Research Paper

Linking Ecosystem Service Supply and Demand to Resilience of Blue-green Space: A Conceptual Framework

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Abstract

Blue-green space, with its natural barrier function in disaster prevention and risk avoidance, has become an important part of urban resilience research. Blue-green space resilience has therefore become an important support for the resilience of urban social-ecological systems. The evaluation of the comprehensive resilience of urban blue-green space is of great significance for improving the overall resilience of cities. Since ecosystem services and the comprehensive resilience of urban blue-green space are both key components of the resilience of urban social-ecological systems. Therefore, this study attempts to establish a correlation between ecosystem services and urban blue-green space resilience, integrate human society and blue-green space material systems through ecosystem services, and propose a PPD evaluation model based on the comprehensive resilience of blue-green space, revealing the two types of interference scenarios faced by the comprehensive resilience evaluation of urban blue-green space, namely "sudden natural disaster risk" and "chronic stress risk". Based on this, a comprehensive resilience evaluation framework for urban blue-green space is constructed through the logical method of "measuring the resilience level to cope with two types of interference-identifying blue-green space that is vulnerable to threats and imbalanced supply and demand-evaluating the comprehensive resilience of urban blue-green space", providing novel research ideas and practical theoretical guidance for the comprehensive resilience measurement of urban blue-green space.

Keywords

Blue-green spaces; Resilience; Ecosystem services; Supply-demand balance; Stress and pulse

1. Introduction

In the context of climate change, The frequent occurrence of extreme weather events reflects the inadequacy of urban emergency response capabilities. As a part of the urban system, blue green space have natural disaster prevention and also can improve the resilience of cities by providing ecosystem services. However, in the existing research on enhancing urban resilience in blue-green spaces, only a single dimension of resilience has been considered (Wang and Wang, 2020), and insufficient consideration has been given to the chronic pressures and intervention measures generated by the human social system.

In this context, our study focuses on exploring the comprehensive resilience assessment method of urban blue-green space, clarifying the correlation between ecosystem services and urban blue-green space resilience, and proposing a comprehensive assessment system based on blue-green space.

2. Progress in research on urban blue-green space resilience assessment

Many researches have concentrated on the impact of blue-green space on human well-being and social justice (Andersson et al., 2019; Dobson, 2021), as well as the role of blue-green space in promoting urban climate resilience and disaster resilience (Lu, Sun and Steffen, 2023). Existing studies have problems such as a single perspective on the resilience of urban blue-green spaces, insufficient dimensions of resilience evaluation factors, and an imperfect resilience evaluation system.

Therefore, considering the multi-type interference brought to cities by climate change uncertainty, this study takes the various natural disaster threats faced by blue-green spaces and the progressive pressures exerted on them by human society as considerations for assessing their resilience, and defines its resilience assessment results as the comprehensive resilience of blue-green spaces.

3. Analysis of the relationship between ecosystem service supply-demand and blue-green space integrated resilience

3.1. Ecosystem services as a key component of urban social-ecological system resilience

Collins (Collins et al., 2011) and other scholars pointed out in 2011 that ecosystem services can connect natural ecosystems with human social systems. Urban socio-ecological system resilience aims to promote positive interactions between natural and social ecosystem. Ecosystem services refer to the terminal natural components generated by ecosystems that contribute to human well-being (Gao et al., 2024). The two are highly compatible at the level of connotation, components and goals (Figure 1), and the concept of urban socio-ecological system resilience is more complex and broader. Therefore, ecosystem services can be considered a key component of urban socio-ecological system resilience.

3.2. Interdependence between ecosystem services and blue-green space resilience

First, blue-green spatial resilience interacts with sustainable ecosystem provisioning. Blue-green spatial resilience determines the ability of cities to maintain their ecological functions under high environmental pressures, such as extreme climate events and anthropogenic interventions, and thus influences the provision and generation of ecosystem services.

Second, blue-green spatial resilience is one of the pathways to achieve ecosystem service goals. Blue-green spaces can not only mitigate environmental pollution and regulate flooding, but also provide positive support for urban residents by providing water resources for living, creating opportunities for water-friendly recreation, and providing aesthetic values (Thiele et al., 2020), and many studies have confirmed that blue-green spaces can enhance human health and well-being (Fisher et al., 2021).

