Wetland Mapping and Landscape Analysis for Supporting International Wetland Cities: Case Studies in Nanchang City and Wuhan City

Geng Zhipeng, Weiguo Jiang, Kaifeng Peng, Yawen Deng, and Xiaoya Wang

***Abstract*—As the second batch of international wetland cities, Wuhan and Nanchang, both provincial capital cities in China, have abundant wetland resources. An important sign of achievement of protecting the urban wetland areas is the international wetland city designation. Understanding the growth and changes of wetlands in international wetland cities is necessary for wetland protection and management. Thus, it is crucial to conduct proper wetland mapping in these international wetland cities. By studying wetland cities, sustainable planning can be provided to promote the coordinated development of wetlands and cities. In this research, Google Earth Engine and random forest machine learning were used. According to the "Data-Information-Knowledge-Wisdom" research framework, we carried out mapping of diverse wetlands in Wuhan and Nanchang with a resolution of 10 m in 2015 and 2020. Then, using the findings of wetland mapping, we examined changes in the wetland landscapes of the two cities. Finally, this study examined changes in international wetland city indicators over this time frame. The research results are as follows. 1) Our wetland mapping results in 2015 and 2020 achieved good accuracy, with an overall accuracy of over 0.90 and a kappa coefficient of over 0.85. 2) The total wetland area in both cities increased. Nanchang grew by 91.11 km^2, whereas Wuhan grew by 290.68 km^2. Most restored wetland areas were far from urban construction areas. In the two cities, the fragmentation of wetlands decreased, the diversity of wetlands increased, and the growth rate of wetlands was high. 3) Wetland rates rose from 17.79% to 19.07% in Nanchang and from 19.74% to 23.12% in Wuhan, according to mapping results between 2015 and 2020. The wetland protection rate in Nanchang remained unchanged, but the wetland protection rate in Wuhan decreased. Wuhan needs to strengthen the protection of increased wetlands. In addition, the study found that most of the increased areas of wetlands were previously cultivated land. The international wetland mapping framework of this study can be easily implemented in other regions of the world.**

***Index Terms*—Data-information-knowledge-wisdom (DIKW), international wetland city, wetland landscape, wetland mapping, wetland rate (WR).**

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I. Introduction

WETLANDS are one of the most significant living habitats for humans, and they are multifunctional and biodiversity-rich ecosystems [1], [2]. Wetland ecosystems have multiple functions, such as maintaining biodiversity, carbon sequestration, water circulation, water purification, and regulating local climate [3], [4]. In addition, wetlands also have important value for cultural and historical heritage and sustainable economic and social development [5]. The wetland ecosystem is mainly affected by climate change and human activities [6], [7], [8]. Since the middle to late 20th century, people have used ecological resources intensively. Examples include overusing wetland water, sediment deposition brought on by the construction of water conservation projects, damage from coastal erosion, and urban development. These factors have caused wetland ecosystems to degrade, resulting in a decrease in wetland area, water quality, and biodiversity and a loss of wetland function [9], [10], [11], [12]. Therefore, it is critical to preserve, rehabilitate, and restore wetlands. On this basis, the top priority in urban development and construction is minimizing the impact of urban construction on the natural environment and taking into account, the protection of wetlands in the process of urban growth [13].

The international wetland city is proposed by the "Convention on Wetlands of International Importance especially as Waterfowl Habitat," also known as Wetland Cities [14]. Its purpose is to protect the natural environment while promoting urban economic growth. So far, international wetland cities have applied for two batches. In applying for an international wetland city in China, it needs to protect and restore wetlands to meet corresponding indicators. This had a good impact on the protection of urban wetlands in China [15]. To comprehend the changes brought about by the bid for international wetland cities, it is crucial to conduct extensive mapping of international wetland cities and collect the present status of wetlands in these cities [16]. The research of International wetland cities focuses on the ecological functions, biodiversity maintenance, water resource management, and other issues of wetlands, exploring the sustainable development of wetlands and cities. It involves wetland cities in different countries and regions, helping to promote experience sharing and cooperation between different regions, and providing cross-border cooperation opportunities for wetland protection and urban planning.

Currently, the majority of urban wetland research is built upon the analysis of already available data. For instance, Yang et al. [17] created a comprehensive index system for evaluating the ecological environment of urban wetlands by analyzing the ecological, geological, and environmental aspects impacting urban wetlands. Festus et al. [18] described the landscape structure of urban wetlands and their contribution to sustainable development using landscape and terrain indices. Lorenzo-Sáez et al. [19] analyzed the amount and accessibility of urban green space at the local level, as well as the direct contribution of urban green space to sustainable development goals. By combining random forest (RF) regression with the Conversion of Land Use and its Effects at Small regional extent (CLUE-S) algorithm, Peng et al. [20] created a spatial allocation model to mimic the spatial dynamics of wetlands in the Wuhan urban agglomeration. Ma et al. [21] created a model for assessing landscape ecological risk, examined the characteristics of its geographical distribution in Dong Ying City in 2020, and identified ecological source points and corridors. Specialized wetland mapping is required for the study region because the analytical outcomes of these studies depend on the data sources.

The existing single category of wetlands cannot meet the research needs of urban wetlands, and it is more suitable for specialized research. Single wetland data types make up the majority of wetland data. For example, water inundation frequency data are widely used in wetland research [22]. Due to the spectral properties and significant ecological implications of mangrove characteristics, mangrove data are extensively studied and exploited [23]. Coastal mudflat data are widely used in the study of coastal cities and marine resources [24]. These statistics simply classify wetlands into broad groups without providing a more in-depth classification [25]. For this situation, Wang et al. [26] successfully mapped international wetland cities using the RF method paired with Google Earth Engine (GEE). This study conducted wetland mapping for two international wetland cities, Wuhan and Nanchang, drawing on Wang's research concepts.

Chen et al. [27] believe that it is necessary to use full chain research in remote sensing analysis. It can integrate remote sensing data acquisition, preprocessing, feature extraction, classification and detection, validation and evaluation, and application in the process of land use and cover monitoring. The goal of full chain research is to integrate various links. By constructing a complete land use monitoring system, it can meet the needs of relevant fields. This article proposes a full chain research based on the data-information-knowledge-wisdom (DIKW) model. The application of the DIKW system is based on the comparative analysis of data, information, and knowledge [28]. It is information that is related to specific situations after "understanding" and can guide "how" to act [29]. In the study of ecological protection and sustainable development, some scholars believe that the analysis and solution of problems according to the research paradigm of DIKW can effectively protect and detect the ecological environment [30]. This research paradigm can be used to attain the related ecological goals that policy-makers can bring about through the methodical process of developing knowledge from data [31]. The research paradigm for wetland mapping by Peng et al. [32] was the DIKW research paradigm, which outlines the steps from data production through analysis outcomes. To create a research framework for wetland city mapping, this project builds on DIKW. It is possible to examine the wetland landscape pattern and ecological changes of international wetland cities using this paradigm to acquire mapping data for such cities.

