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Establishment and application of the health evaluation system for rain-sourced rivers and lakes in coastal cities

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ABSTRACT

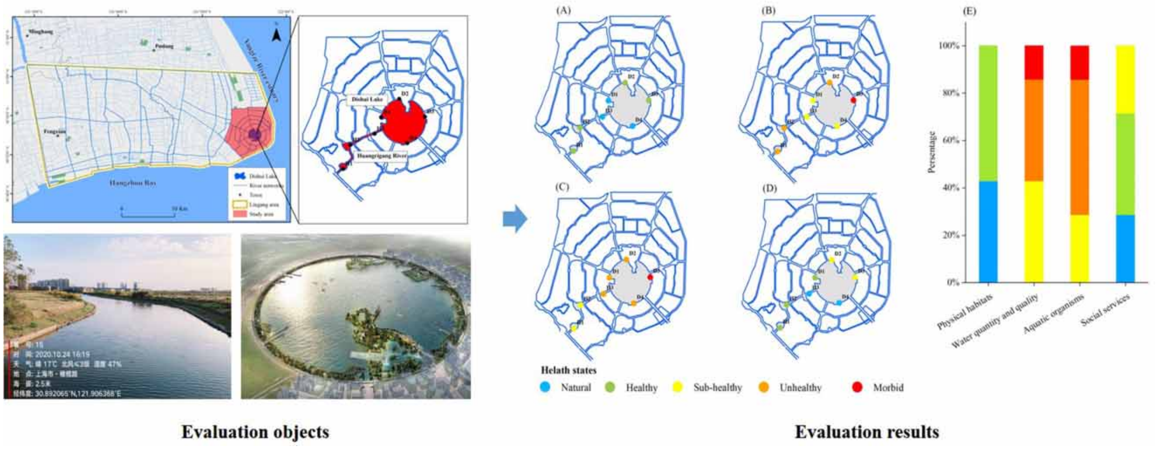
Conducting a health assessment of rivers and lakes is a technical approach that enables the accurate diagnosis of water health status and scientific analysis of aquatic ecological environments. This paper focuses on studying the typical rain-sourced water bodies of Huangrigang River and Dishui Lake (DSL) in Lin-gang, Shanghai. The Australian Stream Condition Index and the Analytic Hierarchy Process were used to establish a typical river and lake health evaluation index system. Expert scoring and least-squares methods were used to determine the weights of each index, and a quartile method was used to establish the evaluation criteria. The evaluation results indicate that the health status of the Huangrigang River is sub-healthy with a score of 72.1, whereas DSL is healthy with a score of 75.7. The low flow velocity of the regional river and the weak mobility of the water body are the main issues affecting the health status of the HRGR. Additionally, the density of phytoplankton in the river is significantly high. Dripping Lake is faced with two major problems: a high risk of eutrophication and a high density of phytoplankton in the lake. This article provides theoretical support for the sustainable use of regional water resource.

Key words: Dishui Lake, Eutrophication, Hydrodynamic enhancement, Lin-gang Special Area

HIGHLIGHTS

- The health evaluation system for rain-sourced rivers and lakes in coastal cities contains four category layers, such as physical habitats, water quantity and quality, aquatic organisms, and social services.
- A typical river is in the sub-healthy and a lake in the healthy state.
- The main problems facing rain-sourced water bodies such as rivers and lakes were related to low flow velocity, weak mobility, and high phytoplankton density.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Rivers and lakes constitute vital components of aquatic ecosystems, playing pivotal roles in flood control, drainage, water supply, irrigation, and the sustenance of aquatic habitats (Chen *et al.*, 2021). However, in recent years, the natural ecosystem model of rivers and lakes has been disrupted due to climate change (Wang *et al.*, 2023), urbanization (Ziyan *et al.*, 2023), and increased anthropogenic disturbances (Ulrika & Tawfiqur, 2023), resulting in a range of ecological, environmental, and social issues. These issues include river disruptions (Han & Endreny, 2014), eutrophication of lakes and reservoirs (Pap *et al.*, 2023), biodiversity decline (Yifan *et al.*, 2022), black smelly water bodies (Wang *et al.*, 2020), and heavy metal pollution (Rady *et al.*, 2023). In response, conducting a health assessment of rivers and lakes, accurately diagnosing the main factors causing the deterioration of river and lake ecosystems, and carrying out water and ecological management are crucial ways to recover the ecological environment of rivers and lakes (Su *et al.*, 2020).

Initially, the evaluation of river and lake health relied on a limited set of physical indicators (e.g., flow velocity) or chemical indicators (e.g., nitrogen concentration) to assess their health status (Norris & Thoms, 1999). However, as human understanding of river and lake health has evolved, the assessment process has grown more intricate. The current evaluation of river and lake health considers the integrity of their ecosystems' structure and function, their self-healing ability under external disturbance, and their social service function in meeting human demands (Zhengxian *et al.*, 2021).

In response to this refined perspective on river and lake health, two main evaluation methodologies have emerged: the biological monitoring method and the comprehensive index method (Zhao *et al.*, 2019). The former relies on the use of representative aquatic organisms, such as fish, macroinvertebrates, zooplankton, and aquatic plants, to reflect the environmental problems. Qualitative and quantitative monitoring data, such as changes in the species composition, biomass, and density of indicator species, are employed in this approach. Examples of typical biological monitoring methods include the River Invertebrate Prediction and Classification Scheme (RIVPACS) (Wright *et al.*, 1984), the Australian River Assessment Scheme (AUSRIVAS) (John, 2004), and the EU Water Framework (WFD) (Kallis & Butler, 2001). The comprehensive index, on the other hand, provides a more comprehensive approach to assessing the health status of a water body by considering multiple physical characteristics, chemical indicators, and the distribution of aquatic organisms. Although this approach is laborious and time-consuming, it provides a more holistic understanding of the specific problems of a river or lake. Examples of typical comprehensive index methods include the Swedish Riparian and Riverien Environment Specifications (Petersen, 1992) and the Australian Stream Condition Index (ISC) (Ladson *et al.*, 1999).