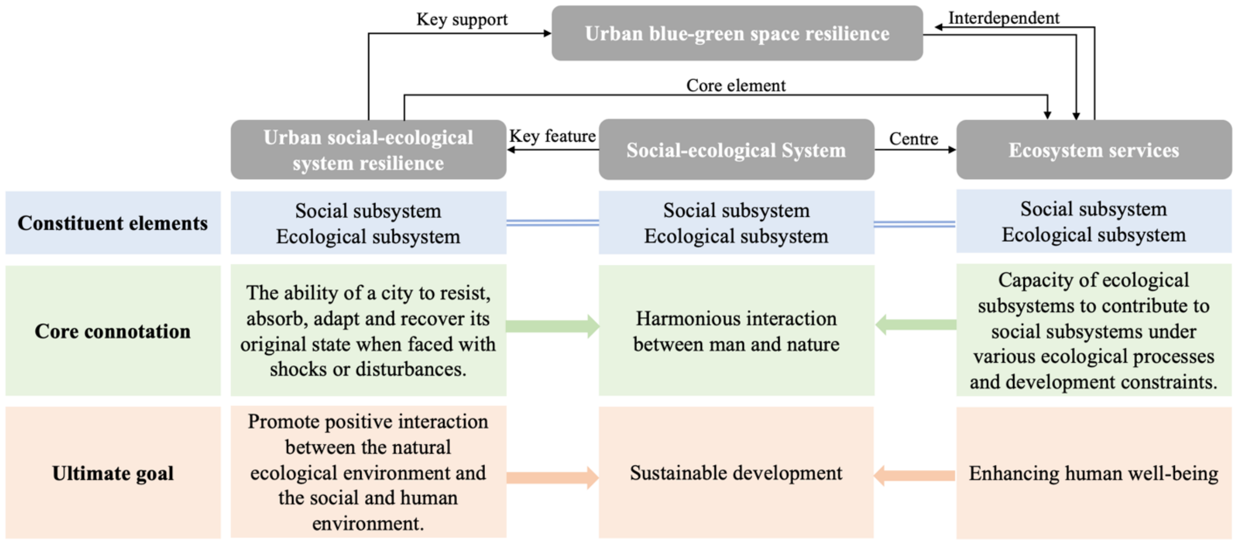

Figure 1. Correlation between ecosystem services and urban blue-green space resilience. Source: Authors.

4. Construction of urban blue-green space integrated resilience assessment system from the perspective of ecosystem service supply-demand balance

Based on the exploration of various types of risks faced by urban blue-green spaces, we constructed a theoretical framework for the comprehensive resilience assessment of urban blue-green spaces; defined indicators for assessing the comprehensive resilience of blue-green spaces; quantified each assessment indicator; and integrated the indicators to construct a comprehensive evaluation model.

4.1. Comprehensive resilience assessment framework for urban blue-green spaces from the perspective of ecosystem service supply-demand balance

Based on the resilience assessment framework of "resistance-adaptability-resilience", this paper incorporates the interaction between the social subsystem and the ecological subsystem into the influencing factors of resilience assessment, that is, through the supply and demand relationship of ecosystem services, to guide the comprehensive resilience assessment of urban blue-green spaces.When the various services provided by the ecological subsystem cannot meet the needs of the human social system, the city will face "slow-onset pressure" risk, and will also be affected by natural disturbances such as rainstorms, typhoons, floods, and fires brought about by climate change, that is, "sudden pulse" risk. Therefore, the urban blue-green space resilience mentioned in this paper is composed of "slow-onset pressure" risks and "sudden pulse" risks. Based on the Press-Pulse Dynamics Model (PPD) of social-ecological systems proposed by Collins (Collins et al., 2011), we further focuses on the comprehensive resilience of blue-green spaces, constructs a PPD assessment framework based on the comprehensive resilience of blue-green spaces, and integrates human society and blue-green space systems through ecosystem services, thereby providing novel research ideas and practical theoretical guidance for the comprehensive resilience assessment of urban blue-green spaces (Figure 2).