At present, there is limited mapping and change analysis for international wetland cities, and our research provides a supplement. The study selected two inland cities from the second batch of international wetland cities, which have the best economic development in their respective provinces. It is more representative of studying urban development and wetland changes. Wetland mapping was performed in the two cities to examine how wetland distribution patterns and patterns changed before the cities were designated international wetland cities. We can look at the benefits for the city's wetlands and the urban biological environment of the city's proposal to host an international wetland metropolis. Theoretically, it supports both other cities' bids to become international wetland cities and the sustainable development of international wetland cities. The content of this study is as follows:

1) international wetland city classification techniques and precision evaluation;
2) analysis of wetland landscape pattern change;
3) examination of how the international wetland city series index has changed.

II. Materials and Methods

A. Study Area

Nanchang City (latitude: 115°27′–116°35′E, longitude: 28°10′–29°11′N) is a region whose territory is mainly plains. The city has numerous lakes, rivers, and other waterways [33]. Wuhan City (latitude: 13°41′–115°05′E, longitude: 29°58′–31°22′N), which is low and flat in the center and hilly in the north and south, belongs to the transition area from plains to hills. There are many small lakes and rich water systems in the city. The Yangtze River passes through the city [7]. With an average annual temperature of 15–18 °C, Nanchang and Wuhan have a subtropical monsoon climate. Their provinces are connected, and both belong to the middle and lower reaches of the Yangtze River [34]. Both cities have a frost-free period of 211 to 272 days. Their annual average precipitation ranges from 1100 to 1700 mm. Suitable for the growth of plants, they are ideal areas for plant growth. In 2022, the two cities successfully applied for the establishment of an international wetland city. Applying for international wetland city status requires time for preparation, thus the years 2015 and 2020 were chosen for the study to reflect changes in the wetlands of the two cities. They are very representative of the provincial capitals of China. The location of the two cities is shown in Fig. 1.

B. Auxiliary Data

GEE has the characteristics of a large number of calculations, fast calculation speed, and high accuracy. Combining the advantages of GEE and machine learning has been proven to be a successful method for rapid and high-precision extraction of

TABLE I
DATA USED IN THE CLASSIFICATION PROCESS

Product name	Date	Spatial resolution	References	Usage
Sentinel-2	2015,2020	10 m	https:// earthengine/datasets/catalog/sentinel	Datasets used in GEE
Landsat-8	2015,2020	30 m	https:// earthengine/datasets/catalog/landsat-8	
JRC	2015,2020	10 m	Pekel et al. [22]	References to sampling points for wetland
Dynamic World	2015,2020	10 m	Brown et al. [37]	
ESA_WC10	2020	10 m	Zanaga et al. [38]	
FROM_GLC30	2015	30 m	Gong et al. [39]	
CLCD	2015	30 m	Yang and Huang [40]	
GRanD	—	—	Mulligan et al. [41]	Reference for validation
GRWL	—	—	Allen and Pavelsky [42]	

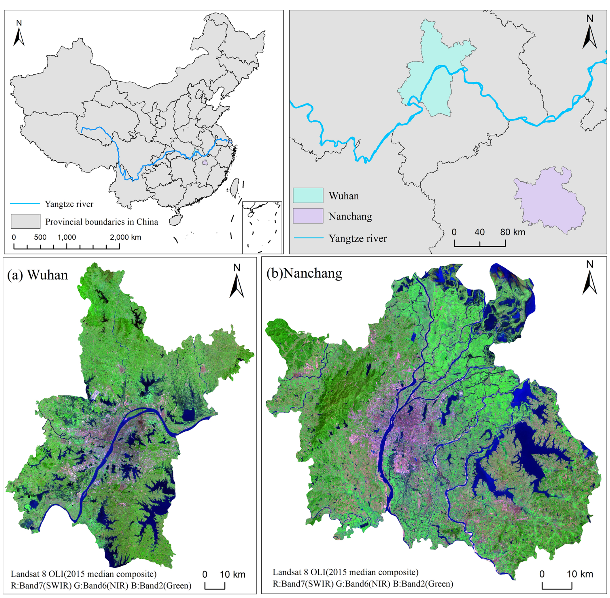


Fig. 1. Study area including Wuhan and Nanchang.

wetland cover types [35], [36]. In this study, combining GEE and RF is used to carry out research on wetland city mapping with a 10-m spatial resolution. We first adopted the stratified sampling principle to sample the study area. To ensure the richness of sampling, this study collected sampling point data for different ground feature categories based on high-resolution images and existing land use data. The auxiliary data are shown in Table I. Eighty percent of the selected samples are used to train the classifier, and twenty percent of the samples are used to verify the classification accuracy. To ensure the accuracy of classification results, about 10 000 sample points were selected in the study area. The study focuses on wetlands, therefore, a larger number of sample points were selected for the wetland class. The number of sampling points can be found in Table II.

C. Research Process

This study suggests a complete framework for wetland information extraction and analysis of international wetland cities based on the research paradigm of DIKW. We believe that using this framework can better support the creation of international wetland cities and wetland ecological assessments.

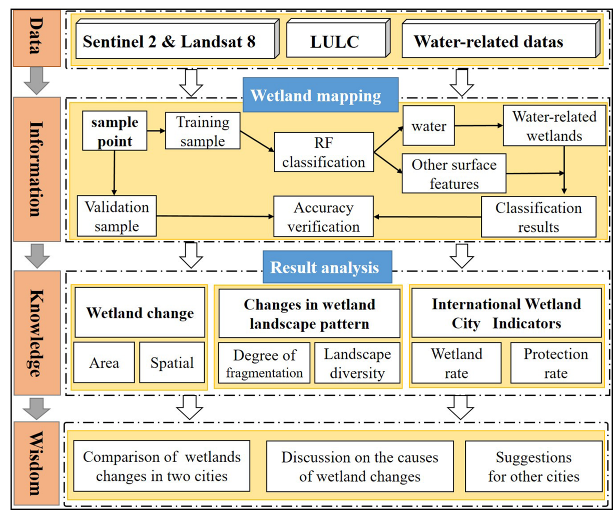


Fig. 2. DIKW-based framework for the research process.

Fig. 2 shows the framework which is mainly composed of the following parts.

1) Data representation research data, including remote sensing data, multiple land use/land cover (LULC) data, and water-related data.
2) The methods used are RF and knowledge rules, implemented on GEE. Extraction and accuracy evaluation of spatial distribution information of wetland types in 2015 and 2020.
3) Analyze the wetland mapping results and obtain corresponding results including wetland changes, wetland landscape pattern index, wetland area rate, and wetland protection area rate.