Numerous studies have focused on evaluating the health of estuaries, urban rivers, and lakes using the biological monitoring method, such as the Fish-based Index of Biotic Integrity (F-IBI), and the comprehensive index method, such as the pressure–state–response (PSR) framework (Yifan *et al.*, 2021; Zhang *et al.*, 2021; Wang *et al.*, 2023). In coastal cities, most of the rivers and lakes form separate embankments that are isolated from the sea to counteract the high salinity of seawater. These rain-sourced water bodies have limited water recharge, mostly from tail water of domestic sewage and sewage treatment plants, resulting in the characteristic micro-capacity and heavy load (Hill *et al.*, 2020), which exacerbates pollution loads, degrades river water quality, reduces self-cleaning capacity, and impairs ecological environments. Evaluating the health of rain-sourced water bodies in coastal cities remains a pioneering endeavor. This study focuses on the typical coastal city of Lin-gang City Shanghai, selecting typical rain-sourced rivers and lakes in the region, developing an applicable regional evaluation system for river and lake health, and conducting a health evaluation to accurately diagnose the water ecological and environmental problems of rivers and lakes in coastal cities.

2. MATERIALS AND METHODS

2.1. Study area

The Lin-gang Special Area is located in the southeastern part of Shanghai, China, covering a total area of 873 km^2 (Ren *et al.*, 2022). The region is bounded by the Yangtze River estuary in the east and Hangzhou Bay in the south (Figure 1). The topography of the area is mainly flat, with a higher elevation rate in the west and lower in the southeast, and a ground elevation generally ranging from 3.5 to 4.5 m. Due to its geographical location, the area is prone to typhoons, heavy rainfall, and tidal fluctuations. The region falls under the north subtropical zone, which is characterized by distinct maritime monsoon features. The climate is warm and rainy in spring, hot and temperate in summer, and cold and dry in winter, with an average temperature of 15.6 °C throughout

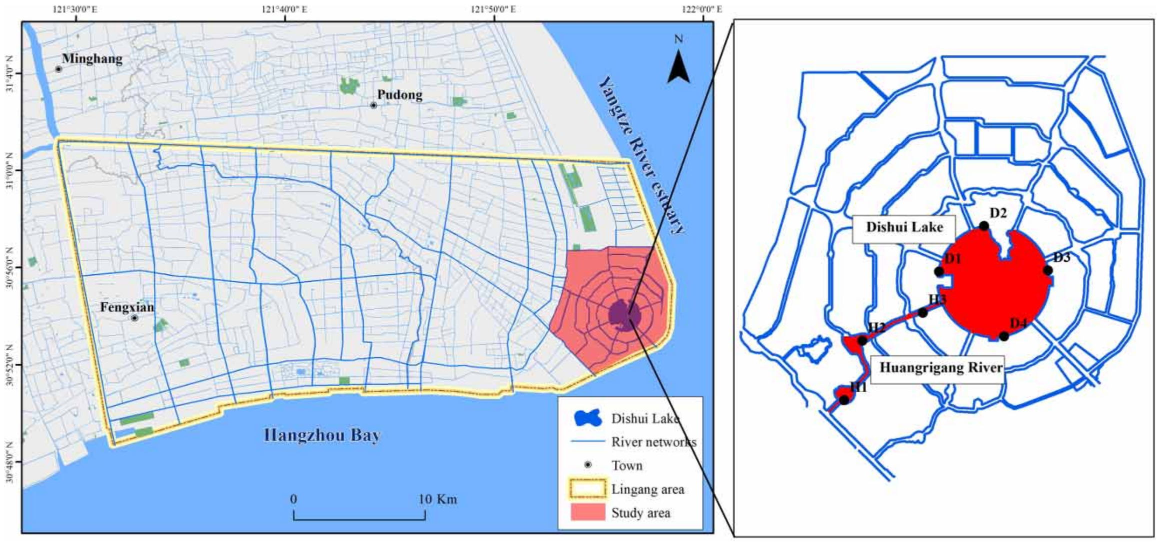


Fig. 1 | Location of Lin-gang Special Area and sampling sites.

the year. Currently, the central area of Dishui Lake (DSL), spanning around 72 km^2, has evolved a water network configuration encompassing a main lake, four ring-shaped rivers, and seven feeder rivers.

In this study, the Huangrigang River (HRGR) and DSL were chosen as the primary evaluation objects. The HRGR and DSL were chosen as study sites based on the following considerations: Firstly, the HRGR serves as a temporary water intake channel for the region, playing a pivotal role in connecting Lingang and another city. Secondly, the DSL serves as the core of the regional water system and is a multifunctional artificial freshwater lake that integrates various purposes such as climate regulation, leisure activities, and aesthetic enhancement.

2.2. Field survey

Two field surveys were conducted at the HRGR and DSL in November 2021 during the dry period and in July 2022 during the rich period. The collected data from each site were subsequently averaged twice. To monitor the health of typical rivers and lakes in Lingang City, a total of seven points were established for investigation purposes, including three points (H1–H3) in the HRGR and four points (D1–D4) in DSL (Figure 1). The investigation focused on the physical characteristics of the rivers and lakes, including lake area, river and lake shoreline conditions, and water level, as well as chemical characteristics such as total nitrogen, total phosphorus, and dissolved oxygen. Additionally, aquatic organisms such as phytoplankton and fish were examined, along with social services such as public satisfaction.

