Advances in the blue-green space evaluation index system

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Abstract

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Abstract : Blue-green spaces composed of water and green spaces have certain ecological, economic, and social benefits for urban development. Many evaluation index systems have been developed to evaluate the health status of urban ecosystems. However, in these evaluation index systems, blue and green spaces are separately evaluated without considering the synergistic effect between water and green spaces in the ecosystem, thus affecting the unified planning and construction of cities. Therefore, based on existing studies, the development process of the blue-green space evaluation index system is divided into three stages: supply service evaluation stage, adjustment service evaluation stage, and cultural service evaluation stage in order to deeply discuss the development path of the blue-green space evaluation index system. The single blue and green evaluation index systems are compared from the perspectives of index selection and evaluation content. Moreover, the characteristics of conventional evaluation methods are discussed in order to propose an applicable evaluation index system and evaluation method of blue-green spaces for evaluating the degree of blue-green integration of cities. The review provides the basis for urban planning and ecological restoration.

Key words : blue-green space; evaluation index system; ecological service function; water body; green space.

1. Introduction

In the process of rapid urban development, social problems (too high urban population density, and aging urban population), environmental problems (urban heat island effect), and mental health problems (depression) gradually occur. Due to the rapid economic development and the increase in living pressure, these problems gradually become prominent and inhibit the construction of urban ecological civilization and the improvement in resident happiness. At the beginning of the 19th century, western countries began to construct urban spaces with health as the premise in order to deal with environmental degradation and public health threats (Corburn, 2004). The exposure to the natural environment (including water bodies and green spaces) can improve people's mental health (Wentworth, 2017) and the natural environment plays a significant role in promoting urban environmental health (Weng and Yang, 2004) and social development (van den Berg *et al.* , 2015). As an "organic aggregate" composed of water and green spaces, the blue-green space has gradually attracted the attention of scholars due to its benefits in ecology, economy, and mental health, and many related theoretical achievements have been obtained. After the construction of "Emerald Necklace" Greenway Park in Boston in the 1910s (Blackmar *et al.* , 1997) , the development of green channel planning (Benedict and Mcmahon, 2006), low-impact development (Grant and Tsenkova, 2012), water-sensitive city (Wong and Brown, 2009), resilient city (Bengtsson *et al.* , 2007), sponge city and other related concepts has highlighted the key role of blue-green spaces in urban planning and design.

A blue-green space is a space with a clear water body that is covered by plants or maintains natural features and can be directly touched or perceived (Leng *et al.* , 2021). In other words, blue includes all natural and artificial water bodies such as rivers, lakes, reservoirs, and wetlands and green includes mountains, woodlands, farmlands, grasslands, ecological corridors, green spaces in parks, residential green spaces, protective green belts, woodlands, nature reserves, and other areas covered by vegetation. Domestic and foreign scholars found that blue-green spaces had more significant ecological, economic, and mental health benefits than single water bodies and green spaces. Ecologically, the synergy between water and green spaces in the ecosystem endows the blue-green space with a significant cooling effect, namely, the Urban Cold Island (UCI) effect, which can effectively alleviate the Urban Heat Island (UHI) effect (Santamouris *et al.* , 2011). Blue-green spaces can provide enough habitat for organisms, purify the air, and reduce noise and carbon storage, thus greatly promoting biodiversity and ecosystem stability (Maller *et al.* , 2005). Economically, compared to cool materials, urban blue-green spaces have the advantages of low cost, environmental friendliness and political acceptability (Hamada and Ohta, 2010; Carvalho *et al.* , 2017). In addition, the applications of sustainable drainage systems (SuDS) and green infrastructure (GI) can better improve urban drainage efficiency, and promote economic growth (Andrew, 2017). Moreover, natural exposure has direct or indirect positive effects on mental health, including perceived recovery (Kaplan, 1995), stress relief (Ulrich *et al.* , 1991), and mood improvement (White *et al.* , 2017).

In the 1990s, ecosystem health became a new goal in regional environmental management (Costanza and Norton, 1992). The health assessment of water and green space ecosystems has been concerned among many organizations and scholars and has become the core content of the current comprehensive assessment of ecosystems. As a composite ecosystem composed of water body and green space, the blue-green space has a more complex spatial structure and diverse ecological functions. The traditional single water body or green space evaluation index system cannot be simply applied in the evaluation of a blue-green space. Therefore, in this paper, relevant studies on the evaluation system of blue-green space indices are summarized in order to discuss the selection of evaluation indices in blue space, green space and blue-green space. Moreover, different evaluation methods are analyzed in order to propose an evaluation index system and an evaluation method suitable for blue-green spaces based on existing studies. The results provide the basis for the evaluation of the degree of urban blue-green integration, urban planning, and ecological restoration.

2. Necessity for establishing a blue-green space evaluation index system

2.1. Multiple benefits of blue-green spaces

Urban green space and water bodies have multiple functions and can meet the diverse requirements of urban development, such as human-centered, organism-centered, and economic construction-centered functions. Among these functions, anthropocentric functions mainly include health functions, entertainment functions, etc. Organism-centered functions are mainly ecological service functions, such as habitat provision, climate control, and pollution control(Rehachova and Pauditsova, 2004). Economic construction-centered functions include increasing urban and resident wealth (Chiesura, 2004). These functions are classified into three aspects: ecological, mental health, and economic benefits.