D. Methodology

1) International Wetland City Mapping Based on RF: The current methods used in land use classification research mainly include machine learning and deep learning. However, wetlands

TABLE II
NUMBER OF SAMPLING POINTS FOR WETLAND MAPPING

Land use	Nanchang in 2015	Nanchang in 2020	Wuhan in 2015	Wuhan in 2020
	Sampling point	Sampling point	Sampling point	Sampling point
river	500	500	500	500
pond	500	500	500	500
Reservoir	500	500	500	500
lake	1500	1500	1500	1500
Herb wetland	724	1028	867	1000
Beach land	407	244	160	154
Woodland	1500	1500	1200	1200
Grassland	400	200	179	418
Cultivated land	4000	4000	3000	2400
Built-up area	1500	1500	1200	1200
ALL	11531	11472	9606	9372

TABLE III
LAND USES CLASSIFICATION SCHEME FOR WETLAND CITIES

Land use	Description
River	Linear water body, extracted from auxiliary data
Lake	Large irregular water body. Intersection with reservoir point of interest (POI) data
Reservoir	Artificial large irregular water body. area>1hm^2
Pond	Small artificial water body. area<1 hm^2
Herb wetland	Natural wetland with dominant woody vegetation.
Beach land	Beach environments between the normal water level and the flood level of rivers and lakes.
Built-up area	The surface is formed by artificial construction activities and the bare lands
Woodland	Natural woody vegetation coverage area, including forests and shrubs
Grassland	The land is covered by natural herbaceous vegetation, and the coverage is greater than 10%
Cultivated land	Land cover for planting crops

are relatively complex, and international wetlands have just been applied in recent years, and the amount of data is insufficient to support deep learning data operations. The RF classification method is well compatible with the shortcomings of data, with fast speed and good accuracy. After comprehensive comparative research, RF was used as the classification method. Obtain sample points through remote sensing data and upload them to the GEE cloud platform. Based on sample points, we classify remote sensing images ten times based on sample points and select the mode of classification as the final result. The relevant code can be found in the attachment. The land cover classification scheme of international wetland cities is comprehensively determined, as shown in Table III [43]. Referring to the research of Wang et al. [26], the first step is to classify water, built-up areas, woodland, grassland, beach land, cultivated land and herb wetland. Then, the water is divided into rivers, reservoirs, lakes, and ponds. The classification categories were obtained by incorporating local wetland characteristics. Confusion matrix is used to evaluate the results of wetland classification. Based on the evaluation results, the overall accuracy (OA) and kappa coefficient of the mapping are obtained.

2) Analysis of Wetland Landscape Patterns in International Wetland Cities: In this article, the fragmentation index is used to represent the fragmentation degree of landscape segmentation, which can reflect the complexity of landscape spatial structure [44]. The diversity index is adopted, which reflects the richness and complexity of wetland landscape types [45]. The land use change index is used to measure the change range of land use type of wetland types in Wuhan and Nanchang before applying for the international wetland city [20]. The formulas are as follows:

$$C_i = \frac{N_i}{A_i} \tag{1}$$

$$\mathrm{H} = -\sum_{i=1}^{m} (P_i)(\log_2 P_i) \tag{2}$$

$$K = \frac{L_b - L_a}{L_a} \times \frac{1}{H} \times 100\% \tag{3}$$

where C_i is the fragmentation index of land use *i*, N_i is the number of patches in landscape *i*, and A_i is the total area of landscape *i*. The higher the C_i value, the higher the fragmentation of wetland type *i*. *H* is the diversity index, P_i is the proportion of the area of landscape type *i*, and *m* is the number of landscape types. The higher the *H* value, the higher the landscape diversity. *K* is the land use change of land type. In this study, this index represents the change in the area of wetland. L_a and L_b are the areas of a certain type of wetland land use type in 2015 and 2020, respectively, and H is the study period. The higher the *K* value, the faster the change in the area of this type of wetland.

3) Analysis of Changes in Indicators of International Wetland Cities: The Chinese government has formulated a more detailed "Nomination Measures for the Recognition of International Wetland Cities" [46]. According to land use classification results, it is easy to calculate the wetland coverage rate and the proportion of protected wetlands in different cities. Here, the term wetland rate (WR) refers to the proportion of the total wetland area to the total urban land area. The term wetland protection rate (WPR) refers to the proportion of the protected area of wetlands to the total area of urban wetlands. All wetlands in the Nanchang and Wuhan conservation parks are counted. The data from Gaode Map and related government documents were used in this study to calculate the area of protected wetlands. If applying to be called an international wetland city, the quantitative indicators require that the WR should not be less than 10% and the WPR should not be less than 50%. The formulas are as follows:

$$\mathrm{WR} = \frac{S_b}{S_a} \times 100\% \tag{4}$$

$$\mathrm{WPR} = \frac{P_a}{S_b} \times 100\% \tag{5}$$

where S_a represents the total area of the city, S_b represents the area of all wetlands in the city in that year, and P_a indicates that the wetland is within the boundary vector of the wetland protection space. That is, the wetland area covered by the policy protection scope, such as wetland parks, and the wetland protection area in the city.

III. Results

A. Accuracy Analysis of Mapping Evaluation Results for Two International Wetland Cities

We compare the wetland mapping data with existing easily available mapping data, based on 20% of sample points. The comparison of remote sensing images and the accuracy are shown in Fig. 3. CLCD does not have wetlands in these two cities, therefore precision evaluation was not conducted. Dynamic World mapping data is missing and distorted. From Fig. 3, it can be seen that ESA data and wetland mapping data have good classification performance. The results of OA and kappa also prove this point. Due to different drafting standards, these data also have their own advantages. The result of the accuracy evaluation is mainly considering the accuracy of wetlands. The accuracy results of Wuhan and Nanchang in 2015 and 2020 are shown in Table IV. Wuhan and Nanchang have similar accuracy results. The producer's accuracy (PA) and user's accuracy (UA) of woodland in the two cities are higher, followed by cultivated land and built-up area, and grassland is the worst. For the PA and UA of rivers, reservoirs, lakes, and ponds are above 0.95. Herb wetland, beach land, and grassland accuracies are poor because these land uses are often mistaken for other land uses. Due to the conversion between herb wetlands and water bodies in different seasons, the selection of sample points for classification will be affected. The wetland mapping results in 2015 and 2020 achieved good accuracy, with OA over 0.90 and a kappa coefficient over 0.85, which can be used for statistical analysis.

B. Wetland Changes in Wuhan and Nanchang From 2015 to 2020

The wetland maps of Wuhan and Nanchang in 2015 and 2020 are shown in Fig. 4. The spatial distribution of wetlands in Wuhan has the following characteristics.

Herb wetlands are mainly distributed on the banks of rivers and lakes adjacent to the Yangtze River and are less distributed in the city. Rivers mainly include the Yangtze River and its tributaries that run through the city. Lakes and reservoirs are distributed not only around the Yangtze River but also in the northern mountains and southeast of the city. The area of beach land is small, mainly distributed along the Yangtze River. The overall trend is more in the south and less in the north, distributed along both banks of the Yangtze River. The herb wetlands in Nanchang are mainly distributed in large lakes and regions in the north and in the junction of lakes in the eastern part of the city. The river flows into the lake from south to north and passes through the downtown area; lakes are distributed in the north and east, and reservoirs are distributed in the central and western cities. Based on the wetland mapping results of Wuhan and Nanchang, the proportion of wetlands in both cities is high, and the majority of wetlands are rivers, lakes, and herb wetlands. However, the distribution of wetlands in Wuhan is relatively balanced, and the distribution of wetlands in Nanchang is more extreme, with different spatial distribution trends.