Water samples were collected from the water bodies using stainless steel buckets. At each sample point, three collections were taken, and the samples were mixed before random sampling. The mixed samples were then fixed with acid and stored frozen in PVC bottles until analysis for biogenic substances in the laboratory.

Fish samples were collected using an electrofishing backpack and subsequently identified, weighed, and counted in the field. Phytoplankton samples were collected in 1,000 mL of water, fixed in the field with 1% Lugo's reagent, and then concentrated to 30 mL after 48 h of sedimentation for phytoplankton community analysis (Chen *et al.*, 2020).

Total nitrogen, total phosphorus, and other water quantity and quality indicators were measured in accordance with the monitoring analysis method of water and wastewater (Ministry of Water Resources of the People Republic of China, 2020). The water temperature, turbidity, and other indicators were measured using a multi-parameter water quality analyzer (Hydrolab HL4, HACH Inc., Tampa, FL, USA). Phytoplankton was quantified using a light microscope (Olympus BX41) at 400× magnification (Hongjun & Yinxin, 2006).

2.3. Index system and weight

Based on standards such as 'Technical Guidelines for River and Lake Health Assessment of Shanghai' (Shanghai Municipal Water Administration, 2023) and 'River and Lake Health Evaluation Guide (trial)' (Ministry of Water Resources of the People's Republic of China, 2020), a typical river and lake health evaluation index system for Lin-gang was established using the Australian ISC method (Ladson *et al.*, 1999) and the Analytic Hierarchy Process (AHP) (Zsombor & Szabolcs, 2022).

The selected evaluation indexes were required to be highly sensitive and responsive to changes in river and lake ecosystems, representative, and able to fully reflect the health condition of the river and lake. Additionally, they needed to be independent among the indexes and show a low correlation among the indexes.

The weights of each indicator were determined using Expert scoring and least-squares methods (Igor *et al.*, 2022; Tongyan *et al.*, 2022). Before the weight solution, the indicators were compared two by two by referring to the literature or interviewing expert opinions, and the matrix $A = [a_{kj}]_{n\times n}$ was obtained, and the importance of a_{kj} was noted as the importance of the Kth indicator to the Jth indicator, then:

$$a_{kj} \approx w_k / w_j \tag{1}$$

where w_k is the weight of the indicator P_k and w_j is the weight of the indicator P_j. Suppose there exists a matrix $F = [f_{ij}]_{n \times n}$ and the elements in the matrix F are:

$$f_{ii} = n - 2 + \sum_{k=1}^{n} a_{ki}, i = 1, \cdots, n \tag{2}$$

$$f_{ji} = -(a_{ij} + a_{ji}) \tag{3}$$

Then, there exists a minimum value of m, and the equation for calculating the subjective weights based on the least-squares method is obtained:

$$\begin{cases} \min m = w^T F w, \\ \text{s.t.} e w^T = 1, \\ w > 0 \end{cases} \tag{4}$$

where w is the weight vector, $w = (w_1, w_2, \ldots, w_n)$, and e is the unit vector.

Solving the model yields the subjective weight vector w':

$$w' = F^{-1} e / e^T F^{-1} e \tag{5}$$

2.4. Assessment criteria and method

The health status of representative rivers and lakes in Lin-gang can be classified into five tiers based on their health assessment score: natural, healthy, sub-healthy, unhealthy, and morbid (Table 1).

The methodology employed in this study involved the application of the quadratic method to ascertain the scoring criteria for each index. The resulting scoring criteria were then evaluated by calculating various statistical measures, including the mean, standard deviation, minimum value, maximum value, and five quartiles ranging from 5 to 95% of the dataset for each index at all data points. The grading criteria of the quadratic method were compared based on these measures. Each index was scored equally, and the resulting scores were used

Table 1 | Qualitative description and representation of each health level.

Health level	Score	Expressions
Natural	$90 \le H \le 100$	🔵
Healthy	$75 \le H < 90$	🟢
Sub-healthy	$60 \le H < 75$	🟡
Unhealthy	$40 \le H < 60$	🟠
Morbid	$H < 40$	🔴

to classify the river health levels into five categories: natural, healthy, sub-healthy, unhealthy, and morbid, which are arranged in descending order.

Using the health evaluation index system developed for typical rivers and lakes in Lin-gang, the comprehensive index for assessing the ecological health of the river was calculated:

$$H = \sum_{i=1}^{\mathrm{n}} (W_i \times I_i) \tag{6}$$

where H is the comprehensive index of the ecological health of rivers and lakes, W_i is the evaluation index weight indicator, and I_i is the standardized value of the evaluation index.

3. RESULTS AND DISCUSSION

3.1. Health evaluation system of the HRGR and DSL

The health evaluation index system for the HRGR and DSL comprises three layers: the target layer, the category layer, and the indicator layer (Table 2). In the HRGR, there are nine evaluation indicators, encompassing two indicators for physical habitats, four indicators for water quantity and quality, two indicators for aquatic organisms, and one indicator for social services. Similarly, DSL's evaluation index system consists of nine indicators, including three indicators for physical habitats, four indicators for water quantity and quality, one indicator for aquatic organisms, and one indicator for social services. Additionally, the evaluation index system for rivers and lakes comprises seven public indicators and four specific indicators. The water fluidity and fish diversity index are specific to rivers, while the percentage of lake area shrinkage and trophic level index are specific to lakes.

Notably, the weight assigned to the water quantity and quality and social service layer in the category layer is 0.3, which is higher than that of the physical habitats and aquatic organisms (Table 3). In HRGR's physical habitat category, the weight distribution is based on the riparian naturalness, the riparian degree of illegal exploitation and utilization, and an equal distribution of the weights for each indicator in the aquatic organisms category. Conversely, in DSL's physical habitat category, the largest weight is assigned to the percentage of lake area shrinkage.