2.1.1. Ecological benefits

Due to the accelerated urbanization process and dense urban buildings, the local temperature, humidity, air convection and other factors of the urban surface have been artificially changed, thus causing the change in urban microclimate (Xu *et al.* , 2019). Many researchers investigated the distribution pattern of the UHI effect (Peng *et al.* , 2016), and the relationships between air temperature (Qiu *et al.* , 2017), land surface temperature (Yu, 2018), and land cover (Gao*et al.* , 2019), and their correlation with ecosystem service values (Anjos and Lopes, 2017) and found that urban green space and water bodies had a good UCI effect.

A blue space, as a low-temperature corridor, can effectively alleviate the UHI effect. The shape and contour of water bodies are the main factors affecting UCI (Dai and Yao, 2021). Due to the unique continuity, linear waters can effectively divide the aggregation status of heat islands, block the regional expansion of the UHI effect, and provide heat dissipation channels for heat exchange between the internal and external parts of urban heat islands (Cheng *et al.* , 2019). Through the physical effect of water evaporation, a surface water body can reduce the temperature of the heat island area well and the closer it is to the center of the urban heat island, the stronger the cooling effect is (Yue and Xu, 2013).

As a natural underlying surface for climate regulation, a green space provides a city with ecosystem services maintaining biodiversity and regulating the urban climate. Vegetation coverage, planting structure, and width of green space affect the UCI effect (Anjos and Lopes, 2017; Yang *et al.* , 2017), and can strengthen the temperature effect in the horizontal direction of the water body. Compared with densely built asphalt roads and concrete roads, a green space has a faster heat absorption rate and a smaller specific heat capacity (Lo *et al.* , 1997). Good physical shading can reduce the leaf surface temperature and transpiration can prevent the air temperature from rising (Kobayashi H, 2005), thus alleviating the UHI effect.

Some scholars studied the relationship between green spaces and the cooling effect of water and found that there was a nonlinear relationship between green space vegetation coverage and the cooling effect of water. In addition, the type of vegetation coverage also affects the cooling effect of water (Table 1). Green spaces and water bodies have a synergistic effect in reducing the ambient temperature and their cooling effects on the surrounding environment are mutually influenced (Robitu *et al.* , 2006; Wu *et al.* , 2018). Therefore, in a limited urban area, the UCI effect can be maximized by constructing a blue-green space in order to promote the development of a city (Montazeri *et al.* , 2017). A blue-green space can provide the habitat to maintain biodiversity and regulate urban climate, displaying its ecological service function as a composite ecosystem.

2.1.2. Mental health benefits

Blue-green spaces can provide good social benefits and greatly affect the livability of modern cities and the well-being of urban residents. The frequency of exposure to the natural environment and vegetation coverage may be important for improving human well-being, especially mental health (Wentworth, 2017). The exposure to the natural environment can increase social cohesion (Kaczynski and Henderson, 2007), reduce stress, improve attention, relieve fatigue (Grigsby-Toussaint *et al.* , 2015), improve mood, and decrease the symptoms of major depressive disorders (Hartig *et al.* , 2014). For example, a good park environment has the functions of attention recovery and stress relief effects (Tan and Li, 2009). Blue-green spaces are associated with children's cognitive development, inhibition of impulsive behavior, prosociality enhancement, and stimulation of imagination and creativity (Dadvand *et al.* , 2015; McCormick, 2017). There is a significant correlation between urban blue-green space and depression in the elderly (Helbich *et al.* , 2019). In 2021, World Health Organization (WHO) released a survey report on blue-green spaces and mental health. The short-term and long-term effects of different types of green spaces and blue spaces on mental health (Table 2) demonstrated the overall positive relationship between blue-green spaces and mental health. Especially, under the background of COVID-19 pandemic, blue-green spaces can serve as a sanctuary for interactive leisure.

2.1.3. Economic benefits

The economic benefits of blue-green spaces are introduced in two aspects. Firstly, a blue-green space can provide a good landscape for a city, increase the attractiveness of the city, promote the development of tourism, and increase the value of real estate in the city. It promotes the productivity of citizens and the growth of urban economy. The beautiful landscape of Singapore and Kuala Lumpur, Malaysia is one of the factors that attract a lot of foreign investment, enhance the property value and increase the financial return of land developers by 5% to 15% depending on the type of a project (Heidt and Neef, 2002). Secondly, green buildings or infrastructure in blue-green spaces, mainly including GI, provides better facilities and entertainment opportunities for human beings in addition to habitats (Ashley, 2017).With vegetation features on the ground, such as swamps, cisterns and rain gardens, based on natural drainage processes SuDS/GI facilities fully integrate the ecological benefits of water bodies and green spaces, promote ecosystem services and improve the efficiency of urban drainage systems and the economic development (van den Berg *et al.* , 2015). In addition, the blue-green space has the benefit of UHI reduction and can reduce energy consumption. A Chicago study showed that increasing tree coverage by 10% in a city could reduce total energy required for heating and cooling by 5% to 10% (Sorensen *et al.* , 1997). Therefore, the development of urban blue-green spaces may be a better solution than cool materials (Carvalho *et al.* , 2017).

