation (Carneiro, 2013). The evaluation study of land use planning implementation, especially about urban growth, and transportation planning are more common (Li, 2022; Zhou, 2017; Duffhues, 2016). there are few studies but with high number of citations on the implementation evaluation of environmental protection-related planning (García-Llorente, 2018; Li, 2017, Fu, 2018; Roeger, Tavares, 2018) are respectively evaluated the implementation of water security planning, coastal planning, land resource protection planning and nature reserve planning. These studies proposed that the implementation evaluation of planning policies mainly focused on qualitative analysis, with limited statistical and quantitative information. Evaluation of planning implementation from the perspective of ecological effect is still insufficient.

In theory, ecological planning guides the evolution of landscape patterns, and the evolving patterns affect ecosystem services. The function of blue and green space pattern has been studied extensively. The landscape patterns have promoted in many cities, especially provided multiple ecosystem services to society (De La Barrera, 2016), such as reducing the heat island effect (Andersson-Sköld, 2015), air quality regulation (Janhäll, 2015), flood regulation (Livesley, 2016), noise reduction (Van Renterghem, Botteldooren, 2016), Microclimate regulation, biodiversity conservation, recreation richness (Wolch, 2014). However, it remains unclear how ecological planning interacts with actual landscape patterns. The research progress in the effects of ecological planning on ecosystem services also lags far behind the demands for ecological planning and design, suggesting a gap between theory and practice. Megacity Beijing, the pioneer of the "Ecological Priority" strategy, was selected as the object of study. Beijing's ecological planning is one of the earliest cities in China. Whether the development is good or bad is directly a symbol of the efforts of the world's largest developing countries in evaluating the quality of people's lives. After long-term ecological planning, there is a lack of action mechanism and effect analysis based on spatio-temporal evolution, and there are limited practice cases or evaluation of ecological planning.

2. METHODS

2.1 Study Area

Beijing is suffering from a series of restriction by ecological and environmental problems which impact the city's sustainable development. Past approaches to urbanization have been looked at to see whether they exacerbated Beijing's eco and sustainable issues. The aggravating issues has been found to be associated with eco-planning implementations. The purpose of this study is to formulate a framework approach to the evaluation of large-scale water-related eco-planning and apply it to the case of megacity Beijing (Fig.1). Beijing proposed water planning and green space planning, since 1958. But plans considered water and ecosystem as a whole hasn't been implemented until the end of 1999. Thus, we choose study period from 2000 to 2015.

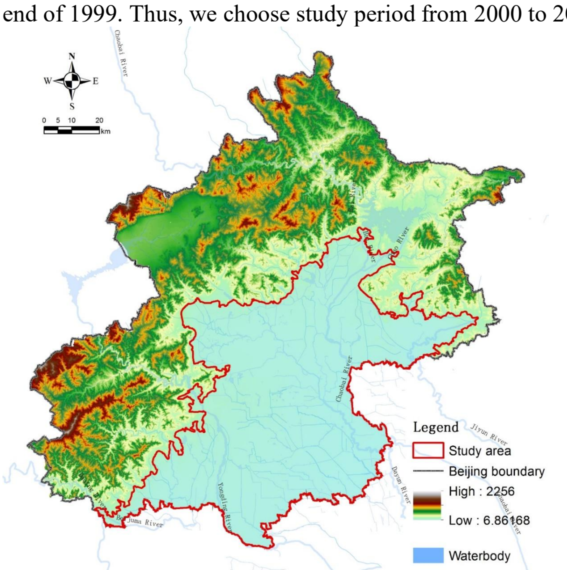

Figure 1. The map of study area

2.2 Blue-green planning and space patterns

Beijing water-related eco-planning contents have analysed and mapped to reveal its spatial-temporal evolution. The spatial-temporal variation of landscape patterns was realized by virtue of landscape indicators, morphological spatial pattern analysis. The Morphological based Pattern Analysis method MSPA (Morphological Spatial Pattern Analysis) has been successfully used to analyze various landscape Morphological changes, showing its strong applicability. MSPA applies a series of image processing techniques to raster layers to classify the target features into different landscape categories such as core and bridge, and studies the morphological mechanism of different features through non-crossing morphological types, but mainly focuses on the construction and optimization of forest, green infrastructure and ecological network pattern. MSPA divides the foreground pixels of raster binary images into seven mutually exclusive types: core, islet, edge, perforation, bridge, loop and branch. Guidos software was used to analyze the landscape morphological changes in each period and reveal their indicative significance.