Table 2 | Evaluation index framework of HRGR and DSL.

		Indicator layer	
Target layer	**Category layer**	**HRGR**	**DSL**
River and lake health	Physical habitats	Riparian naturalness (R1) Riparian degree of illegal exploitation and utilization (R2)	Percentage of lake area shrinkage (L1) Riparian naturalness (L2) Riparian degree of illegal exploitation and utilization (L3)
	Water quantity and quality	Ecological flow guarantee rate (R3) Water quality (R4) Self-purification capacity (R5) Water fluidity (R6)	Ecological flow guarantee rate (L4) Water quality (L5) Trophic level index (L6) Self-purification capacity (L7)
	Aquatic organisms	Phytoplankton density (R7) Fish diversity (R8)	Phytoplankton density (L8)
	Social services	Public satisfaction (R9)	Public satisfaction (L9)

Table 3 | The calculated index weights.

		HRGR		DSL	
Category	**Weights**	**Indexes**	**Weights**	**Indexes**	**Weights**
Physical habitats	0.2	R1	0.6	L1	0.4
		R2	0.4	L2	0.3
				L3	0.3
Water quantity and quality	0.3	R3	0.3	L4	0.3
		R4	0.2	L5	0.2
		R5	0.3	L6	0.3
		R6	0.2	L7	0.2
Aquatic organisms	0.2	R7	0.5	L8	1.0
		R8	0.5		
Social services	0.3	R9	1.0	L9	1.0

Furthermore, in the water quantity and quality category, the degree of ecological flow guarantee rate and the trophic level index carry greater weight than the degree of water quality and self-purification capacity.

According to the quadratic method to obtain the assignment criteria of each indicator of the HRGR and DSL, each indicator assignment criterion is shown in Table 4.

3.2. Health status of the HRGR and DSL in the target layer

According to the scoring criteria in Table 4, scores were assigned to various health assessment indicators for the HRGR and DSL, as shown in Table 5. Among them, the indicator data for R3, L1, and L4 were sourced from the Shanghai water resource bulletin (https://swj.sh.gov.cn/szy/), while the rest of the indicator data were obtained through on-site sampling. Combining the indicator weights from Table 3 and the health score calculation method in Equation (6), the comprehensive health scores for the HRGR and DSL were calculated as 78.43 and 75.63,

Table 4 | The reference value of indexes.

Indexes	Units	Natural	Healthy	Sub-healthy	Unhealthy	Morbid
R1 (L2)	%	0–5	5–25	25–50	50–75	>75
R2 (L3)	%	0–20	20–60	60–90	90–100	100
R3 (L4)	% (dry season) % (wet season)	≥30 ≥50	20–30 40–50	10–20 30–40	5–10 10–30	<5 <10
R4 (L5)	–	90–100	75–90	60–75	40–60	0–40
R5 (L7)	mg/L	≥7.5	≥6	≥3	≥2	0
R6	m/s	0.1–0.15	0.05–0.1	0.03–0.05	0–0.03	0
R7 (L8)	10^5 cells/L	≤40	40–200	200–500	500–1000	≥5000
R8	–	>3	2–3	1–2	0–1	0
R9 (L9)	–	95–100	80–95	60–80	30–60	<30
L1	%	<5	5–10	10–20	20–30	≥40
L6	–	≤10	10–42	42–50	50–65	≥70

Table 5 | Data sources and scores in the indicator layer.

HRGR			DSL		
Indexes	**Data sources**	**Scores**	**Indexes**	**Data sources**	**Scores**
R1	Field investigation	85.7	L1	Shanghai water resources bulletin	100.0
R2	Field investigation	100.0	L2	Field investigation	87.2
R3	Shanghai water resources bulletin	100.0	L3	Field investigation	100.0
R4	Field investigation	82.0	L4	Shanghai water resources bulletin	100.0
R5	Field investigation	85.0	L5	Field investigation	84.3
R6	Field investigation	10.0	L6	Field investigation	53.2
R7	Field investigation	24.3	L7	Field investigation	95.2
R8	Field investigation	87.6	L8	Field investigation	21.2
R9	Field investigation	89.3	L9	Field investigation	92.0

respectively. Referring to the health status classification table in Table 1, the HRGR is determined to be a healthy river, while DSL is classified as a healthy lake (Figure 2(a)).

The spatial distribution of the health status of the HRGR and DSL is illustrated in Figure 2(b). In the HRGR, the health condition improves gradually from upstream to downstream, where H1 is the sub-healthy state, and H2 and H3 are healthy states. Notably, 33.3%of the points are in a sub-healthy state, while the remaining 66.7% are in a healthy state. Conversely, DSL displays a more even distribution of health conditions, with 50% of the points classified as healthy and the other 50% as sub-healthy. Specifically, D4 and D1 are the healthy state, while D2 and D3 are sub-healthy states. Additionally, the southwest region of the lake exhibits a relatively better health condition than the northeast region.