2.2. Lack of practical basis

A blue-green space is a measure of social environment, economy, and health and closely related to the happiness and satisfaction of urban residents. At present, many evaluation index systems of urban water body and green space have been developed as the basis for evaluating urban health and urban ecological civilization and have promoted the construction of blue-green spaces. In existing studies, water bodies and green spaces were separately evaluated without considering the coordinated planning and comprehensive urban ecosystems. In addition, without enough reliable and comprehensive indices, it is impossible to evaluate the spatial structure and ecological functions of blue-green spaces. In addition, water conservancy, greening, and landscape departments have different planning functions, so the separate construction of water body and green space have resulted in many problems. such as blue-green division. Natural hydrological conditions, land-water interlaced zones, or the connectivity of urban water-green corridors is not considered, thus affecting the integrated construction of urban blue-green spaces and severely limiting the quality of the constructed urban ecological environment. Therefore, it is particularly important to determine the appropriate evaluation indices and evaluation criteria based on previous studies and establish a scientific index system and an evaluation method to evaluate the degree of blue-green integration in urban planning.

3. Evaluation index systems of blue-green spaces

In the process of rapid urban development, some problems such as the destruction of ecological balance inevitably existed due to imbalanced planning, thus eventually leading to urban sub-health of a city. Therefore, the "symptoms" and "causes" of urban environmental problems are often explored by constructing an evaluation index system, in order to obtain suitable countermeasures for urban restoration and subsequent ecological restoration. Therefore, the construction of cities has experienced the following transformation stages: the initial stage focusing on water bodies and green spaces for the purpose of providing the material basis for human beings, the second stage of providing the ecological functions of climate regulation, and the third stage focusing on the cultural and support benefits. In more urban planning, economic construction has shifted to people-centered construction and the happiness and satisfaction of urban residents are increasingly considered. The evaluation index system of blue-green spaces has also developed (Table 3).

3.1. Evaluation of supply services

After World War II, in order to quickly restore urban economy, the process of urbanization has been accelerated. Humans are eager to obtain materials from the nature and accumulate resources, thus leading to serious environmental problems such as sharp decline in biodiversity, river pollution, and green space destruction. Governments and some scholars of various countries have begun to pay attention to environmental quality in order to provide sustainable supply resources for urban development through restoring water bodies and green spaces. River health evaluation index systems and green space health evaluation systems have been successively established.

In 1981, based on the concept that a good water ecosystem must have a perfect biological community structure, with the biological integrity index (IBI) was first proposed for evaluating the quality of water environments. After 16 indices of species composition were quantified, including the indices of nutritional structure and individual health status, the water environment quality was divided into 6 levels according to the characteristics of biological integrity (Karr, 1991). In 1984, the River Invertebrate Prediction and Classification Project (RIVP-ACS) was proposed (Wright *et al.* , 1998) to predict the biomass of macroinvertebrates in a river without any human disturbance with different characteristics of various areas and then the predicted biomass value was compared with the actual monitored value of macroinvertebrates in the river to evaluate the health status of the river. In 1994, the Australian River Evaluation Program (AUSRIVAS) (Simpson *et al.* , 1999) was proposed to predict the theoretical biomass in a river with the hydrological indices (habitat structure, water flow state, and continuity), physical and chemical parameters, indices of invertebrates and fish aggregates, water quality indices, and ecotoxicological indices.

In general, the evaluation based on these indices can obtain intuitive results. The obtained biomass reflects the available resource from a water body, and provides the basis for subsequent fishing or protection. In these evaluation systems, only the changes in biomass in water bodies, especially invertebrate biomass, are considered, but whether invertebrates are index species for the habitat is not considered. Therefore, these systems cannot accurately reflect the stress on river ecosystems.

In green space evaluation, the symptoms of land diseases can be evaluated with key indices such as erosion, fertility loss, hydrological anomalies, infrequent outbreaks or inexplicable local extinctions of certain species, and degradation of agricultural products and forestry products (Carmony, 1992). However, due to the economic development, both greening construction and environmental protection should be considered equally. Green coverage rate, green space rate, and park area per capita should be introduced to the evaluation index system so as to improve evaluation results (Zhang, 2010). Existing green space evaluation index systems often only focus on the quantity of green spaces and ignore the quality of green spaces, so they cannot meet the requirements for building a high-quality ecological city in the new era. Therefore, in the future subsequent evaluation system, quantitative and qualitative indices of water bodies and green spaces should be selected and the interaction between water bodies and green spaces should be comprehensively considered to reflect the complex structure and functions of the blue-green fusion space.

3.2. Evaluation of regulation services

After a city enters the stable development stage, heat island effect, environmental pollution, too high urban population density, and poor social health, threatened safety and other social problems have gradually emerged. Due to the destroyed urban natural environment, the influences of the natural environment on human survival, life, and production are widely concerned. Therefore, the benefits of urban water bodies and green spaces have been extensively explored in order to arouse public awareness of nature protection. Subsequently, relevant evaluation index systems were established to evaluate the environmental loss and develop a reasonable and targeted restoration plan based on the key impact indices. Therefore, the targets of evaluation index systems were gradually changed from ecosystem supply services to regulation services (Table 3).