2.3 Ecological Effectiveness

Water ecological issues are not only water itself, but also closely related to urban environment. The ecosystem service includes support, regulation and supply were simulated to integrate ecological effectiveness and its temporal-spatial dynamics.

Supply service

Understanding the spatial and temporal ecohydrological responses to plannings is especially critical to Beijing given the large challenges of water shortage facing this rapidly urban sprawling. Regional water supply can be well described by water yield (WY) defined as the difference between received precipitation (P) and evapotranspiration (ET), which is a function of many factors including climate, land use and land cover (LULC). WY represents the maximum water availability for natural ecosystems and human society. Water yield model is based on the Budyko assumption and annual average precipitation (Budyko 1974). Annual actual evapotranspiration (ET) was estimated using the empirical model presented by Zhang et al. (2001):

$$WY = P - ET \tag{1}$$

where P = the annual total precipitation (mm)
ET = the annual actual evapotranspiration, based on the empirical model of Zhang ET al. (2001).

$$ET = \frac{P(1 + \omega \frac{PET}{P})}{1 + \omega \frac{PET}{P} + (\frac{PET}{P})^{-1}} \tag{2}$$

where PET = annual potential evapotranspiration (mm)
ω = the plant-available water coefficient
P = the annual mean precipitation (mm)
ET = the annual actual evapotranspiration (mm)

PET is calculated by summing monthly potential evapotranspiration using the Hamon method (Hamon, 1963), where the required variables include monthly T and day length. The length of the day was calculated as a function of latitude. The daily meteorological data (solar radiation, precipitation and temperature) were obtained from the China Meteorological Data Sharing Service system, and the interpolation raster maps of stations inside and outside the Beijing metropolitan area were made by Kriging method using ArcGIS10.2 software. The plant-available water coefficient ω was assigned a value by land use type, according to the existing literature support (Zhang, 2001; Lu, 2013), 2.0 for woodland, 1.0 for shrub-land, 0.5 for grassland and cropland, and 0.1 for artificial land and barren land in this study. ET of water body is defined as the minimum value of P and PET, namely ET = Min (P, PET) (Lu, 2013).

$$PET = k \times 0.165 \times 216.7 \times N \times \left(\frac{e_s}{T + 273.3}\right) \tag{3}$$

where k = proportion coefficient (dimensionless)
N = day length (x / 12 hours)
e_s = saturated vapor pressure (mb)
T = average monthly temperature (c)

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Support service

To estimate Net Primary Production (NPP) supporting service functions based on MODIS data and the terrestrial Carnegie Ames-Stanford Approach (CASA). The CASA model proposes that vegetation NPP be calculated as the product of photosynthetically active radiation (APAR) modulating absorption and light use efficiency (ε) factor (Potter, 1993).

$$NPP(x,t) = APAR(x,t) \times \varepsilon(x,t) \tag{4}$$

where NPP = Net primary productivity of pixel x at time t (g/m^2a)

APAR = the canopy-absorbed incident solar radiation (MJ/m^2)

ε = the light utilization efficiency of APAR ($g\ C/MJ^2$)

The required data CASA (Carnegie Ames Stanford Approach) models include land cover, NDVI (Normalized Difference Vegetation Index), and climate data. The annual total NPP ($g\ C\ m^{-2}\ year^{-1}$) is the sum of the NPP for each of the 12 months within a year. All the data used to map supply service and support service are presented in Table 1.

Datasets	Data type	Spatial resolution	Time scale	Data sources
Meteorological data	Point		2000-2015	http://cdc.cma.gov.cn/
Topographical parameters	Raster	90m	2000	http://srtm.csi.cgiar.org
Remote-sensing data	Raster	30m	2000-2015	http://glovis.usgs.gov/
MODIS NDVI	Raster	250 m	2000-2015	http://ladsweb.nascom.nasa.gov/data/

Table 1. The datasets used for mapping ecological effectiveness

Regulating service

The assessment of regulating service effect consists of two parts, namely, the assessment of cooling effect and the assessment of Carbon storage effect. In terms of cooling regulation, the method of assessing heat island effect based on Land Surface Temperature (LST) inversion algorithm.

leaf area index (LAI) can reflect biophysical processes such as carbon flux and is widely used in carbon storage. Previous studies have shown that the metropolitan area as a whole is the carbon source, while urban green vegetation can be called the local carbon sink in the urban area, and the carbon absorption of plants has the effect of offsetting the total amount of anthropogenic CO_2 emissions. LAI product mainly adopts remote sensing inversion method, using MODIS imaging spectrometer data remote sensing inversion of LAI. The remote sensing inversion is based on the surface reflection in clear sky state as input, so the surface reflectance of multi-day clear sky state is synthesized in advance, and Cloud removal and other noise processing are carried out, and an improved synthesis algorithm with minimum visible band selection is used to effectively eliminate both the influence of clouds and cloud shadows. Leaf area index and photosynthetically effective radiation absorption coefficient of vegetation are obtained by inversion of the canopy radiative transfer equation, and the input data are the synthesized cloud-free surface reflectance data.