The variation in the health condition of the HRGR between upstream and downstream is attributed to anthropogenic activities in the surrounding area. The H1 section, situated in the main university district of Lin-gang

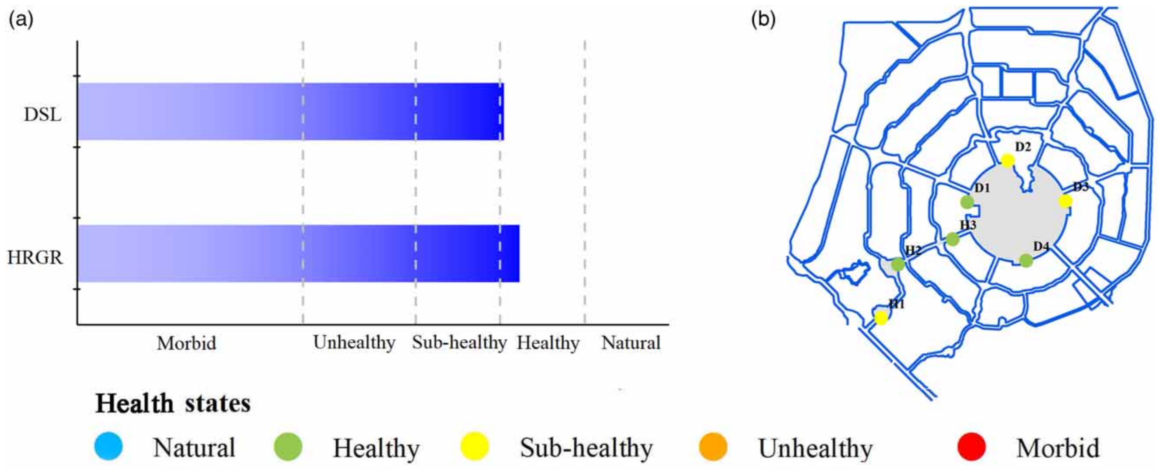


Fig. 2 | Health assessment results for the HRGR and DSL. (a) Total scores for the HRGR and DSL and (b) spatial distribution of health status in the HRGR and DSL.

Special Area, is densely populated, and the river's health is negatively impacted by the direct discharge of domestic wastewater. The H2 section, a primary fishing and agricultural area, is also contaminated by waste garbage and farming wastewater, leading to poor health conditions. Recently, ecological restoration projects, such as underwater forest construction and shore softening, have been implemented by the Lin-gang government to improve the area's health condition. As a result, H2 is the healthy state, and H3, located in an integrated park area of coastal leisure, cultural tourism, and ecological protection, has a circular purification wetland that has significantly improved its health condition.

DSL is an inner urban rainfall type lake, where ecological replenishment mostly occurs through regional rainfall and a small portion via tidal water from the HRGR through the northern and eastern river network, while the lake's water is exchanged through the western HRGR and the southern river network draining Hangzhou Bay. The northeastern part of the lake is affected by agricultural activities, resulting in the entry of water with higher nutrients through the northeastern river network, leading to water pollution. Additionally, due to regional development and construction, some rivers in the northeast are severely disconnected, resulting in reduced water inflow into the lake. The weaker water flow in the northeast compared to the southwest causes nutrient deposition in the former, leading to a lower health condition of the lake.

3.3. Health evaluation of the HRGR and DSL in the category layer

The physical habitats category of the natural state comprises 42.9% of the total points, while the healthy state accounts for the remaining 57.1% (Figure 3(a) and 3(e)). The typical river and lake possess a sound physical

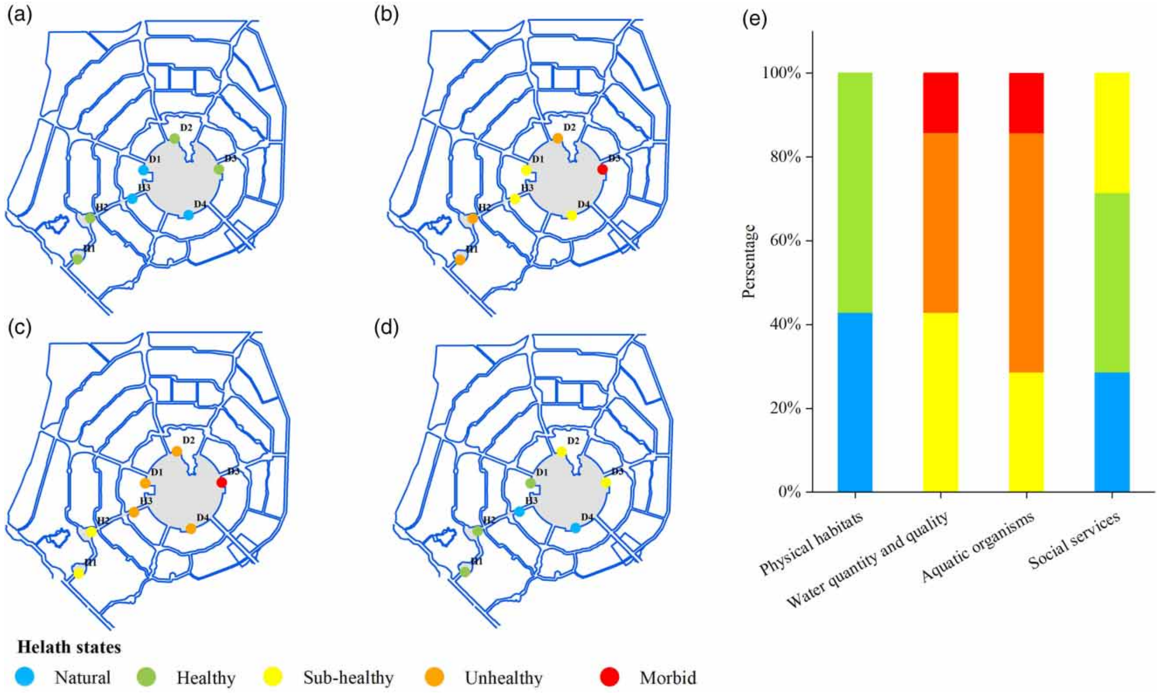


Fig. 3 | Health assessment results on four category layers in the HRGR and DSL. (a) Health assessment results on physical habitats, (b) health assessment results on water quantity and quality, (c) health assessment results on aquatic organisms, (d) health assessment results on social services, and (e) the proportion of health status in the category layer.

state, exemplified by the good natural state of the shoreline. Specifically, the river bank at the HRGR is constructed primarily using vertical slurry stone revetment and pebble ecological revetment, resulting in excellent bank stability. DSL, an artificial lake, features several beach activity spaces, such as Dripping Lake West Island and North Island, the Dripping Lake Children's Suburban Park landscape belt surrounding the lake, and basic public facilities. Moreover, most of the shoreline comprises an ecological slope, thereby exhibiting a healthy natural condition.