The regulation services of an urban ecosystem involve four aspects: hydrology, ecology, environment, and society. The evaluation indices of the regulation services of urban rivers and lakes involve the elements of six aspects: hydrological characteristics, water environment quality, structure and function of water ecosystems, waterfront spatial structure, landscape effect, and stress factors (Zhang *et al.* , 2005). The indices that fully reflect the pressure, state, and response of river basins, such as population density, annual GDP growth rate, water resources per capita, annual rainfall, forest coverage, and industrial wastewater treatment rate, should be selected to evaluate the health status of ecosystems (Yan *et al.* , 2008). In addition, the wind environment, light environment, building and surrounding environment can be selected to comprehensively evaluate the greening development potential and quantitatively analyze the cooling characteristics and cooling efficiency of vertical greening (Shi, 2018). In Wetland Ecosystem Health Evaluation Index System proposed by the Wetland Conservation and Management Center of the State Forestry Administration, the health status of wetland ecosystems should be evaluated in five aspects: water environment, soil, biology, landscape, and society (Qian *et al.* , 2016).

These evaluation systems comprehensively consider the ecological service functions of water bodies and green spaces in urban ecosystems for regulating climate and preventing floods, and can analyze the factors affecting the stability of urban ecosystems based on specific functional indices and evaluation results. The comprehensive evaluation based on water, soil, land, atmosphere reflects the interaction between various natural elements, so that the environmental problems can be explored and the health conditions of ecosystems can be judged by evaluation results for ecosystem restoration. Due to the enhanced awareness of ecological civilization and natural restoration in urban planning, the comprehensive evaluation of water bodies and green spaces is significant. In the comprehensive evaluation, some characteristic indices are integrated together to reflect the interaction between them and the characteristics of the urban blue-green space as a composite ecosystem and improve the evaluation system.

3.3. Evaluation of cultural services

The Declaration on the Human Environment issued in 1972 emphasized the relationship between development and protection from the perspective of environmental protection. Subsequently, many countries started large-scale ecological restoration and urban ecosystem restoration in order to provide a happy living environment for urban residents through building a healthy ecosystem. Ecosystem health initially meant that the organization of the ecosystem was not damaged or weakened, and had a certain restoration ability (Costanza and Norton, 1992). Then, in the concept of ecosystem health, human health factors were introduced. It was believed that ecosystem health depended on the judgment by the whole social system, so human welfare should be considered. Therefore, more researchers focused on the urban development and residents' perception of urban blue-green spaces and gradually emphasized cultural services supplied by blue-green spaces, including aesthetics, landscape, and mental health benefits (Table 3).

Xia Jihong (Xia, 2005) believed that an ecological riparian zone was a dynamic open water-land interlaced ecosystem, established a set of comprehensive evaluation index system for riparian ecosystem, and expounded the evaluation method of an ecological riparian zone from four perspectives, including structural stability, landscape suitability, ecological health, and safety. On this basis of the above system, ecological characteristic indices such as strong self-healing ability were introduced to carry out health evaluation of urban lakes and provide a theoretical basis for ecological restoration, planning, and construction of urban lakes (Wu *et al.* , 2020). According to the development characteristics of urban waterfront space, in order to build a modern economic-ecological-social city, ten principles of waterfront vitality were proposed and mainly involve ecological indices, public indices, full-time indices, accessible indices, hydrophilic indices, permeable indices, economic indices, mixed indices, sign indices, life indices and other indices (Zhang, 2009). A slow-travel-friendly waterfront strip park space evaluation system and scoring criteria were also established based on analytic hierarchy process (AHP), so that the friendliness of waterfront parks could be evaluated from three aspects: slow-travel paths, slow-travel facilities, and slow-travel landscapes (Zhong *et al.* , 2021).

In the history of the blue-green space evaluation index system, the evaluation indices have been gradually expanded from biological indices to habitat indices and human-related ecological service indices. The above history was basically consistent with the stages of urban development. Urban development has experienced the initial agricultural society, to industrial society and information society. Therefore, the demands for the environment has changed from material supply to habitat provision and cultural services. Therefore, the later blue-green space evaluation index systems retained the previous key indices that had an impact on ecological restoration and contained some relevant indices that were in line with the vitality of modern society, thus emphasizing the influence of the integrated natural ecosystem in blue-green spaces on ecological service function and urban development potential. The later system provided the basis for urban planning. In the future blue-green space evaluation index system, based on the concept of economic-society-ecological integration, the benefits of water bodies and green spaces related to social development and human well-being should be comprehensively considered. Qualitative and quantitative indices make the evaluation results more accurate and can better reflect the quality of a blue-green space (Table 3).

4. Evaluation methods

Many evaluation methods for urban water bodies and green spaces are available, including AHP, principal component analysis (PCA), fuzzy comprehensive evaluation method (FCED), cluster analysis (CA), etc. Each method has its own advantages and disadvantages and is suitable for different evaluation objectives. According to the complexity of evaluation calculation and evaluation objects, evaluation methods can be divided into general evaluation methods and comprehensive evaluation methods. General evaluation methods include AHP and PCA. Comprehensive evaluation methods are obtained introducing the membership degree of fuzzy mathematics and the grayscale concept of gray system theory and include FCED and CA.