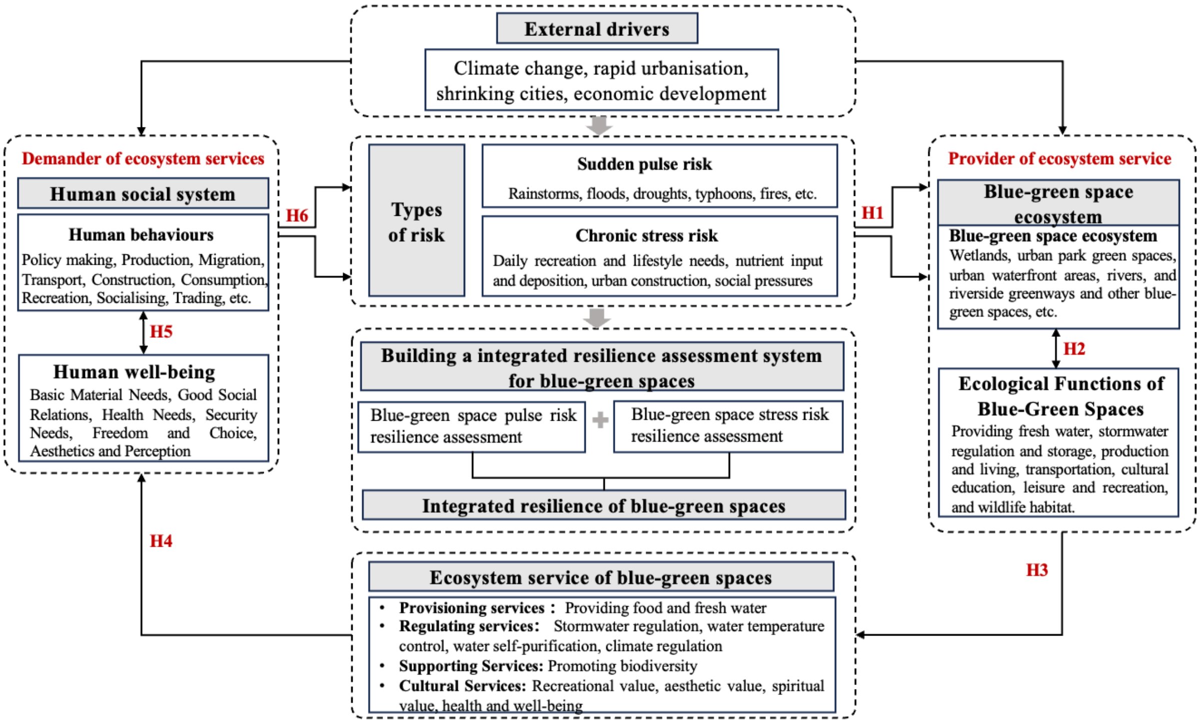

Figure 2. PPD model based on integrated blue-green space resilience. Source: Authors.

4.2. Indicator system of urban blue-green space integrated resilience assessment from the perspective of ecosystem service supply-demand balance

4.2.1 "Sudden pulse risk" resilience assessment indicator system

"Sudden natural shocks" refer to common natural disasters brought to cities by climate change. Combined with the risk avoidance functions of urban blue-green spaces, extreme high temperature weather, rainstorms and floods, and forest fires are selected to represent the common disasters faced by urban blue-green spaces. The three basic characteristics of resilience are matched one by one with the time sequence of disaster occurrence, namely resistance (before disaster), recovery (during disaster), and adaptability (after disaster). Urban blue-green space resilience assessment indicators are selected from three different time sequences, thereby we constructed an urban blue-green space resilience assessment indicator system coping with multiple disaster types and multiple time sequences (Table 1).

Table 1. Indicators for assessing the resilience of urban blue-green spaces to "sudden pulse risk". Source: Authors.