The evaluation results of the water quantity and quality category indicate that 42.9% of the assessment points are classified as sub-healthy, while an equivalent of 42.9% are deemed unhealthy. Moreover, 14.2% of the points fall under the morbid, with no points being evaluated as healthy (Figure 3(b) and 3(e)). The regions displaying poor chemical indicators are mainly located in the upper reaches of the HRGR and the northeastern section of DSL. These regions comprise built-up areas, such as the primary university town in Lin-gang, where alterations in land use patterns have altered the substrate's properties. Consequently, the impervious area has increased, and pollutants present in the land area enter rivers and lakes through rainfall-runoff, resulting in a pooling area for pollutants.

The aquatic organisms category evaluation results reveal that 28.6% of the points are sub-healthy, 57.2% are unhealthy, and 14.2% are morbid (Figure 3(c) and 3(e)). Lin-gang is a plain city river network characterized by a relatively flat terrain, with a ground elevation generally ranging from 3.5 to 4.5 m. The area exhibits an undulating topography, with the rivers and lakes largely in a non-flowing state, making it susceptible to water body eutrophication. The scores of phytoplankton density in the HRGR and DSL are 24.3 and 21.2 (Table 5), thereby increasing the risk of water bloom.

The evaluation results of the social service layer indicate that 28.6% of the points are in natural, 42.8% points are healthy, and 28.6% of the points are sub-healthy (Figure 3(d) and 3(e)). In line with the 'water city coexistence' model, DSL and its drainage channel HRGR have established water culture promotion projects such as nautical museums, marine parks, walkways around the lake and river, and ecological wetlands. These initiatives have facilitated the integration of scenic planning with river and lake management, creating a significant public activity platform that enhances the social function of the river and the lake service. As a result, tourists and citizens can now enjoy water-based leisure and entertainment activities.

3.4. Limiting factors of the HRGR and DSL

Among the nine evaluation indicators of the HRGR, the water fluidity (R6) and phytoplankton density (R7) were found to be in an unhealthy and morbid status (Figure 4(a)). Similarly, among the nine evaluation indicators of DSL, the trophic level index (L6) and phytoplankton density (L7) were also identified to be in an unhealthy and morbid status (Figure 4(b)). It is noteworthy that the phytoplankton density of typical rivers and lakes in Lin-gang is high, posing a risk of water bloom.

Improving the hydrodynamics of rivers and lakes plays a pivotal role in enhancing the oxygen saturation levels of water bodies, expediting the chemical and biological purification processes, bolstering the self-cleansing capacity of water bodies, and restoring aquatic habitats (Li *et al.*, 2013b). Specifically, enhancing the mobility of water bodies in urban river networks can effectively reduce nutrient concentration, thus mitigating the risk of malodorous water bodies (Pierfranco & Carmelina, 2021). In the case of lake hydrodynamic enhancement, it can substantially reduce the concentration of chl-a and total phosphorus (TP) in lake water bodies (Li *et al.*, 2013a; Boqiang *et al.*, 2021). However, the flow velocity of water bodies in the HRGR is generally within the range of 0.00–0.01 m/s, while the flow velocity of water bodies in DSL is less than 0.03 m/s, indicating a state of weak flow. An increase in the residence time of river water bodies can reduce water flow mixing and dilution, leading to the accumulation of suspended particles and a propensity for eutrophication (Li *et al.*, 2014).

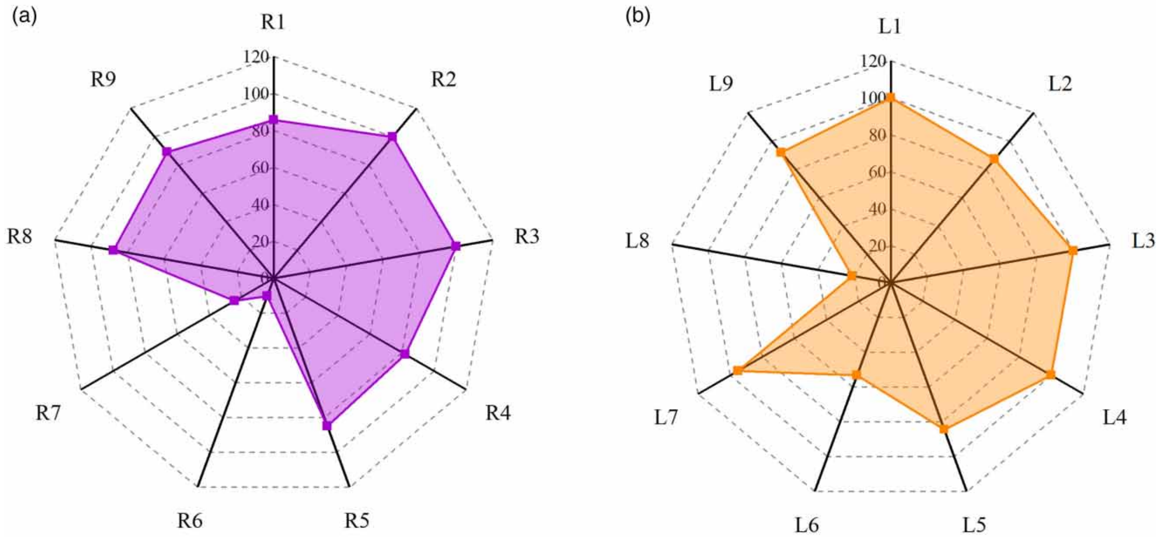


Fig. 4 | Health assessment results of each evaluation index of the HRGR and DSL. (a) Assessment results of the HRGR and (b) assessment results of DSL.