4.1. General evaluation method

In AHP, with a system as the research object, the influence of each factor in each level on the results is quantified. The evaluation method is characterized by clear logic, simplicity, and practicality and can be used for the systematic evaluation of unstructured characteristics and multi-objective, multi-criteria, and multi-period systematic evaluation. However, the evaluation method requires a large quantity of statistical data and faces the difficulty in determining the weight. In addition, the exact calculation methods of eigenvalues and eigenvectors required in AHP are complicated.

In PCA, original complex variables are transformed into several comprehensive variables for analysis. Factor analysis requires sample size and does not fully consider the relative importance of the indices themselves.

As traditional evaluation methods, both AHP and PCA have the advantages of clear logic, simplicity, and practicality, and are suitable for evaluating the systems with simple structures and clear hierarchical relationships. As a composite ecosystem composed of water and green spaces, the complex blue-green space may lead to its higher ecological carrying capacity and stronger vitality. Therefore, a hierarchical structure model can be established with AHP and the ecological carrying capacity of blue-green space can be comprehensively evaluated from two aspects of ecological support and environmental pressure (Zhao *et al.* , 2020). The main factors affecting the vitality of blue-green spaces can be analyzed with PCA. Although general evaluation methods have a clear hierarchy, the weight determination process is subjective and requires excessive calculation, thus affecting the accuracy of evaluation results. Therefore, in the future, the basic evaluation methods can be combined to improve evaluation results.

4.2. Comprehensive evaluation method

In FCED, some uncertain problems are determined according to the basic theory of fuzzy mathematics and the principle of fuzzy relationship. The evaluation results are more accurate, but the difficulty in weight determination and the ambiguous statistical interrelationships between indices also affect the evaluation process.

In CA, according to the principle of “type-clustering”, similar data are acquired for the purpose of analyzing the inherent characteristics and laws of things. The analysis process of CA is simple and intuitive, but it requires a sample size, which increases the difficulty in obtaining the clustering conclusion.

Through the improvement in basic evaluation methods, many comprehensive evaluation methods are gradually obtained. These evaluation methods can avoid excessive subjective influences and improve the accuracy of results. The analysis process is relatively simple and applicable to many problems. In the evaluation process of blue-green spaces, it is necessary to comprehensively consider its ecological background status, local social and economic conditions, residents' experiences and feelings. Index selection and weight determination should be based on expert consultation and AHP, so the subjective factors affect the accuracy of evaluation results. Without comparison results, the rationality of evaluation results cannot be verified. Therefore, the AHP can be combined with the fuzzy evaluation method or the CA in order to improve evaluation results. In the future, according to the structures and functions of evaluation objects, based on the existing evaluation methods, combined evaluation methods can be used. In addition, more practical and convenient evaluation methods can be developed.

5. Conclusions and Outlook

Due to rapid urban development, the environmental hotspot has changed from initial supply services to the later regulation function, and then to the current cultural service function. Urban development has gradually shifted from the initial orientation to economic construction to people-oriented development. The blue-green space system, in which water bodies and green spaces are intertwined and continuously integrated, can promote the sustainable development of urban natural systems, the construction of livable cities, and the improvement in urban vitality. In the review, the development process of the blue-green space evaluation index system is summarized because of previous studies. The relationships between water bodies, green spaces, and blue-green spaces and the complex structures and functions of blue-green spaces are analyzed as a composite ecosystem in order to provide the basis for subsequent blue-green space planning.

In existing studies on blue-green spaces, blue spaces and green spaces are separately evaluated and a combined evaluation index system for blue-green spaces is not available. The suggestions are provided as follows:

1) The indices of water bodies and green spaces should be comprehensively considered, in order to evaluate the blue-green space. The blue-green space is a complex system composed of water and green spaces. The mutual influence between water and green spaces form ecological service functions, unlike that in a single water body or a green space. Therefore, in the evaluation of a blue-green space, it is necessary to select indices considering water and green spaces for comprehensive evaluation.

2) People-oriented urban construction is significant. Urban blue-green spaces have environmental landscape functions and ecological service benefits and provide residents with space for recreational activities, thereby increasing residents' physical activities, promoting social interaction and integration, and bringing positive effects to the public's physical and mental health. In other words, the construction quality of blue-green spaces is closely related to the happiness and quality of life of urban residents. Therefore, the selection of indices should reflect the ecological service function or social function for human beings.

3) Multi-scale and periodic evaluation are recommended. According to the size of the range, blue-green spaces can be classified into large blue-green spaces and micro blue-green spaces. According to different scales of evaluation objects, a multi-scale evaluation index system with the hierarchy of "city-district-community-people" can be constructed to cover the macroscopic whole area and an individual. In addition, the constructed evaluation index system should be based on the overall planning of urban and rural areas and the "people-oriented" planning idea. It is necessary to improve the supervision mechanism and establish a periodic evaluation system. Long-term monitoring and evaluation can provide the basis for improving urban planning quality and subsequent construction.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work report in this paper.