Land surface temperature (LST) is a good indicator of the energy balance and greenhouse effect on the Earth's surface, and it is a key factor in the geophysical processes of regional and global-scale. The ground temperature obtained from satellite data inversion reflect the average condition of surface temperature for each image element, and can reflect the spatial distribution characteristics of the surface temperature field in more detail. Although the error of surface temperature inversion using remote sensing data is unavoidable, it is still the most effective and easiest way to obtain surface temperature over a large area, which is also an advantage of MODIS images to reflect the difference of surface temperature distribution over a large area. This study used split-window algorithm that is the most common method for LST retrieval from satellite data. The data has been verified by precision.

2.4 Effectiveness Evaluation Framework

The spatial-temporal dynamics of ecological planning, landscape patterns and ecosystem services were then organically coupled for comparative analysis of consistency and correlation, so as to investigate the mechanism by which ecological planning acts on landscape patterns.
The content and objective of planning and the effects of service were connected to define the regulatory effectiveness of ecological planning. Fulfilling planning goals is the fundamental task of plan implementation, as well as an essential sign of planning success. We build a comprehensive framework that integrates the performance and conformance criteria along with evaluation of outcomes of plan implementation. Planning implementation evaluation comprises five steps in Fig.1: 1) usage of planning contents in the master plan structures; 2) conformance between outcomes and plans; 3) ecological benefits and impacts of the outcomes; 4) realization degrees of planning goals; 5) planning goals' influences on decision-making. This framework classifies degrees of planning implementation.

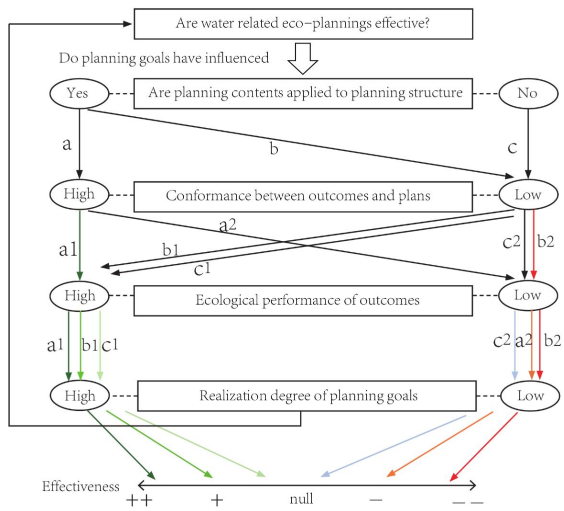

Figure 2. The Effectiveness Evaluation Framework

3. RESULTS

3.1 Water-related eco-planning from 2000-2015

The water-related eco-planning from 2000 to 2015 aimed to improving the connectivity of water systems, restore the ecological function of river courses, and build watershed-based water network system that is coordinated, connected by multiple corridors, circulates at multiple levels, and is ecologically healthy. Blue spaces such as natural waters, wetlands and ponds should be protected. Ecological protection, restoration and construction of wetlands should be strengthened, and ecological wetlands should be reserved in the estuarine areas of important branches flowing into the main stream. Gradually restore the natural ecosystem of the riverside zone and the reservoir zone, improve the ecological microcirculation of the riverbank, and improve the self-purification function of water bodies. Overall planning of waterfront landscape construction, to create a waterfront space with complex functions and well-designed opening and closing. Improve the hydrophilicity of the river, to meet the citizens leisure, entertainment, viewing, experience and other needs.