The wetland area in the two cities changed significantly from 2015 to 2020. The results of the area change of all land uses in Wuhan and Nanchang from 2015 to 2020 are shown in Fig. 5. The total wetland area in Wuhan increased from 1693.80 to 1984.48 km^2, whereas the total wetland area in Nanchang has increased from 1277.01 to 1368.12 km^2. In short, the wetland area in Wuhan has increased by 290.68 km^2, whereas the wetland area in Nanchang has increased by 91.11 km^2. Both cities have a significant increase in the area of herb wetlands. The herb

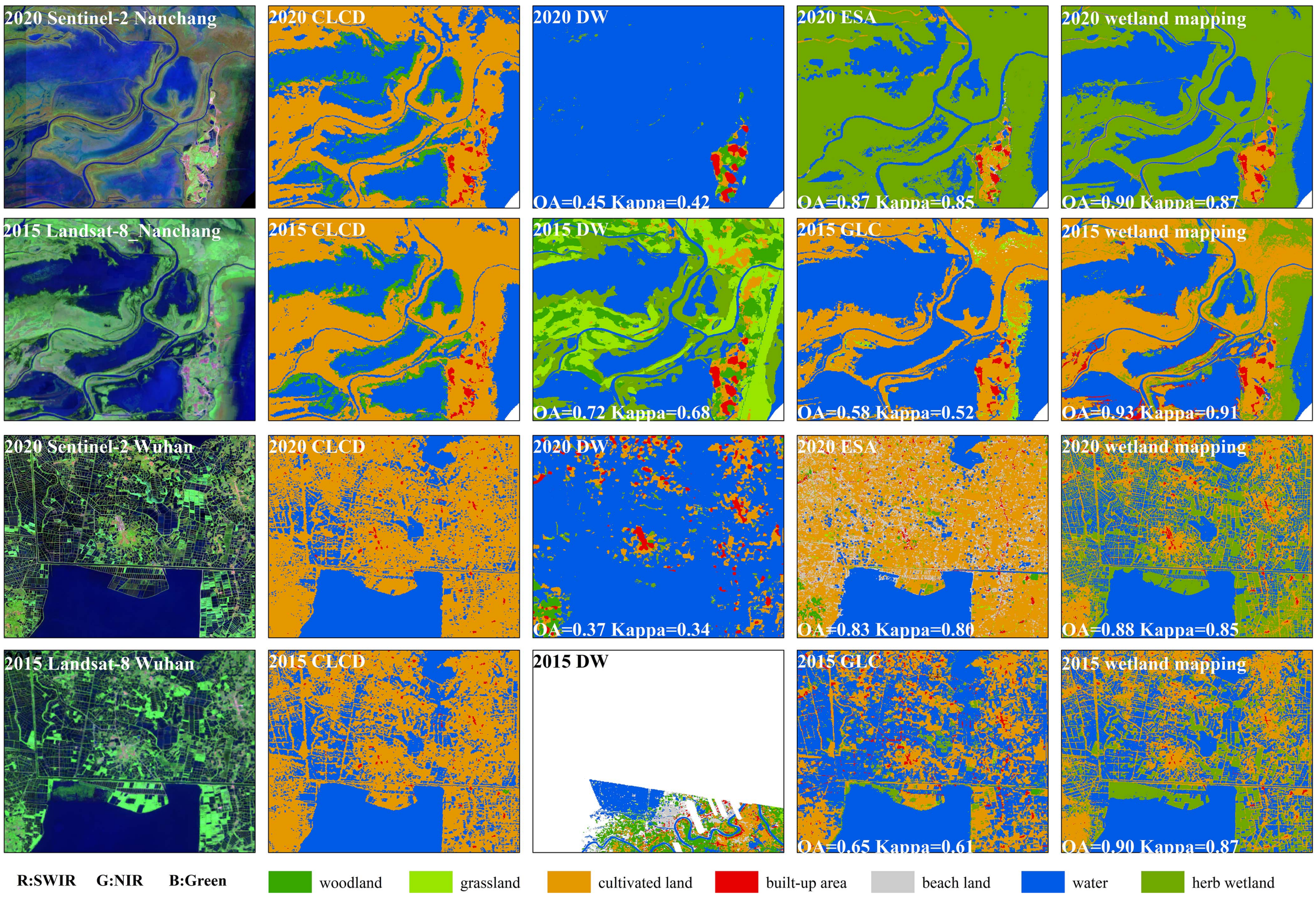


Fig. 3. Comparison of accuracy between wetland mapping results and other mapping data.

TABLE IV
LAND USE ACCURACY RESULTS OF WUHAN AND NANCHANG IN 2015 AND 2020

Land use	Nanchang in 2015		Nanchang in 2015		Wuhan in 2015		Wuhan in 2015	
	PA	UA	PA	UA	PA	UA	PA	UA
River	0.96	0.95	0.97	0.96	0.96	0.97	0.97	0.97
Reservoir	0.96	0.96	0.98	0.97	0.97	0.98	0.98	0.95
Lake	0.96	0.95	0.95	0.97	0.97	0.96	0.98	0.96
Pond	0.97	0.96	0.96	0.95	0.96	0.95	0.95	0.93
Beach land	0.88	0.93	0.87	0.95	0.70	0.88	0.66	0.91
Herb wetland	0.67	0.92	0.60	0.83	0.78	0.89	0.64	0.77
Woodland	0.94	0.97	0.94	0.98	0.96	0.98	0.98	0.99
Grassland	0.65	0.78	0.67	0.81	0.68	0.82	0.60	0.80
Cultivated land	0.97	0.83	0.98	0.89	0.98	0.89	0.92	0.81
Built-up area	0.89	0.91	0.92	0.97	0.87	0.87	0.90	0.91

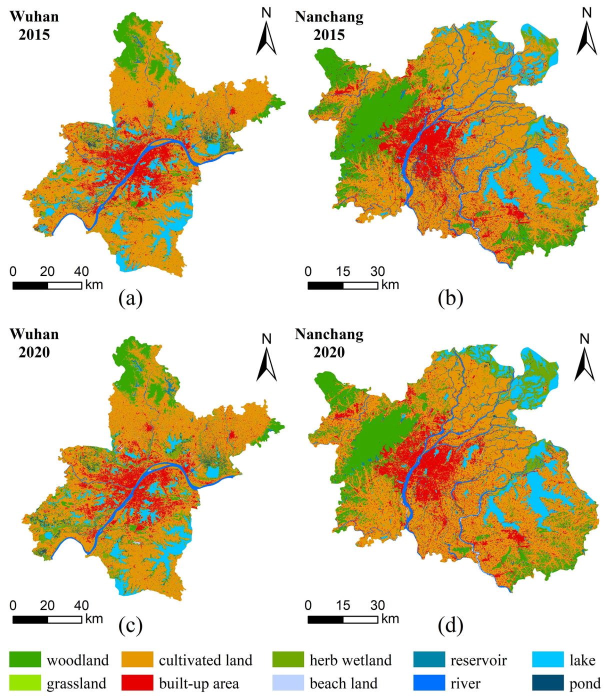


Fig. 4. Land use mapping results for Wuhan and Nanchang in 2015 and 2020.

wetlands in Wuhan have increased by 415.08 km^2, whereas the herb wetlands in Wuhan have increased by 153.75 km^2. The possible reason is that seasonal lakes and rivers are prone to transformation with herb wetlands [47]. Therefore, in the mapping results, the area of herb wetlands increased more than the total wetland area.