Disaster type	Disaster occurrence timing	Evaluation index	Relevance
Extreme heat weather resilience	Resistance (Pre-disaster)	Landscape pattern risk resistance index	+
	Recovery (During disaster)	Blue-green space area	+
		Blue-green space proportion	+
		Blue-green space mixing degree	+
		Vegetation coverage rate	+
		Arbor and shrub vegetation coverage	+
		Proportion of arbor to shrub	+
		Coverage of native tree species	+
		Water body coverage ratio	+
		Water body area	+

		Riparian vegetation buffer width	+
		Distance between green space and water body	-
		Water system morphology index	+
		Patch dominance	+
		Patch regularity	+
		Patch cohesion	+
Flood resilience	Resistance (Pre-disaster)	Percentage of green form types	+
		Number and richness of wind-resistant tree species	+
		Tree growth space	+
		Tree daily maintenance efforts	+
		Tree layout and form in narrow wind-through areas	+
	Recovery (During disaster)	Water system connectivity index	+
		Land runoff coefficient	+
		Permeable underlying surface ratio	+
		Rainwater storage facility completeness	+
		Water body shore type	+
		Vegetation index	+
	Adaptability (Post-disaster)	Vegetation coverage rate	+
		Proportion of water body area where aquatic plants are cultivated	+
		Riparian vegetation buffer width	+
Forest fires resilience	Resistance (Pre-disaster)	Proportion of fire-resistant tree species	+
		Width of compound firebreaks	+
		Plant diversity	+
		Degree of understory cover of flammable dead wood	-
	Adaptability (Post-disaster)	Proportion of fire-resistant and regenerative plants	+

When facing extreme high temperature weather, blue-green space can regulate urban microclimate and enhance urban biodiversity (Wang and Yang, 2023). The risk resistance index of blue-green space before disaster can reflect the ability of blue-green space to cope with extreme high temperature weather (Chen et al., 2022). Area, proportion and mixing degree of blue-green space all play a positive role in promoting the cooling capacity of blue-green space (Liao et al., 2021; Wang, Sheng and Wang, 2024; Zhou et al., 2023). High vegetation coverage can enhance the system's resistance to disturbances (Chen, Zhou and Chi, 2021). The carbon sink and transpiration effects of vegetation can effectively alleviate urban heat island effect (Chen et al., 1998). Trees and shrubs can also reduce the ambient temperature (Huang and Wang, 1998). In addition, native tree species have better adaptability and resilience to high temperature environments than introduced plants (Yang, Yang and Qiu, 2022). Water bodies can reduce temperature by changing surface radiation (Xiu, Wei and Wang, 2018). At the same time, vegetation in riverbank buffer zones can also reduce water temperature (Zeng, Huang and Xiao et al., 2010), and green spaces close to water bodies can improve thermal comfort (Huang et al., 2021). In addition, different patch combinations can affect the spread of local cooling sources (Wang, Sheng and Wang, 2024).

During typhoon and flood disasters, blue-green space plays a certain role. Before the disaster occurs, the complexity of the tree, shrub and grass layer structure has a positive effect on the wind protection effect (Wang, Shen and Wang et al., 2023). The damage to park green space caused by strong typhoons is caused by natural factors (Xiao and Feng, 2014) and human factors (Liu and Xu, 2020; Guo et al., 2020). In addition, high-rise dense buildings or canyon terrain aggravate the damage to green space caused by strong winds or typhoons (Liu et al., 2020). When a disaster occurs, a smooth and circulating water system can effectively improve the system's ability to recover from flood disturbances (Gao et al., 2020). The flood infiltration capacity of the underlying surface also has a certain impact on its resilience (Vijayraghavan et al., 2021). In addition, rainwater reuse systems can alleviate urban waterlogging (Wang and Palazzo, 2021). Ecological revetments of water bodies can buffer flood impacts (Qiao, Liao and Randrup, 2020), and improving vegetation index is the key to improving stormwater resilience (Li et al., 2023). The adaptability of blue-green space to stormwater resilience is mainly reflected in the purification of water bodies after the disaster. Plants can purify water quality with their adsorption and barrier capabilities (Wang and Zhang, 2016). In addition, riparian vegetation buffer zones can effectively intercept and retain sediment. Additionally, the wider the riparian vegetation, the more obvious the decontamination effect (Zhou and Wang, 2014).