3.2 Water and Ecological Patterns

Ecological source areas are a combination of water and green space. Based on the MSPA spatial pattern graph in Fig.2, in the prospect of the ecological source area, the core area accounts for the most, while the area of islets and loops accounts for the minimum. In 2000, within the metropolitan area of Beijing, most ecological source areas are concentrated in the western and northern underhills and fragmented in the central and eastern plains. Overall, the background region in study area were decreased from 2000 to 2015. The background region was transformed into the foreground and the core region was connected in the region with the concentrated distribution of the core region. The core part in the western and eastern underhill areas had been gradually fragmented and reduced during the 15 years. The bridge, edge, branch and loop areas of ecological sources in plain areas increased. From 2005 to 2015, ecological source areas gradually converged at large-scale fragments in the central city, generating many new branches and connecting bridges, while longer-distance fragments of the core disappeared. from 2000 to 2005, the core and bridge areas along rivers increased and connected as corridors, such as Yongding river, Wenyu river and Chaobai river. The core and edge areas in the second green belt increased too, mainly located in Olympic Park and urban parts of Liangshui river. From 2005 to 2015, the core area increased, mainly due to the gradual aggregation and connectivity of the previously fragmented core areas in the metropolitan area. Therefore, with the increase of perforation, islets, edges, bridges, loops and branches were reduced due to the partial transformation into core areas.

3.3 Ecological Effectiveness

Among the ecological service effectiveness, the overall effectiveness of water supply service from 2000 to 2015, shows an increasing trend, but the proportion of service area with increasing service effect decreased gradually: from 2000 to 2005, the proportion of service effect increased area was 96.90%, from 2010 to 2015, the increased area proportion was sharply reduced to 47.56%. From 2000 to 2005, water supply services showed an increasing trend, mainly in the northeast of the Beijing metropolitan area. From 2005 to 2010, the main trend of increasing water supply services was still observed. From 2010 to 2015, water supply services showed a decreasing trend, mostly in central urban areas and southern areas, especially in Yongding River.

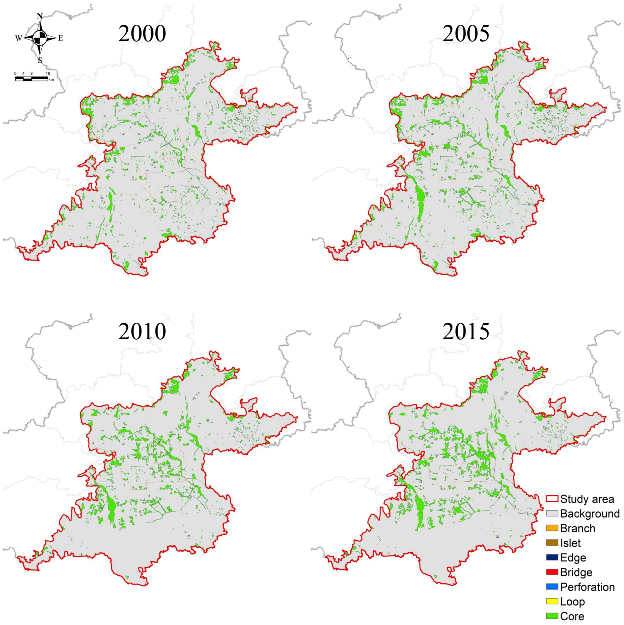

Figure 3. MSPA changes of study area

The support service effectiveness from 2000 to 2015, 56.9% of the Beijing metropolitan area was detected to have no significant NPP change. The percentage of the coverage of statistically significant NPP changes was 19.0% of the study area for NPP greening (restoration) and 24.1% for browning (degradation) with great spatial heterogeneity. From 2000 to 2005, most of the landscape had a stable support service status. 15.0% of the study area experienced net significant vegetation greening, whereas the 2.1% of the area experienced significantly browning. The proportion of significantly green areas was higher than that of significantly brown areas, with a difference of 7.1 times. From 2005 to 2010, processes of significant NPP greening and browning coexisted, which resulted in a slight net browning trend at the city level. The proportion of significantly greening was 2.0%; The proportion of Spaces that were significantly browning was 5.1%. From 2010 to 2015, the proportion of regions with significant improvement in support service was 7.9%. The proportion of significantly degraded area was 3.0%.

The growth of carbon storage regulation effect was slightly higher than the decrease. The range of values increased, from 0 to 79.65 in 2000 to 3.76 to 97.43 in 2015. Regions with significant increases in the regulation effect of carbon storage were found to be located in center of Beijing. The region with an increasing trend in the regulation effect of carbon storage was 53.08%, which is slightly higher than the region with a decreasing trend, which is 46.92%. The area with significant increase accounted for 7.29% of the total area, which was larger than that with significant decrease (2.21%).

The areas with increased greenhouse effect accounted for 83.57% of the total area. The overall surface radiation in the Beijing metropolitan area was mainly increasing, with the areas with significant increases accounting for 11.17% of the total area. The areas with significant improvements in surface radiation accounted for 1.38% of the total area, and the areas with significant reductions in greenhouse effect were concentrated in the first green corridors of urban areas. In addition, it is evident that the greenhouse effect is significantly reduced in the corridors of the Chaobai, Yongding, and Tonghui rivers.