To analyze the spatial changes in wetlands in Wuhan and Nanchang in the process of international wetland city application. All wetlands in the two cities are classified into three types: increase, unchanged, and decrease. To demonstrate spatial changes, we selected four typical spatial areas. These are shown in Fig. 6. Wetlands in the two cities exhibit similar spatial changes. The increased location of the Nanchang wetland is at the boundary of the northeast lake. The increase in wetlands in Wuhan is mainly in the areas around the lakes in the southwest. The increased locations of wetlands in both cities are located around lakes far from built-up areas. Although the wetland areas of these two cities increased, there are still some wetlands decreased. In Wuhan, lakes decreased by 151.38 km^2, ponds decreased by 16.21 km^2, and rivers decreased by 14.16 km^2. In Nanchang, rivers decreased by 26.25 km^2, reservoirs decreased by 5.60 km^2, lakes decreased by 7.18 km^2, and ponds decreased by 10.29 km^2.

The small area of wetlands located in the central and southern regions of Nanchang decreased significantly. The wetland decrease in Wuhan is mainly concentrated in built-up areas on the north bank of the Yangtze River. Among them, Fig. 6(a), (b), (e), (h), and (g) shows typical wetland increased regions. According to the mapping results, these typical increased areas are located in areas far away from built-up areas, with most of the surrounding areas being cultivated land. During the 2015–2020 period, the area of wetlands increased significantly, and the categories of wetlands also increased. The significantly increased wetland type is herb wetland. Moreover, Fig. 6(c), (d), and (f) are typical decreased regions. The wetlands in these areas are mainly located in built-up areas. During 2015–2020, the wetlands in these areas decreased slightly, with some wetlands turning from water into herb wetlands. Based on the results of typical regional images and statistical analysis, the main types of wetland growth in Wuhan are ponds and herb wetlands. The growth of wetland types in Nanchang is dominated by herb wetlands.

TABLE V
Fragmentation Index of Wetland Features in Wuhan and Nanchang in 2015 and 2020

City	Nanchang		Wuhan	
Year	2015	2020	2015	2020
Herb wetland	599.80	194.41	462.89	411.56
Beach land	595.57	379.29	2120.73	1079.61
Reservoir	4.34	5.51	18.99	1.06
River	5.68	6.97	0.46	0.54
Lake	3.84	2.54	0.70	0.73
Pond	449.72	365.85	300.34	335.34

The transfer area of land use in Wuhan and Nanchang is shown in Fig. 7. The land use change in Wuhan and Nanchang can be divided into two types. One is the transformation of wetlands and nonwetlands. The figure shows the transfer between woodland, grassland, cultivated land, built-up areas, and wetlands. From 2015 to 2020, a large amount of cultivated land in the two cities was converted to wetlands. Among them, 409.84 km^2 of cultivated land in Wuhan has been converted into wetlands, while 233.04 km^2 in Nanchang has been converted into wetlands. The cultivated land in Nanchang has also increased by 32.99 km^2, and the building area has increased by 16.44 km^2, all of which come from the transformation of forest land. This shows that Nanchang is still increasing its built-up area while adding wetlands, while Wuhan is mainly focusing on the transformation of adding wetlands. The other is the transfer between wetlands. There are many changes between Wuhan and Nanchang wetlands with similar characteristics, especially for wetland categories, such as ponds, herb wetlands, and beach land. There are many transitions between these wetlands, which may be influenced by climate or human activities.

C. Analysis of Landscape Index Changes in Wuhan and Nanchang

The wetland landscapes in Wuhan and Nanchang have obvious similarities. The change results of the fragmentation index of wetlands are shown in Table V. The fragmentation index of herb wetlands, beach land, and ponds in the two international wetland cities is high, indicating that the connectivity of these three types of wetlands is poor. From 2015 to 2020, the fragmentation of these three types of wetlands in Nanchang decreased significantly, which indicates that the connectivity of

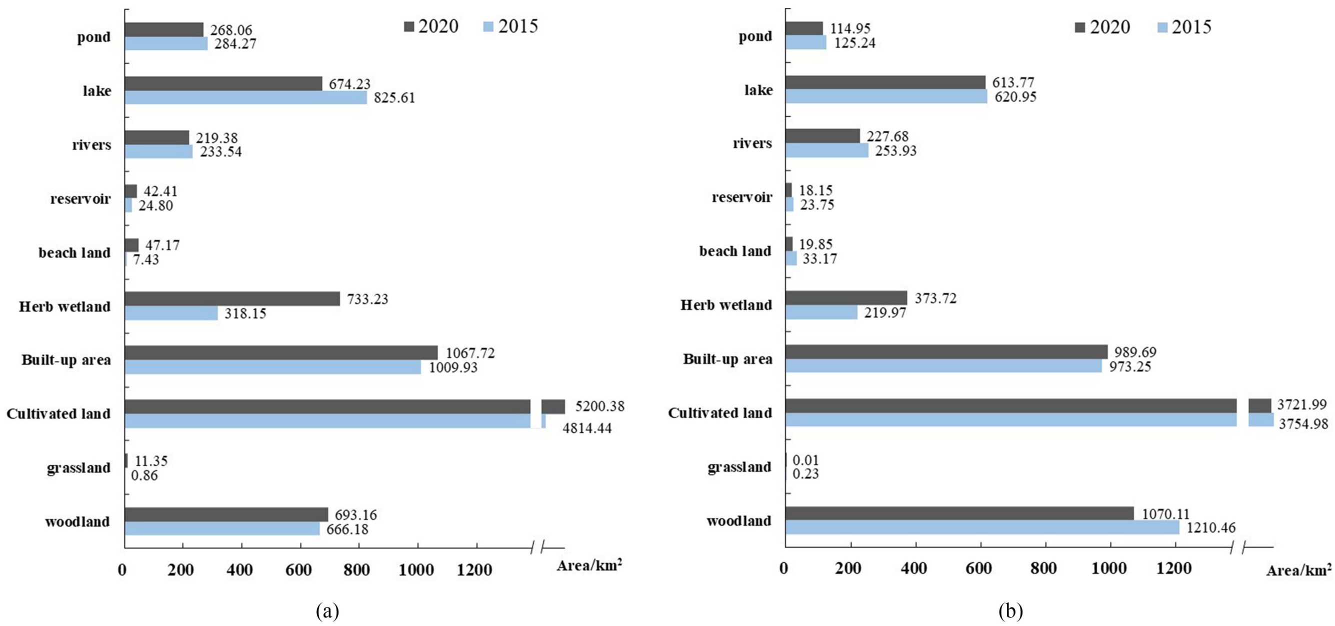


Fig. 5. Land use areas of Wuhan and Nanchang in 2015 and 2020. (a) Wuhan. (b) Nachang.