During forest fires, before a disaster occurs, the ratio of highly fire-resistant tree species and the width of the multi-layer fire-prevention forest belt can help enhance the blue-green space's resistance to fire risks. The coverage of flammable also impact its resistance. After a disaster occurs, fire-resistant and regenerative plants have strong post-disaster sprouting capabilities, which can improve the park's green space's ability to self-repair from fires (Yang, Yang and Qiu, 2022).

4.2.2 "Chronic stress risk" resilience assessment indicator system

1）Ecosystem service supply indicators for blue-green space

According to the classification of Millennium Ecosystem Assessment (MEA), the ecosystem services of urban park green spaces can be divided into four types: provisioning services, regulating services, supporting services, and cultural services (Xiao, et al. 2020). This study selected three categories of ecosystem services that are most relevant to human well-being, seven dimensions of provision, and 23 evaluation indicators (Table 2).

Table 2 Indicators of ecosystem service provisioning in urban blue-green spaces. Source: Authors.

Ecosystem service types	Supply dimension	Evaluation index	Relevance	Literature source
Regulation services	Flood management	Impervious pavement ratio	-	Shen, 2012
		NDVI	+	Wang and Wang, 2020
	Water quality purification	Proportion of cobblestone or muddy shores in bank porosity	+	Cong, 2009
		Proportion of concrete or other rigid shores in bank porosity	-	Cong, 2009
		Proportion of aquatic plants	+	Wu et al., 2001
		Width of riparian vegetation buffer strip	+	Zhou and Wang, 2014
		Percentage of pollutant input	-	Murrain, 1984
		Water surface coverage	+	Fang et al., 2021
		Percentage of ecologised bank slopes	+	Fang et al., 2021
	Microclimate regulation	Cold island effect		Wang and Wang, 2020
		Arbor coverage rate	+	Liu and Lin, 2015
		Plant space structure	+	Liu and Lin, 2015
Supporting Services	Biodiversity	Habitat richness	+	Zeng et al., 2020
	Habitat health	River meandering	+	Yu et al., 2021
		River connectivity	+	Fu et al., 2020
Cultural services	Provision of recreational opportunities	Number of recreational activity types	+	Xiao and Du, 2011
		Number of recreational space types	+	Tang et al., 2013
		Recreational site area	+	Xiao and Du, 2011
		Number of service facility types	+	Xiao and Du, 2011
		Richness of waterside facilities	+	Zhang and Yao, 2004
		Visibility of water features	+	Tang et al., 2013
		Richness of landscape furnishings	+	Zhang et al., 2015
	Historical and cultural heritage	Number of ancient and famous trees	+	Xiao and Du, 2011

2）Ecosystem service demand indicators for blue-green spaces

At present, researches have different understandings of ecosystem service demand. This paper understands it as "basic materials, good social relations, health needs, security needs, freedom and choice, aesthetics and perception required to achieve human well-being". This study draws on the research results of Wang Mangmang et al. and use demand quantity and quality to represent ecosystem service indicators(Table 3).

Table 3 Indicators of demand for ecosystem services in urban blue-green spaces. Source: Authors.

Ecosystem service demand types	Evaluation index	Literature source
Demand quantity	POI density	Wang and Wang, 2020
	Floor area ratio	Wang and Wang, 2020
	Population density	Zhai et al., 2019
	Construction land ratio	Zhai et al., 2019
Demand quality	Population density over 60	Wang and Wang, 2016
	Population density under 18	Wang and Wang, 2016
	Unemployed population density	Wang and Wang, 2020
	Non-local population density	Wang and Wang, 2020
	Recreational satisfaction	Wang and Wang, 2020

4.2.3 Urban blue-green space integrated resilience assessment index quantification and evaluation model

On the basis of building a resilience assessment index system, the index weights were determined and a comprehensive evaluation model was established. Through the three steps of "measuring the resilience level to two types of disturbances - identifying blue-green spaces that are vulnerable to threats and imbalanced supply and demand - evaluating the comprehensive resilience of urban blue-green spaces", the resilience assessment of urban blue-green spaces was achieved. The specific research framework is shown in Figure 3.