Additionally, the abundance of nutrients received by algae at the bottom of the water enhances biomass growth, ultimately resulting in the formation of cyanobacterial blooms (Wu *et al.*, 2015).

4. CONCLUSION

Freshwater ecosystems in coastal cities, particularly those formed by rainfall, are facing ecological challenges due to their limited capacity and heavy pollution load. It is important to evaluate the health of these water bodies and carry out targeted restoration measures to maintain their ecological function. The article selected the HRGR and DSL as typical rivers and lakes in the Lin-gang Special Area and established a health evaluation index system using ISC and AHP methods. The evaluation results showed that the HRGR was sub-healthy, while DSL was healthy. The main problems facing these water bodies were related to low flow velocity, weak mobility, and high phytoplankton density.

Regarding the typical rivers and lakes in the Lin-gang Special Area, the primary task in the current water environment conditions is to control exogenous pollution, which includes the treatment of domestic sewage, as well as point and surface source pollution control. Subsequently, river and lake hydrodynamic control measures can be implemented by adopting multi-source diversion of clear water replenishment and constructing gates and pump projects to increase the fluidity of river water, thereby reducing the hydraulic residence time of the lake. Finally, long-term control of the river and lake water environment can be achieved through river and lake ecological restoration and modernized intelligent control measures.

This paper proposes a health assessment method for coastal rain-sourced lakes and rivers and applies it, providing theoretical support for achieving sustainable utilization of regional water resources. However, the research outcomes are only applied to a typical lake and river in Lingang, Shanghai. In future research, it is necessary to expand the application of the health assessment method for coastal rain-fed lakes and rivers. Starting from a watershed scale, the reliability of detection and evaluation results and the applicability of the assessment method need to be examined. Furthermore, the current evaluation indicator data heavily rely on manual sampling, which is influenced by various natural factors like weather and artificial factors such as sampling personnel's skills and proficiency. Future research should combine emerging monitoring technologies like satellite remote sensing and environmental DNA with health assessment, aiming to enhance the reliability of assessment results.

AUTHORS' CONTRIBUTIONS

S.W. conceptualized the study, performed data curation, did formal analysis, investigated the methodology, wrote the original draft, and reviewed and edited the manuscript. Y.L. conceptualized the study, did funding acquisition, and supervised the work. X.P. was involved in data curation and formal analysis, and reviewed and edited the manuscript.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Boqiang, Q., Jianming, D., Kun, S., Jia, W., Justin, B., Jian, Z., Yunlin, Z., Guangwei, Z., Hans, W. P. & Li, W. (2021). Extreme climate anomalies enhancing cyanobacterial blooms in Eutrophic Lake Taihu, China. *Water Resources Research 57*, e2020WR029371.

Chen, Q., Shi, W., Huisman, J., Maberly, S. C., Zhang, J., Yu, J., Chen, Y., Tonina, D. & Yi, Q. (2020). Hydropower reservoirs on the upper Mekong River modify nutrient bioavailability downstream. *National Science Review 7*, 1449–1457.

Chen, Q., Chen, Y., Yang, J., Maberly, S. C., Zhang, J., Ni, J., Wang, G., Tonina, D., Xiao, L. & Ma, H. (2021). Bacterial communities in cascade reservoirs along a large river. *Limnology and Oceanography 66*, 4363–4374.

Han, B. & Endreny, T. A. (2014). Detailed river stage mapping and head gradient analysis during meander cutoff in a laboratory river. *Water Resources Research 50*, 1689–1703.

Hill, A. F., Rittger, K., Dendup, T., Tshering, D. & Painter, T. H. (2020). How important is meltwater to the Chamkhar Chhu headwaters of the Brahmaputra River? *Frontiers in Earth Science 8*, 81.

Hongjun, H. & Yinxin, W. (2006). *The Freshwater Algae of China: Systematics, Taxonomy and Ecology*, vol. 100. Science Press, Beijing, p. 150.

Igor, T., Pierre-Frédéric, V., Elisabeth, L., Víctor, B. & Nicola, C. (2022). An unfitted radial basis function generated finite difference method applied to thoracic diaphragm simulations. *Journal of Computational Physics 469*, 111496.

John, J. (2004). Assessment of river health in Australia by diatom assemblages – A review. *Oceanological and Hydrobiological Studies 33*, 95–104.

Kallis, G. & Butler, D. (2001). The EU water framework directive: Measures and implications. *Water Policy 3*, 125–142.

Ladson, A. R., White, L. J., Doolan, J. A., Finlayson, B. L., Hart, B. T., Lake, P. S. & Tilleard, J. W. (1999). Development and testing of an index of stream condition for waterway management in Australia. *Freshwater Biology 41*, 453–468.

Li, Y., Tang, C., Wang, C., Anim, D. O., Yu, Z. & Acharya, K. (2013a). Improved Yangtze River Diversions: Are they helping to solve algal bloom problems in Lake Taihu, China? *Ecological Engineering 51*, 104–116.

Li, Y., Tang, C., Wang, C., Tian, W., Pan, B., Hua, L., Lau, J., Yu, Z. & Acharya, K. (2013b). Assessing and modeling impacts of different inter-basin water transfer routes on Lake Taihu and the Yangtze River, China. *Ecological Engineering 60*, 399–413.

Li, W., Qin, B. & Zhu, G. (2014). Forecasting short-term cyanobacterial blooms in Lake Taihu, China, using a coupled hydrodynamic–algal biomass model. *Ecohydrology 7*, 794–802.

Ministry of Water Resources of the People's Republic of China (2020). *River and Lake Health Evaluation Guide (Trial)*. China Environmental Science Press, Beijing.