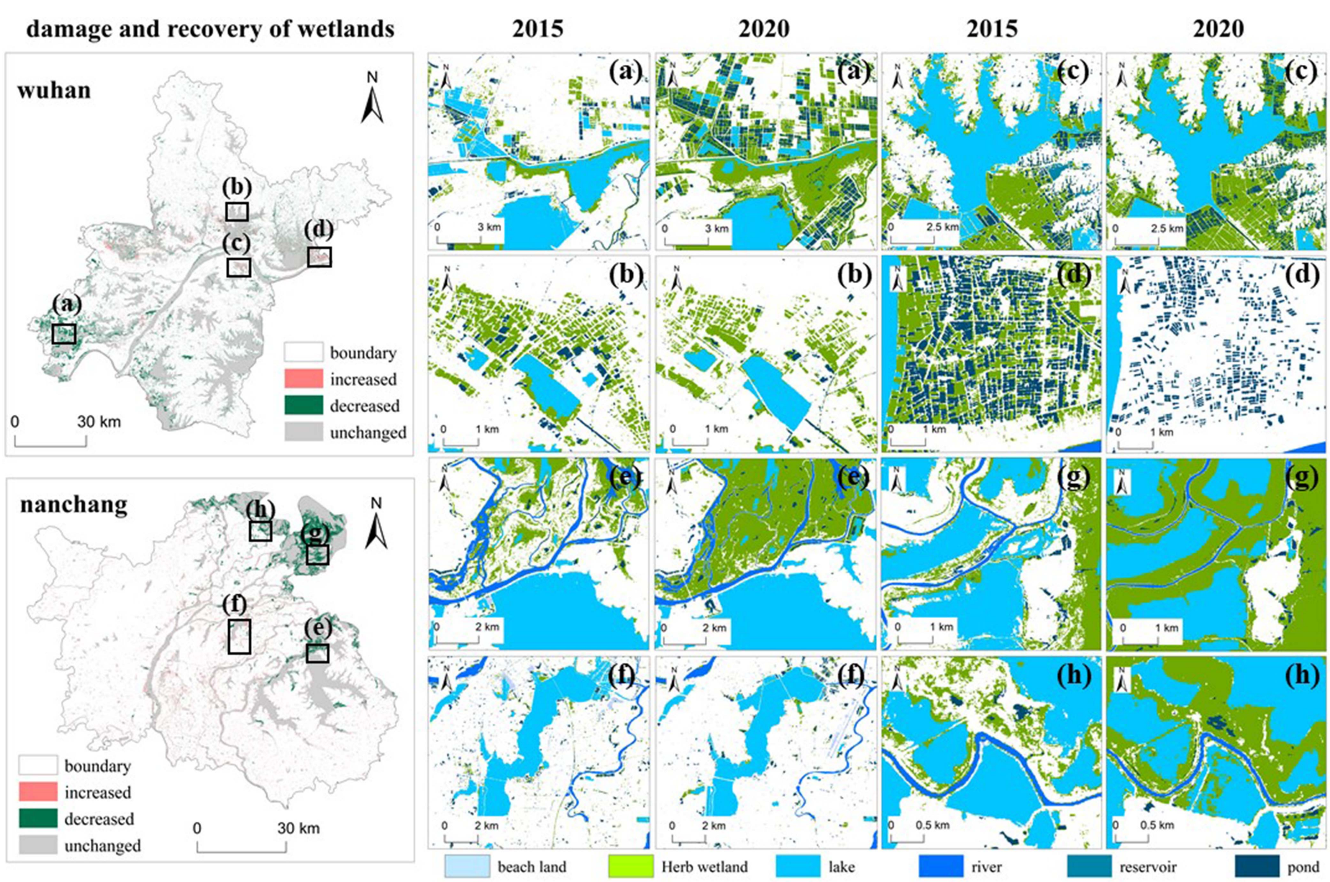
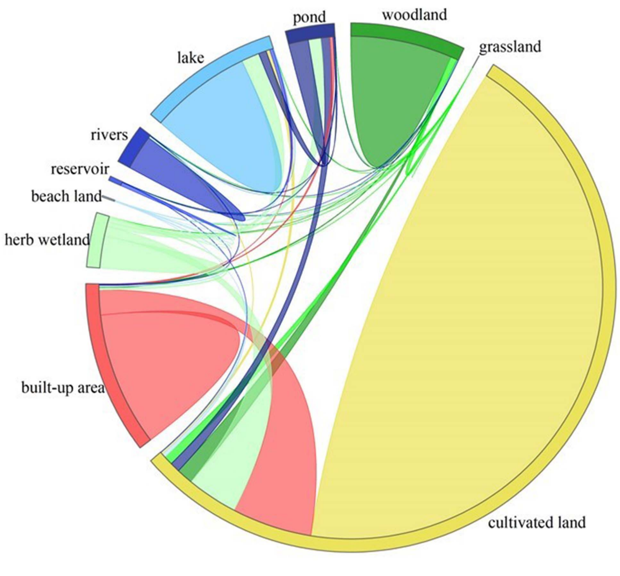
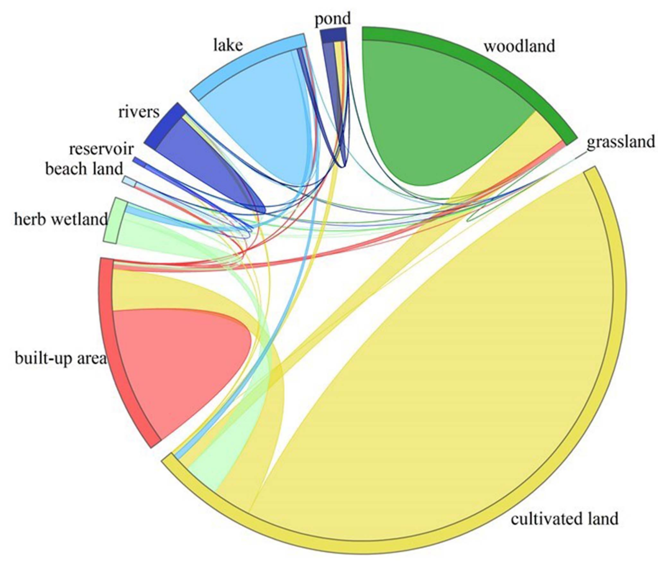


Fig. 6. Spatial changes in wetlands in Wuhan and Nanchang from 2015 to 2020. (a), (b), (e), (h), and (g) Typical regions for wetland growth. (c), (d), and (f) Typical regions for wetland reduction.



(a)



(b)

Fig. 7. Chord diagram of land use transfer in Wuhan and Nanchang from 2015 to 2020. (The outer circle represents the area of land uses in 2015; the inner circle represents the area in 2020). (a) Wuhan. (b) Nanchang.

TABLE VI
WETLAND DIVERSITY INDEX IN WUHAN AND NANCHANG IN 2015 AND 2020

City	2015	2020
Nanchang	0.79	0.82
Wuhan	0.84	0.96

these three types of wetlands increased. The fragmentation index of herb wetlands and beach land in Wuhan decreased from 2015 to 2020, but the fragmentation index of ponds increased. The fragmentation index of reservoirs, rivers, and lakes is small, and the connectivity of these three types of wetlands is good. Although there were changes in Wuhan and Nanchang during 2015–2020, the changes were small. In general, the fragmentation index of wetlands in Wuhan and Nanchang decreased. The degree of fragmentation represents the degree of fragmentation of the landscape, which reflects the complexity of the landscape spatial structure and the degree of human interference with the landscape. Therefore, it can be considered that the impact of human activities on the wetlands in the two cities has been reduced, and the connectivity between wetlands has been improved in the two cities.