In the process of measuring the resilience of "sudden pulse risk", an urban blue-green space resilience assessment index system is constructed to cope with various types of disasters and consider the multi-temporal dynamics of "before-during-after-disaster", and the indicators are integrated through a comprehensive evaluation method. In the process of measuring the resilience of the risk of "chronic stress risk", the supply and demand relationship of ecosystem services is used to characterize its resilience level. Finally, the blue-green space that is vulnerable to disasters is superimposed on the blue-green space with unbalanced supply and demand, and the comprehensive resilience evaluation results of the blue-green space are obtained, which will guide the comprehensive resilience planning of the blue-green space.

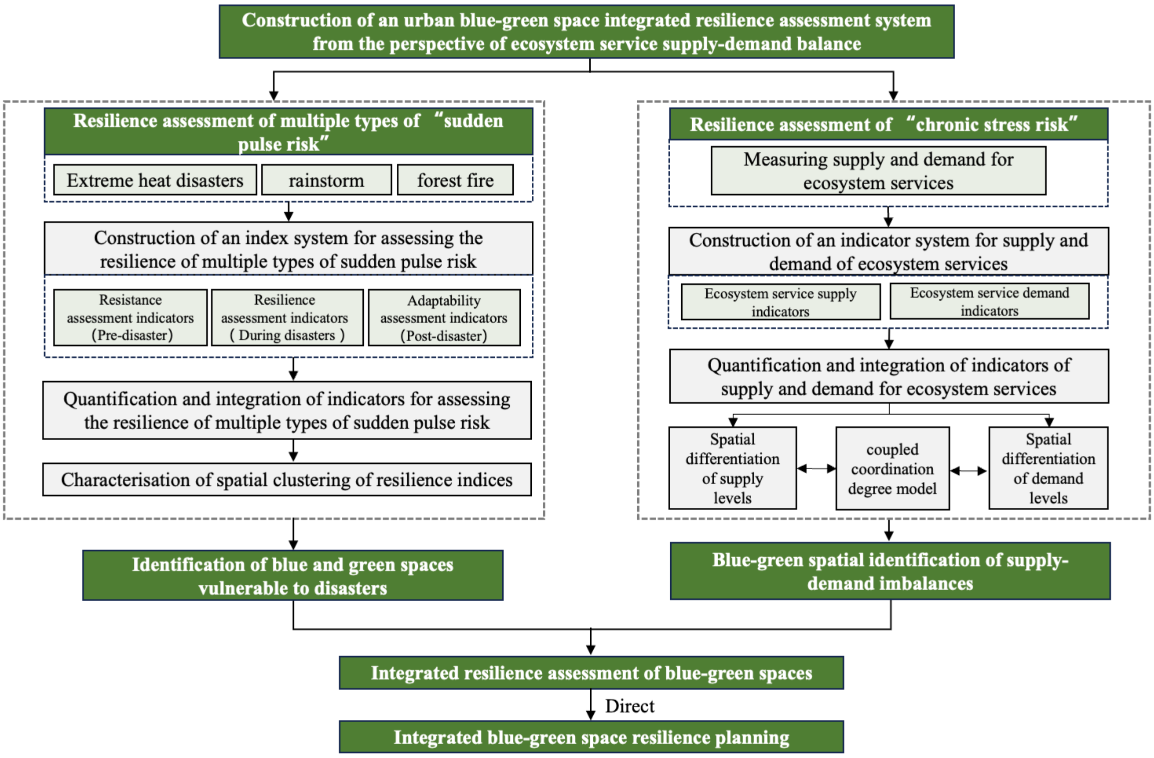

Figure 3. Urban blue-green space integrated resilience assessment model. Source: Authors.

5. Conclusion

This paper conducts a correlation analysis between "ecosystem service supply and demand relationship" and "blue-green space resilience", and constructs a conceptual framework for urban blue-green space resilience assessment from the perspective of ecosystem service supply and demand balance. In the future, we should further explore the factors and influencing mechanisms that affect the comprehensive blue-green spacial resilience, integrate the resilience planning into the multi-level spatial planning system, and use the comprehensive resilience assessment results of blue-green space to guide urban blue-green space resilience planning.

6. Funding

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