Norris, R. H. & Thoms, M. C. (1999). What is river health? *Freshwater Biology 41*, 197–209.

Pap, S., Zhang, H., Bogdan, A., Elsby, D. T., Gibb, S. W., Bremner, B. & Taggart, M. A. (2023). Pilot-scale phosphate recovery from wastewater to create a fertiliser product: An integrated assessment of adsorbent performance and quality. *Water Research 228*, 119369.

Petersen, R. C. (1992). The RCE: A riparian, channel, and environmental inventory for small streams in the agricultural landscape. *Freshwater Biology 27*, 295–306.

Pierfranco, C. & Carmelina, C. (2021). A 2D-SWEs framework for efficient catchment-scale simulations: Hydrodynamic scaling properties of river networks and implications for non-uniform grids generation. *Journal of Hydrology 599*, 126306.

Rady, M. M., Elrys, A. S., Selem, E., Mohsen, A. A., Arnaout, S. M., El-Sappah, A. H., Tarabilyu, K. A. E. & Desoky, E. S. M. (2023). *Spirulina platensis* extract improves the production and defenses of the common bean grown in a heavy metals-contaminated saline soil. *Journal of Environmental Sciences 129*, 240–257.

Ren, H., Wu, Q., He, W., Wang, W., Luo, X., Li, Q. & Jiang, Z. (2022). Research on regional low-carbon development path based on LEAP model: Taking the Lin-gang special area as an example. *Energy Reports 8*, 327–335.

Shanghai Municipal Water Administration (2023). *Technical Guidelines for River and Lake Health Assessment of Shanghai*. Available at: https://swj.sh.gov.cn/cmsres/56/56d89cad82fd4d97ab192d7e1fa99925/b5ed9b8955cbec90db7c6fdb1057d6cc.pdf.

Su, Y., Li, W., Liu, L., Li, J., Sun, X. & Hu, W. (2020). Assessment of medium and small river health based on macroinvertebrates habitat suitability curves: A case study in a tributary of Yangtze River, China. *Water Policy 22*, 602–621.

Tongyan, Z., Yingjie, W., Shengrui, Z., Yingying, W. & Hu, Y. (2022). Evaluation of ontological value of regional tourism resources: A case study of Hainan Island, China. *Journal of Geographical Sciences 31*, 1015–1038.

Ulrika, C. & Tawfiqur, R. (2023). Behavioural responses of fishes to anthropogenic disturbances: Adaptive value and ecological consequences. *Journal of Fish Biology*. DOI: https://doi.org/10.1111/JFB.15322.

Wang, X., Song, W., Li, N., Lu, J., Niu, X., Ma, Y., Ding, J. & Wang, M. (2020). Ultraviolet-B radiation of *Haematococcus pluvialis* for enhanced biological contact oxidation pretreatment of black odorous water in the symbiotic system of algae and bacteria. *Biochemical Engineering Journal 157*, 107553.

Wang, Y., Qiang, L., Shuai, S., Yonglong, L., Shengjie, Y., Zili, F. & Zhen, S. (2023). A climate-water quality assessment framework for quantifying the contributions of climate change and human activities to water quality variations. *Journal of Environmental Management 333*, 117441.

Wright, J. F., Moss, D., Armitage, P. D. & Furse, M. T. (1984). A preliminary classification of running-water sites in Great Britain based on macro-invertebrate species and the prediction of community type using environmental data. *Freshwater Biology 14*(3), 221–256.

Wu, T., Qin, B., Brookes, J. D., Shi, K., Zhu, G., Zhu, M., Yan, W. & Wang, Z. (2015). The influence of changes in wind patterns on the areal extension of surface cyanobacterial blooms in a large shallow lake in China. *Science of the Total Environment 518*, 24–30.

Yifan, S., Weiming, L., Liu, L., Wei, H., Jinjing, L., Xuyang, S. & Yun, L. (2021). Health assessment of small-to-medium sized rivers: Comparison between comprehensive indicator method and biological monitoring method. *Ecological Indicators 126*, 107686.

Yifan, S., Lin, G., Yun, L., Ziwu, F., Chen, X., Yang, L., Yipeng, L., Rui, D., Guoqin, L., Jingxiu, W., Guangyu, C., Jianhao, S., Wenhan, Z. & Jingtian, M. (2022). A novel indicator for defining plain urban river network cyanobacterial blooms: Resource use efficiency. *Heliyon 8*, e10601.

Zhang, Z., Li, Y., Wang, X., Li, H., Zheng, F., Liao, Y., Tang, N., Chen, G. & Yang, C. (2021). Assessment of river health based on a novel multidimensional similarity cloud model in the Lhasa River, Qinghai-Tibet Plateau. *Journal of Hydrology 603*, 127100.

Zhao, Y. W., Zhou, L. Q., Dong, B. Q. & Dai, C. (2019). Health assessment for urban rivers based on the pressure, state and response framework – a case study of the Shiwuli River. *Ecological Indicators 99*, 324–331.

Zhengxian, Z., Yun, L., Xiaogang, W., Yuan, X., Yipeng, L., Zhiyong, W. & Nanbo, T. (2021). Investigating the spatiotemporal dynamic evolution and driving factors of wastewater treatment efficiency in the context of China's River Chief system. *Ecological Indicators 129*, 107991.

Ziyan, K., Jianfeng, T., Lei, Y., Jing, S. & Yaoyang, X. (2023). Linking pharmaceutical residues to dissolved organic matter and aquatic bacterial communities in a highly urbanized bay. *Science of the Total Environment 871*, 162027.

Zsombor, S. & Szabolcs, D. (2022). Distance-based aggregation in group AHP. *Journal of Decision Systems 31*, 98–106.

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