Analysing urban green infrastructure network (GIN) for resilience and ecosystem services: The standards and methods

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Abstract. The widespread spread of COVID-19 in cities has revealed problems with current urban planning. In view of these problems, scholars have looked forward to the development direction of future cities. Through literature review, this study finds that achieving these development goals is highly correlated with urban ecological services (ES). The realization of ES function depends on the green infrastructure (GI), and the actual construction of GI needs the analysis and judgment of its spatial structure, that is, the green infrastructure network (GIN), through urban planning policies. Therefore, this study will analyze the concept and GIN research progress based on a literature review, to clarify the core concerns of current relevant research; Then, the evaluation of GIN is analyzed based on a literature review, including the necessity of evaluation, the criteria followed by evaluation and the methods used in evaluation, to identify the most effective evaluation criteria and methods at present and provide theoretical basis for future specific research. Therefore, GIN construction in the city can be more scientific for the future of urban public health events to play a positive role.

Keywords: Urban Planning, Green Infrastructure Network, Geo-Spatial, Ecosystem Services.

1. Research background

The outbreak of COVID-19 in cities around the world poses a great threat to the life and health of all mankind [1], and reflects the lack of current urban planning ability to cope with public health emergencies [2]. However, modern urban planning originated from the response to urban health problems [3]. Therefore, judging from the large-scale outbreak of urban diseases in 2020, urban health problems still need further research. On this issue, scholars have reached the following consensus: First, control urban population density. Second, the protection and construction of natural landscapes should be fully considered. Thirdly, adequate urban space reservations should be made in the urban planning process. Fourth, improve the construction of urban ventilation corridors. Fifth, optimize urban functional zoning and improve the health level of urban residents [1, 2, 4]. In summary, these five consensuses, or to put it differently, the five development directions are intricately linked to urban ecosystem services (ES). ES encompass natural ecosystems and the species within them that sustain life and fulfil human needs [5]. They encompass provisioning, regulation, support, and cultural services [6], from which humans directly or indirectly derive various values and benefits [7]. ES can be further divided into ES demand and ES supply. ES demand represents the quantity of ecosystem services required or expected by society [8], representing the urban residents' need for ecosystem services, which must be met through ES supply. ES supply refers to the capacity to provide specific ecosystem products and services in a particular region for a specified period [9]. This supply capacity relies on the quantity, quality, and diversity of green infrastructure (GI) [10]. In essence, GI constitutes the ES supply system, and realizing the value of ES for urban residents and solving urban issues hinges on constructing GI within cities [11]. To carry out GI construction in urban areas, it is imperative to develop urban planning policies based on spatial structure analysis to effectively and precisely allocate space and land for GI.

Therefore, this paper will analyze the process of GI spatial structure research based on a literature review, to clarify the core concerns of current relevant research; Then the evaluation of GI spatial structure is analyzed based on the literature review, including the necessity, criteria and methods of evaluation, to identify the most effective evaluation criteria and methods at present. Then it provides a theoretical basis for future research.

2. The evaluation standards and methods of green infrastructure network (GIN)

2.1. Green infrastructure network

The rapid advancement of urbanization has led to the gradual breakdown of extensive habitat patches, resulting in reduced connectivity [12]. To address habitat fragmentation, protect biological habitats, and enhance landscape connectivity, some scholars have introduced the concept of green infrastructure (GI) as a sustainable ecological network. GI comprises a system of natural areas and open spaces primarily consisting of nodes and links [13]. In 1999, the U.S. Presidential Commission on Sustainable Development, in its publication "Towards a Sustainable Development of the United States - A Prosperity, Opportunity, and Healthy Environment for the Twenty-first Century," introduced the idea of green infrastructure as the nation's natural life support system. It serves as a framework for preserving land and water, supporting native species, maintaining natural ecological processes, conserving air and water resources, and improving the well-being and quality of life of American communities and individuals [14].

Between 1999 and 2014, scholars continually expanded and refined their earlier research, offering new interpretations of green infrastructure. Some widely referenced and elaborated upon ideas include the East Midlands Green Infrastructure Scoping Study: Final Report in 2005, which defined GI as a multifunctional network of green spaces within designated areas, enhancing the livability of both existing and emerging communities [15]. Benedict and McMahon argued in 2006 that GI represents a strategic plan and management network for natural land, artificial landscapes, and public spaces, intending to safeguard ecosystem values and functions while providing benefits to humanity [13]. The 2009 report "Green Infrastructure: Connected and Multifunctional Landscapes" asserted that GI should be considered a form of land use rooted in the concept of ecosystem services. It emphasized that GI facilities of various scales should not be limited to serving a single function and introduced the crucial idea that connectivity and versatility distinguish GI from traditional landscape planning and management [16].