CRediT Authorship Contribution Statement

Z-M. Z. and Y-J. Z. conceived the ideas, designed and funded this study; X-X. J., X L. and Z-F. W. collected the data; X-X. J. led the writing of the manuscript; Z-M. Z. wrote-review and edited the paper. All authors contributed critically to the drafts and gave final approval for publication.

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References:

Andrew, R.F.(2017). Spatial Evaluation of Multiple Benefits to Encourage Multi-Functional Design of Sustainable Drainage in Blue-Green Cities. Water 9, 953.*https://doi.org/10.3390/w9120953*

Anjos, M., Lopes, A.(2017). Urban Heat Island and Park Cool Island Intensities in the Coastal City of Aracaju, North-Eastern Brazil. Sustainability 9, 1379. *https://doi.org/10.3390/su9081379*

Ashley, R.H., Digman, C., Gersonius, B., Shaffer, P., Bayliss, A., Bacchin, T.(2017). It's not drainage anymore: It's too valuable. In Proceedings of the 14th IWA/IAHR International Conference on Urban Drainage, Prague, Czech Republic.

Benedict, M.A., Mcmahon, E.T.(2006). Green Infrastructure: Linking Landscapes and Communities. Island Press, Washington, D.C., USA.

Bengtsson, J., Hargreaves, R., Page, I.C.(2007). Assessment of the Need to Adapt Buildings in New Zealand to the Impacts of Climate Change.

Blackmar, E., Schuyler, D., Beveridge, C., Rocheleau, P., Larkin. D.(1997). Frederick Law Olmsted: Designing the American Landscape.

Bolund, P., Hunhammar, S.(1999). Ecosystem services in urban areas. Ecol. Econ. 29, 293-301.*https://doi.org/10.1016/S0921-8009(99)00013-0*

Carvalho, D., Martins, H., Marta-Almeida, M., Rocha, A., Borrego, C.(2017). Urban resilience to future urban heatwaves under a climate change scenario: A case study for Porto urban area (Portugal). Urban Climate 19, 1-27. *https://doi.org/10.1016/j.uclim.2016.11.005*

Cheng, L., Guan, D., Zhou, L., Zhao, Z., Zhou, J.(2019). Urban cooling island effect of main river on a landscape scale in Chongqing, China. Sustainable Cities Soc. 47, 101501.*https://doi.org/10.1016/j.scs.2019.101501*

Chiesura, A.(2004). The role of urban parks for the sustainable city. Landsc. Urban Plann. 68, 129-138.*https://doi.org/10.1016/j.landurbplan.2003.08.003*

Corburn, J.(2004). Confronting the challenges in reconnecting urban planning and public health. Am. J. Public Health 94, 541-546.

https://doi.org/10.2105/ajph.94.4.541

Costanza, R., Norton, B.G.(1992). Ecosystem Health: New Goals for Environmental Management. first ed. Washington D.C.

Dadvand, P., Nieuwenhuijsen, M. J., Esnaola, M., Forns, J., Basagana, X., Alvarez-Pedrerol, M., Rivas, I., Lopez-Vicente, M., De Castro Pascual, M., Su, J., Jerrett, M., Querol, X., Sunyer, J.(2015). Green spaces and cognitive development in primary schoolchildren. Proc. Natl. Acad. Sci. U.S.A. 112, 7937-7942.

https://doi.org/10.1073/pnas.1503402112

Dai, Y. Q., Yao, Y. X.(2021). The exploration and study of ecological indicator species in the planning of blue-green space in Shanghai. Water Resour. Plan. Des., 12, 18-22.

Flader, S. L., Clicottal, J. B.(1991). The river of the mother of God and other essays by Aldo Leopold. Wisconsin, U.S.A.

Gao, J., Yu, Z., Wang, L., Vejre, H.(2019). Suitability of regional development based on ecosystem service benefits and losses: A case study of the Yangtze River Delta urban agglomeration, China. Ecological Indicators 107, 105579.*https://doi.org/10.1016/j.ecolind.2019.105579*

Grant, J. L., Tsenkova, S.(2012). New Urbanism and Smart Growth Movements. Elsevier, San Diego.

Grigsby-Toussaint, D. S., Turi, K. N., Krupa, M., Williams, N. J., Pandi-Perumal, S. R., Jean-Louis, G.(2015). Sleep insufficiency and the natural environment: Results from the US Behavioral Risk Factor Surveillance System survey. Prevention Med. 78, 78-84.*https://doi.org/10.1016/j.ypmed.2015.07.011*

Hamada, S., Ohta, T.(2010). Seasonal variations in the cooling effect of urban green areas on surrounding urban areas. Urban For. Urban Green. 9, 15-24.*https://doi.org/10.1016/j.ufug.2009.10.002*

Hartig, T., Mitchell, R., de Vries, S., Frumkin, H.(2014). Nature and Health. Annu. Rev. Public Health 35, 207-228.

Heidt, V., Neef, M.(2002). Benefits of urban green space for improving urban climate. International Symposium on Urban Forestry and Eco-Cities, Shanghai, P.R. China, pp. 84-96.

https://doi.org/10.1007/978-0-387-71425-7_6

Helbich, M., Yao, Y., Liu, Y., Zhang, J., Liu, P., Wang, R.(2019). Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. Environ. Int. 126, 107-117.