3.4 Changes of Conformance and performance

As shown in Table 2, from 2000 to 2015, the proportion of spatial conformance in water-related ecological planning implementation was gradually increased and was always higher than the proportion of spatial low conformance. High conformity rates were 52.06% from 2000 to 2005, 62.58% from 2005 to 2010, and 78.50% from 2010 to 2015.

Period		Proportion		Proportion
2000-2005	High conformance	52.06%	Low conformance	47.94%
2005-2010		62.58%		37.42%
2010-2015		78.50%		21.50%

Table 2. Changes of conformance

The trend of performance of water-related eco-planning implementation based on ecological effectiveness decreased in the Beijing megacity area. Within the planning area, the ecological performance reached 74.96% during 2000 - 2005, decreased to 44.77% during 2005 - 2010, and increased slightly to 54.88% during 2010 - 2015. A large-scale restoration beyond the planned area was more effective. Ecological performance outside the planned area gradually declined, reaching a high level of 58.18% in 2000 - 2005, before falling to 25.75% in 2005 - 2010 and 21.44% in 2010 - 2015.

Period		a1	a2	b1	b2	c1	c2
2000-2005	Area (km^2)	408.03	16.39	203.08	187.71	2590.88	1573.49
	ratio	50.05%	2.01%	24.91%	23.03%	43.27%	26.28%
2005-2010	Area (km^2)	976.41	609.92	158.56	790.19	249.42	1228.08
	ratio	38.52%	24.06%	6.25%	31.17%	4.02%	19.77%
2010-2015	Area (km^2)	1643.40	1019.64	218.33	511.19	189.48	466.24
	ratio	48.44%	30.06%	6.44%	15.07%	3.08%	7.59%

Table 3. Changes of ecological performance

4. DISCUSSION

4.1 High conformance but insufficient performance

According to the results, strong conformance in planning implementation does not imply high performance. Inadequate conformance does not imply low performance. The scale and frequency of implementation increased year by year, and the level of spatial and temporal conformance also increased. But the ecological performance of planning decreased gradually. It is not less important to understand why and under what circumstances these deviations occur. Grey infrastructure implementation ratio is still considerably higher than that of green infrastructure construction. The simplification of multiple causes of the problem into a single cause makes it easy to adopt a strategy of technological solutions that succeed in the short term, but prove unsustainable and less resilient in the long term. When dealing with some extreme weather events, such as catastrophic rain, the excessive measures scheme is ambiguous. As a result, the hydrological effects on the watershed have not improved.

4.2 Busy coping with short-term problems but insufficient forward-looking

The reservoir effect refers to the fact that over-reliance on reservoirs increases their vulnerability, thereby increasing the potential damage caused by drought. Such "reservoir effect" may exacerbate poor performance. A large number of related master plans and special plans, such as urban flood protection planning, urban landscape planning, urban river and lake planning, have been developed to address the problem of ecological water issues. Most of these plans focus on a specific problem, but it becomes difficult to solve the whole urban ecological problem, such as the contradiction between flood discharge safety and water environment protection, and the contradiction between flood diversion management and water conservation. It is an effective way to develop from a single flood control objective to multi-objective development such as flood control, urban environment improvement, ecological water demand and urban reuse.

4.3 The hydrological storage process and ecological service benefits of wetland are not brought into play

Beijing has witnessed more than double the total land cover in the past 10 years and has experienced several devastating flood events in the same period. Various studies have shown that one of the main causes of the recent flooding events in Beijing is the lack of residual capacity of the drainage system to cope with extreme weather events. In addition, these studies show that these urban areas do not have sufficient water storage capacity to permeate and store rainwater during heavy rains. Megacity Beijing do not retain their natural forms water infrastructure systems, such as ponds, rivers and lakes, and wetlands. The principles and methods of ecological planning were finally summarized to strengthen the expected controllability of ecological planning and provide an important basis for scientific decision-making in building an ecological civilization in Beijing.

5. CONCLUSIONS

Our results indicated that Beijing metropolitan area experienced both ecological restoration and browning degradation with great spatial heterogeneity. The conformance of water-related eco-planning implementation was better than performance. The analysis and evaluations carried out confirm insufficient implementation of improving ecological city in the field of water-related eco-planning in Beijing, which is alarming. This study provides scientific basis for the capital ecological management, comprehensive decision-making of sustainable development and promoting the construction of ecological civilization.

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