The landscape diversity index of wetlands in the two cities was analyzed, including lakes, rivers, ponds, herb wetlands, beach land, and reservoirs. The results are shown in Table VI. The wetland landscape diversity index of Nanchang and Wuhan increased from 2015 to 2020. In Wuhan, the wetland diversity index increased from 0.84 to 0.96. The wetland diversity index in Nanchang increased from 0.79 to 0.82. The wetland diversity index reflects the richness and complexity of wetland landscape types [47]. The increase in the wetland diversity index indicates that the richness and complexity of wetlands have increased.

The land use change index reflects the intensity of wetland change. Fig. 8 shows the area change rate of all types of wetlands in Wuhan and Nanchang from 2015 to 2020. The index of herb wetlands in Nanchang increased significantly, with a growth rate of 0.69. The indices of beach land, reservoirs, lakes, and ponds all decreased. The maximum reduction in beach land is 0.40, and the minimum reduction in lakes is 0.01. The wetland area in Wuhan increased significantly, especially the wetland change index of herb wetlands, beach land, and reservoirs (1.3, 5.36, and 0.71, respectively). The wetland area of rivers, lakes, and ponds decreased, and the index is less than 0.20. The wetland change indices of Wuhan and Nanchang differ significantly, especially for the relatively small mudflats and reservoirs. Jiang et al. [49] believe that larger wetlands have a greater ability to withstand external environmental impacts. In this study, wetlands with small areas showed significant changes. Therefore, we believe that wetlands with smaller areas are more susceptible to changes under the same external environment.

D. Analysis of Index Changes in International Wetland Cities

The designation as an international urban wetland city requires that the WR in the administrative region should exceed 10% and the WPR should not be less than 50%. The goal of becoming a wetland city is to follow the relationship between wetlands and people and fully consider the integration of cities, wetlands, and people's well-being. Based on the results of wetland mapping, the WR can be obtained by analyzing the proportion of wetland-type features in the urban area. To calculate the protection rate, it is necessary to count the wetland area in the protected areas and parks of the two cities. The protected areas include wetlands included in the government documents. The results are shown in Table VII. Compared with the changes during 2015–2020, the WPR in Nanchang has essentially not

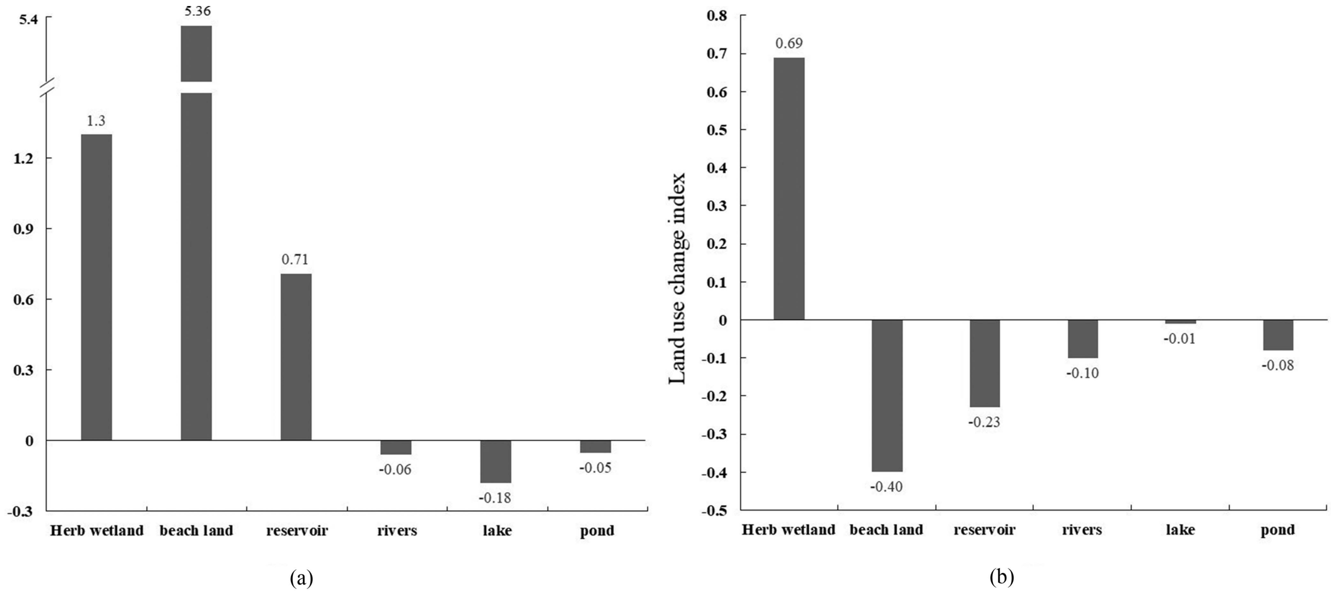


Fig. 8. Land use change index of wetlands in Wuhan and Nanchang from 2015 to 2020. (a) Wuhan. (b) Nanchang.

TABLE VII
CHANGE IN WETLAND PROTECTION RATE AND WETLAND RATE IN WUHAN AND NANCHANG

WR	2015	2020	WPR	2015	2020
Wuhan	19.74%	23.12%	**Wuhan**	54.05%	48.57%
Nanchang	17.79%	19.07%	**Nanchang**	66.07%	66.20%

increased, but the WPR in Wuhan has decreased. This is because the added wetlands in Wuhan are not in protected areas (covered by protection policies).

IV. GUIDELINES FOR GRAPHICS PREPARATION AND SUBMISSION

A. *Reasons for the Change in Herb Wetlands in Two Cities*

According to the results section, the area of herb wetlands in both cities has increased most significantly. Here are two main reasons for the increase in herb wetlands. The first reason is the weakening of human impact on the environment. The decrease in human activities' invasion and destruction of wetlands may be due to the adoption of wetland protection policies by the two cities. Wuhan has currently divided six national-level large-scale wetland protection parks to strengthen wetland protection. Nanchang has issued the Poyang Lake Protection Act, which does not allow reclamation of farmland from the lake, and requires that farmland be returned to the lake. Both cities have introduced strict wetland protection bills. The bills include hiring some wetland protection experts, including water conservancy, natural resources, ecological environment, urban–rural development, agriculture and rural areas, and meteorology. The bills encourage citizens and other organizations to participate in wetland protection through voluntary services, donations, cooperation, and other forms. Units and individuals who have made outstanding contributions to wetland protection work will be commended and rewarded. If there is any behavior that damages the wetland, it will be punished. The second reason is that the growth conditions of herb wetlands are suitable. Herb wetlands in Wuhan and Nanchang are mainly composed of reeds and fast-growing plants [50]. In some artificial wetlands, some herb wetlands have been artificially restored to protect riverbanks and purify wastewater. Artificial restoration of shallow water is a suitable growth environment for these herb wetlands. The climate conditions of these two cities are suitable for the growth of herb wetlands. In the context of policy protection of wetlands, wetlands can grow well in their natural state.