In summary, these scholars' perspectives on GI can be distilled into three key points: 1. Emphasizing the interconnectedness of humanity and the environment, integrating nature into human communities, and seeking a balance that addresses both ecological and human-centric concerns. 2. Exploring how GI concepts and methods can be further examined and implemented. 3. Stressing multifunctionality, denotes the ability to provide multiple functions and benefits within the same spatial scale, highlighting the diverse advantages of multifunctional networks. In other words, if these interpretations of GI can be translated into practical applications in urban planning, it becomes possible to some extent to realize the development goals of the five cities mentioned in response to public health crises.

Considering that the establishment of Green Infrastructure Networks (GIN) within urban areas can partially contribute to achieving urban development objectives, how to ensure that GIN construction aligns with these developmental goals? This research will delve into the assessment of GIN, addressing two key questions: Why is it necessary to evaluate green infrastructure, and how can such an assessment be conducted?

2.2. *The significance of evaluating GIN*

Many Chinese cities are grappling with issues such as landscape fragmentation, decreased urban green space, biodiversity loss, and environmental pollution due to rapid urbanization [17]. In the context of China's current territorial spatial planning system, which aims to build an ecological civilization, assessing GIN can offer an objective understanding of regional ecological conditions, safeguard territorial ecological security, and enhance the development of ecological networks [18]. Employing various GIN evaluation methods can guide the construction of urban GIN, fostering multifunctional-oriented urban GIN, which is a future research direction [19]. Notably, T. Weber in the United States introduced a specific GIN assessment system (GIA) for Maryland, which the state government recognized and applied, contributing to ecological environment protection [20]. In 2009, Chinese scholars Fu and Wu conducted a case study on Weber's GIA, highlighting its practical value in China's rapid urbanization stage, where GIN evaluation helps protect urban green spaces, farmland, and forests efficiently. China should establish a GIN evaluation system at various spatial levels, from provinces to villages, to enhance ecological protection [21]. Moreover, GIN assessment in China supports the government's ecological civilization construction, improving GIN construction, investment, and urban problem management [22]. Thus, supervising and evaluating GIN construction is crucial.

In summary, the importance of evaluating GIN construction includes: 1. Developing an objective understanding of GIN. 2. Guiding future GIN construction based on evaluation results. 3. Enhancing policy formulation and problem-solving efficiency. 4. Protecting urban green spaces for the ecosystem. Furthermore, different scholars use various criteria for GIN evaluation, leading to some confusion in evaluation standards. Therefore, the criteria for evaluating GIN in this study will be determined in the next stage of research.

2.3. *The standards for evaluating GIN*

Currently, there is no fixed standard for GIN evaluation, resulting in high diversity. Weber, in the evaluation of GIN in Maryland from 2004 to 2006, analyzed core areas and connections, serving as a basis for GIN improvement [20]. In 2013, Qiu Yao evaluated GIN in Shenzhen based on spatial components, graded core areas and connections, and conducted a comprehensive classification [23]. Wang Jieqiong in 2015 established an evaluation method with ecological services as the core value to optimize and guide GIN construction in cities [24]. In 2017, Li Yonghua graded the ecological characteristics of GIN in Hangzhou and proposed spatial control measures for ecological protection [25]. Wu Yinpeng in 2017 constructed a grading system for the importance of GIN's core areas and connections, clarifying their significance and spatial distribution [26]. In 2019, Xie Yusong classified the functions of various green spaces in GIN during the evaluation of city-scale GIN, offering a theoretical basis for optimizing the urban landscape pattern [18].

In general, the evaluation criteria for GIN include 1. Analysis and evaluation based on spatial form, dividing it into core areas and connections. 2. Analysis and evaluation considering ecological characteristics. 3. Analysis and evaluation of the landscape function of GIN components. These three criteria share similarities, focusing on the spatial structure centred around GIN core regions. The core region is crucial for ecosystem services, as highlighted by Zhu in 2020, where larger core areas offer more effective ecosystem services [27]. Notably, habitat fragmentation in urban areas, as discussed by most scholars, results from the lack of connectivity between GIN core regions [25-26]. Optimizing the spatial structure of GIN can mitigate and enhance the consensus on 5-point urban planning. Therefore, this research will adopt the spatial structure of GIN as the assessment criterion, with a particular emphasis on the GIN core region and its connectivity.