Kaczynski, A. T., Henderson, K. A.(2007). Environmental correlates of physical activity: A review of evidence about parks and recreation. Leisure Sci. 29, 315-354. https://doi.org/10.1080/01490400701394865

Kaplan, S.(1995). The restorative benefits of nature: Toward an integrative framework. J. Environ. Psychol. 15, 169-182.*https://doi.org/10.1016/0272-4944(95)90001-2*

Karr, J. R.(1991). Biological Integrity: A Long-Neglected Aspect of Water Resource Management. Ecol. Appl. Publ. Ecol. Soc. Am. 1, 66-84.

https://doi.org/10.2307/1941848

Kobayashi, H., T. K.(2005). The use of urban green spaces to improve the thermal environment. World Sustainable Building Conference, Tokyo, Japan.

Leng, H., Yan, T. J., Yuan, Q.(2021). Research progress and enlightenment of mental health effects of blue-green space. Urban Plan. Int., 1-18.

Lo, C. P., Quattrochi, D. A., Luvall, J. C.(1997). Application of high-resolution thermal infrared remote sensing and GIS to assess the urban heat island effect. Int. J. Remote Sens. 18, 287-304.

Maller, C., Townsend, M., Pryor, A., Brown, P., St, Leger, L.(2005). Healthy nature healthy people: 'contact with nature' as an upstream health promotion intervention for populations. Health Prom. Int. 21, 45-54.*https://doi.org/10.1093/heapro/dai032*

McCormick, R.(2017). Does Access to Green Space Impact the Mental Well-being of Children: A Systematic Review. J. Pediatr. Nurs.-Nurs. Care Child. Families 37, 3-7.

https://doi.org/10.1016/j.pedn.2017.08.027

Montazeri, H., Toparlar, Y., Blocken, B., Hensen, J. L. M.(2017). Simulating the cooling effects of water spray systems in urban landscapes: A computational fluid dynamics study in Rotterdam, The Netherlands. Landsc. Urban Plann. 159, 85-100.*https://doi.org/10.1016/j.landurbplan.2016.10.001*

Park, J., Kim, J-H., Lee, D. K., Park, C. Y., Jeong, S. G.(2017). The influence of small green space type and structure at the street level on urban heat island mitigation. Urban Forestry & Urban Greening 21, 203-212.*https://doi.org/10.1016/j.ufug.2016.12.005*

Peng, J., Xie, P., Liu, Y., Ma, J.(2016). Urban thermal environment dynamics and associated landscape pattern factors: A case study in the Beijing metropolitan region. Remote Sens. Environ. 173, 145-155.

Qian, Y. F., Lou, Y., Chu, Y. X., Liu, J., Hu, J. J.(2016). Health and value evaluation of Dongting Lake wetland ecosystem. Wetland Sci. 14, 516-523.

https://doi.org/10.11821/yj2009060022

Qiu, G. Y. , Zou, Z., Li, X., Li, H., Guo, Q., Yan, C., Tan, S.(2017). Experimental studies on the effects of green space and evapotranspiration on urban heat island in a subtropical megacity in China. Habitat Int. 68, 30-42.*https://doi.org/10.1016/j.habitatint.2017.07.009*

Rehachova, T., Pauditsova, E.(2004). Evaluation of urban green spaces in Bratislava. Boreal Environ. Res. 9, 469-477.

Robitu, M., Musy, M., Inard, C., Groleau, D.(2006). Modeling the influence of vegetation and water pond on urban microclimate. Sol. Energy 80, 435-447.*https://doi.org/10.1016/j.solener.2005.06.015*

Santamouris, M., Synnefa, A., Karlessi, T.(2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Sol. Energy 85, 3085-3102.*https://doi.org/10.1016/j.solener.2010.12.023*

Shi, B. G.(2018). Evaluation on development potential and cooling effect of vertical greening in Xinjiekou district of Nanjing city. Nanjing University, Nanjing.

Simpson, J., Norris, R., Barmuta, L.(1999). AusRivAS-National River Health Program: User Manual Website version. Australia.

Sorensen, M., Smit, J., Barzetti, V.(1997). Good Practices for Urban Greening. first ed. Washington, D.C.

Tan, S. H., Li, J.(2009). Pressure release and energy recovery function of urban public green space. Chin. Landsc. Archit. 25, 79-82.

Theeuwes, N., A, Solcerova, Steeneveld, G. J.(2013). Modeling the influence of open water surfaces on summertime temperatures and thermal comfort in the city. Journal of Geophysical Research 118, 8881-8896.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., Zelson, M.(1991). Stress recovery during exposure to natural and urban environments. J. Environ. Psychol. 11, 201-230.*https://doi.org/10.1016/S0272-4944(05)80184-7*

van den Berg, M., Wendel-Vos, W., van Poppel, M., Kemper, H., van Mechelen, W., Maas, J.(2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. Urban Forestry & Urban Greening 14, 806-816.*https://doi.org/10.1016/j.ufug.2015.07.008*

Weng, Q., Yang, S.(2004). Managing the adverse thermal effects of urban development in a densely populated Chinese city. J. Environ. Manage. 70, 145-156.

https://doi.org/10.1016/j.jenvman.2003.11.006Get rights and content

Wentworth, J.(2017). Urban Green Infrastructure Ecosystem Services. POST brief from UK Parliamentary Office of Science and Technology, London, UK.