B. *Two International Wetland Cities Can Provide Suggestions for Other Cities*

The comparative analysis of Wuhan and Nanchang can better reflect the common points of the two different wetland cities and provide a reference for other cities to protect wetlands. In the process of applying for the international wetland city designation, the wetlands of the two cities have similarities and differences. The increase in wetlands in Wuhan is mainly related to the transformation of cultivated land. Nanchang exhibits similar trends as Wuhan, but the built-up area of Nanchang has also increased. The change in the two cities demonstrates that the increase in wetlands does not affect the construction and development of cities. The increase in wetland areas in the two cities is mainly due to the transformation of cultivated land. If other cities in China want to become wetland cities, they can take measures to transform farmland into wetlands and increase their WR. Besides, these cities should create more protected areas and wetland parks to improve WPRs.

The efforts of the two cities serve as a reference when applying for designation as an international wetland city.

1) *Management's attention*. The government departments and corresponding functional units in Wuhan and Nanchang have provided decision-making support for the bid to host an international wetland city. In particular, they plan the scope of protected areas and wetland parks to prevent the destruction of wetlands. At the same time, corresponding wetland policies have been issued, and corresponding protection and supervision institutions have been established. Clearly, wetland area, WPR, wetland ecological status, and other indicators should be included in the government performance assessment.
2) *Spare no effort in publicity*. Wetland publicity should be enhanced through education town halls, television broadcasting, WeChat social platforms, wetland websites, newspapers, volunteers, social welfare organizations, etc. Local organizations can carry out various forms of publicity activities to let the masses deeply understand, recognize, and protect wetlands.
3) *Reasonable utilization and sustainable development*. Emphases should be placed on wetland nature reserves and wetland parks, wetland agriculture, wetland flower industry, wetland product processing industry, wetland health industry, wetland ecotourism industry, etc., thus allowing for a win–win situation between wetland protection and utilization and economic development. The characteristics of these two different cities can provide a reference for other cities in China to apply for international wetland city status. However, the particularities of their respective cities should also be taken into account in the reference process.

C. Innovation and Applicability

At present, people use a variety of machine learning algorithms to study land use classification. After research and verification, RF shows relatively good results. This study uses existing land use data and auxiliary data to map international urban wetlands [51]. The literature shows that it is ideal for RF to have a large number of samples because it is directly related to accuracy [52]. Therefore, the number of sample points selected in this article is large, so the classification accuracy obtained by RF classification is higher. In addition, water is subdivided according to the knowledge rules so that the mapping of wetlands is more and the results are more detailed. Corresponding policy measures should be taken by comparing the changes in different wetland categories. For example, to meet the WR in the construction of international wetland cities, the government can adopt the policy of returning cultivated land to wetlands. To improve the WPR, more protected areas and wetland parks can be created in cities. This study is especially aimed at the wetland landscape of international wetland cities. It combines the DIKW research paradigm to build a comprehensive and systematic research framework for wetland information extraction, analysis, and decision support. The data used in the study include the existing land use data and some auxiliary data related to wetlands. Combining the auxiliary data to classify the land data can save manpower and material resources in the selection process of sample points. The software and GEE used in the study can be used for free or easily obtained. It is easy to transfer research to other cities and obtain the development status of corresponding urban wetlands.

D. Deficiencies and Prospects

Although this study provides a detailed classification of land cover in international wetland cities, there are still some limitations. In terms of classification methods, the classification method studied is RF classification. At present, this classification method has a high utilization rate, wide applicability, and strong universality. Some scholars can demonstrate the advantages of the improved method by comparing RF with some deep learning algorithms [53]. Due to the limitations of RF, it is difficult to improve the accuracy using a single method, but coupling RF with other methods can yield new discoveries and results. Coupling machine learning with other methods or models to improve efficiency and accuracy is also a future research trend. In classification, roads, and water bodies in buildings are easily misclassified, and some farmland and herbaceous wetlands are misclassified. This is a common problem in wetland classification work at present, due to the similarity of their spectra. We have introduced and modified some knowledge rules for other types and easily confused types and achieved good accuracy. This classification method is also more suitable for wetland classification. In the future, in-depth research will be conducted on the aforementioned homospectral foreign objects, geometric feature confusion, and other aspects. In terms of data acquisition, this study used Sentienl-2 and Landsat-8 data. Due to the limitation of data resolution, the classification of wetland types is not the most precise. With the popularity of high-resolution data both domestically and internationally, wetland classification based on high-resolution remote sensing data will be a new research direction in the future. However, considering the timing issue, it is necessary to solve the optimization problem of obtaining temporal and spatial scales through spatiotemporal fusion of multisource remote sensing data, which is a challenge for future research. The next step will consider conducting more detailed research on international wetland cities based on multisource remote sensing data, including the ecological functions of wetlands, the role of wetlands in urban ecology, and changes in ecological network patterns.

V. Conclusion

This research uses the overall DIKW framework, which is scientific and universal. Wetland mapping was conducted in Wuhan and Nanchang. The study used manual acquisition of sample points and combined RF and GEE methods for international wetland mapping. According to the results of the mapping, the wetland change characteristics of Wuhan and Nanchang before and after the bid for the international wetland city were analyzed. To serve the ecological construction and development of international wetland cities as a support for the research of international wetland cities. Research can provide accurate results of wetlands for international wetland cities, which is of great significance for the systematic research of urban wetlands. The research conclusions are as follows.

1) The accuracy of the mapping results of the two international wetland cities is high. The OA and kappa coefficients of the mapping results of Wuhan and Nanchang exceed 0.85. The results can be used for subsequent statistical analysis.
2) The spatial distribution of wetlands in Wuhan is generally more in the south and less in the north, while Nanchang is generally more in the east and less in the west. The increased area of wetlands in Wuhan is 290.68 km^2, including mainly herb wetlands and ponds. The increased area is located around the lake in the southwest of the city. The increased area of the wetlands in Nanchang is 91.11 km^2, which is mainly herb wetlands.
3) The increased area is located around the lake in the northeast of the city. The increase in the areas of the two wetlands is mainly due to the conversion of cultivated land. The wetland landscapes in Wuhan and Nanchang have obvious similarities. The fragmentation index of wetland surface features is reduced. The increase in the wetland diversity index. Therefore, we believe that the impact of human activities on wetlands in the two cities has decreased, while the connectivity between wetlands has improved, and the richness and complexity of wetlands have increased. At the same time, the categories of wetlands with smaller areas are more vulnerable to change due to the impact of the external environment.
4) The WRs of Wuhan and Nanchang are above the research standard of the international wetland city requirements, and the WR increased from 2015 to 2020. The WPR of Nanchang remained unchanged. The WPR of Wuhan decreased to less than 50%, and these growing wetlands in Wuhan lack corresponding protection.

The study found that the establishment of wetland parks around or inside the city can effectively protect the reduction of wetlands in the city. The establishment of the policy of protected areas away from urbanization can restore the wetland occupied by cultivated land.

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