2.4. The methods for evaluating GIN

Weber employed the Green Infrastructure Assessment (GIA) methodology from 2004 to 2006, utilizing landscape ecology and conservation biology principles alongside GIS and spatial data analysis to examine the spatial structure of GIN [20]. In 2013, Qiu Yao combined Morphological Spatial Pattern Analysis (MSPA) with connectivity analysis to analyze the spatial structure of GIN [23]. Kang applied MSPA for spatiotemporal quantitative analysis of GI in the Seoul metropolitan area, demonstrating its usefulness in developing protection strategies and enhancing environmental protection value assessment maps [28]. Yang Zhiguang used MSPA to identify the core ecological areas in Guangzhou and constructed an ecological corridor network with the Minimum Cumulative Resistance (MCR) model, proposing optimization measures for the ecological network [29]. Chen Zhu-an integrated MSPA and MCR models to identify potential ecological source areas and corridors in the landscape, offering guidance for ecological network construction in Yujiang County and serving as a reference for other regions [30].

It's worth noting that MSPA often complements other analytical techniques to comprehensively analyze and assess GIN spatial structures. This combination enhances the depth of GIN analysis. The analysis of GIN spatial structures using MSPA is not limited to a single time point; it also involves comparative assessments at different times to understand construction trends and develop a more comprehensive understanding of GIN.

In 2020, Pan Mei and other scholars primarily focused on GIN component functions when examining the Beijing-Tianjin-Hebei region's GIN. They chronologically analyzed various functional types of GIN components to reveal the evolving trajectory of GIN functionality, laying the groundwork for future GIN development [31]. Several scholars have conducted time series analyses of GIN, providing insights into temporal changes in GIN spatial structures, which inform future research and development of the GIN at the study site [32-36]. In essence, using MSPA to analyze historical remote sensing imagery enables planners to gain a comprehensive understanding of the developmental trends in the GIN spatial structure of that area.

To summarize, before the advent of MSPA, GIS was the primary method for spatial analysis of GIN. After 2009, MSPA became the predominant method. According to a review of 28 articles worldwide that used MSPA as a method and GIN as a research object, 50% of them employed MSPA to evaluate GI components, while 10.7% combined MSPA with connectivity analysis. In other words, approximately 60% of the articles that used MSPA as a research method evaluated the spatial structure of GIN. These pieces of evidence demonstrate that MSPA is the mainstream method for studying GIN and underscore its relevance to the analysis of GIN spatial structures. However, as observed in the literature review, MSPA often requires supplementation with other tools to conduct a comprehensive analysis and evaluation of GIN's spatial structure.

3. Conclusion and perspective

In conclusion, this study takes the outbreak of COVID-19 in cities as the entry point and reflects on urban public health events from the perspective of urban planning. Based on the five-point consensus on the development direction of urban response to public health events formed by current scholars, this study points out that these five points of consensus can be satisfied through ES, and the function of ES requires GIN as a physical space carrier. To enable GIN to effectively achieve the five-point consensus of urban development under the formulation of planning policies, the evaluation of GIN is further studied in this study. By analyzing the importance of GIN evaluation, this study found that the emphasis of evaluation lies in the determination of evaluation criteria. Through the analysis of GIN evaluation criteria, this study found that the core and connectivity of GIN became the focus of GIN evaluation. By analyzing GIN core and connectivity analysis methods, this study found that MSPA became the mainstream analysis method.

Looking forward to the future, in the analysis and research of urban GIN, MSPA can provide both quantitative and qualitative geographical information scientific basis for the formulation of urban planning policies through the analysis of GIN in various cities, on top of this, MSPA analysis can

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analyze the same research area based on the same time interval. Thus, the spatial and temporal pattern analysis of urban GIN based on MSPA is formed. Based on this spatio-temporal analysis, the spatio-temporal changes of GIN core area and connectivity can be analyzed separately in the process of specific data processing, and these two types of elements can be graded, to provide a quantitative basis for judging the construction priority in the process of urban planning policy formulation, and improve the efficiency of realizing ES through urban planning.

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