White, M. P., Pahl, S., Wheeler, B. W., Depledge, M. H., Fleming, L. E.(2017). Natural environments and subjective wellbeing: Different types of exposure are associated with different aspects of wellbeing. Health Place 45, 77-84.*https://doi.org/10.1016/j.healthplace.2017.03.008*

Wong, T. H. F., Brown, R. R.(2009). The water sensitive city: principles for practice. Water Sci. Technol. 60, 673-682.*https://doi.org/10.2166/wst.2009.436*

Wright, J. F., Furse, M. T., Moss, D.(1998). River classification using invertebrates: RIVPACS applications. Aquat. Conserv.: Mar. Freshwat. Ecosyst. 8, 617-631.

Wu, D., Wang, Y., Fan, C., Xia, B.(2018). Thermal environment effects and interactions of reservoirs and forests as urban blue-green infrastructures. Ecol. Indicators 91, 657-663.*https://doi.org/10.1016/j.ecolind.2018.04.054*

Wu, J. P, Liu, L. S., Wang, Q. W., Gao, J. J.(2020). Study on evaluation index system of urban Lake ecological health. Water Power 46, 1-3+112.

Xia. J. H.(2005). Theory and Application of ecological riparian zone comprehensive Evaluation. Hohai University, Nanjing.

Xu, Q. H., Song, B. J., Yang, Y. Q.(2019). Experimental study on the effect of water landscape on urban heat island in strip urban green space. Intell. Build. Smart City, 17-19+22.

Yan, L., Wang. J. K., Huang. H.(2008). Evaluation of ecosystem health in Dongxi Watershed based on PSR framework model. Resour. Sci., 107-113.

Yang. A. S., Juan, Y. H., Wen, C. Y., Chang, C. J.(2017). Numerical simulation of cooling effect of vegetation enhancement in a subtropical urban park. Appl. Energy 192, 178-200.

Yu, Z. W.(2018).The cooling effect of urban green infrastructure: From how to where, Department of Geosciences and Natural Resource Management, Faculty of Science. University of Copenhagen, Copenhagen.

Yue, W. Z., Xu, L. H.(2013). Thermal environmental effects of typical urban water landscape. Acta Ecol. Sin. 33, 1852-1859.

Zhang, C. L.(2010). Research on evaluation system and application of Ecological garden city in Hebei Province. Yanshan University, Qinhuangdao.

Zhang, F.L., Liu, J. L., Yang, Z. F.(2005). Health assessment of urban river and lake ecosystem: A case study of "Six Seas" in Beijing. Acta Ecol. Sin., 227-235.

Zhang, P. P.(2009). Preliminary study on the construction of urban waterfront space vitality. Zhongnan University, Changsha.

Zhao, Z. F., Shi, W., Qiu, X. Z., Wang, S. Q., Ouyang, H., Sun, X. Y., Yang, Z. C.(2020). Evaluation of Water ecological carrying capacity of Yuehai Lake based on analytic Hierarchy process. Environ. Sci. Technol. 43, 213-219.

Zhong, W. X., Xu, M. H., Chen, Z. C.(2021). Study on spatial evaluation of slow friendly waterfront belt park. J. Guangdong Landsc. Archit. 43, 18-21.

Table 1 Ecological benefits of different types of blue-green spaces.

Types	Research Contents	Research Results
Green space	Compared cooling effects of different forms of green spaces	Among polygonal,
	Purification effect of urban green space on air pollutants	Urban green space
Blue space	Influencing factors of water-cooling effect	The cooling effects
	Compared cooling effects of different water bodies	Planar waters in t
Blue-green space	Microclimate effects of vegetation and water bodies on urban squares	In the presence of

Types	Research Contents	Research Results
	Thermal environmental effects of urban reservoirs and forests and their interactions	There was a nonli

Table 2 Studies on the impact of blue-green spaces on mental health.

Mental health	Mental health	Blue space	Green space
Short term	Influence	+	+
	Vitality		+
	Restorative outcomes	+	+
	Perceived stress	+	+
	Physiological stress	+	+
	Problem behavior	+	+
	Brain activity		+
Long term	Overall mental health	+	+
	Severity of a mental disorder	+	+
	Prevalence of a mental disorder	+	+
	Satisfaction with life	+	+
	Quality of life	+	+
	Subjective well-being	+	+

Note: "+" represents existing studies.

Table 3 History of the blue-green space index evaluation system

Types of Ecological Services	Blue space	Green space	Blue-green space	References
Supply service	[?]			(Karr, 1991; Wright *et al.*, 1998; Simpson *et al.*, 1999)
		[?]		(Flader and Clicottal, 1991; Zhang, 2010)
Regulating service	[?]			(Zhang *et al.*, 2005)
		[?]		(Yan *et al.*, 2008; Shi, 2018)
Cultural services			[?]	(Xia, 2005; Zhang, 2009; Wu *et al.*, 2020; Zhong *et al.*, 2

Note: "[?]" represents existing studies.