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GIS-Based Empirical Research on Changes of Wuhan's Lake-side Pattern

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Abstract: There is often a close spatial relationship between urban development and water bodies. Functionally, the relationship can also be in many forms: from water supply for human and industrial use to purely aesthetic functions. These relationships are all, in their own way, critical elements of the sustainability of urban development, making the careful management for water bodies and riparian areas of fundamental importance. This study quantifies the historical changes of urban development pattern in lakesides of 27 lakes located in Wuhan's main urban area. Image data from 1989-2009 is used to analyze the spatial changes in a GIS environment. The study shows how the land development, such as urban construction, transportation and agricultural development have affected the riparian areas of these water bodies. It discloses objective laws governing the historical changes of Wuhan's lakeside pattern, and the correlations among the laws to provide strong technical support and theoretical reference for the future integrated development and protection of Wuhan's lakes and to present decision-making support for urban construction and management.

Keywords: Wuhan, GIS, lakeside pattern, historical changes

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0 Introduction

Various roles of water in the city

Urban waterfronts form the interface between water bodies and the adjoining land. The interactions between water and land are of paramount importance for their quality and functioning. The urban waterfront is an area showing many natural characteristics and rich natural processes[1]. While waterfronts have always been special places where land and water meet, they have also recently become sites where dramatic urban restructuring processes are occurring, thus it is also one of the areas most affected by human activities and urban disturbance[2]-[3]. Contemporary urban waterfront transformations both reflect and constitute changes in governance, economic regulation, and societal conception of the non-human environment[4]. This study examines some aspects of the urban transformation on lake front sites in Wuhan.

Definition of lakes and lakeside pattern

Chinese scientists define the lake as: a natural complex system including the lake basin, the lake water and the substances contained in the water (minerals, dissolved matters, organic matters and aquatic organisms, etc.), which participates in natural cycles of matter and energy[5]. The definition is quite comprehensive, however, it does not quantify the volume and area limitations of a lake, which leads to a degree of vagueness in their spatial extent. In fact, the concept of "urban lakeside" is relatively vague. In most cases, urban lakeside is used as an equivalent of urban waterfront. Literally, urban lakeside is a certain scope of intracity area where a water body meets its surrounding land and characterized by water and land together functioning as the dominant factors of its environment[6]. For practical purposes, the urban lakeside's spatial extent includes a water space of 200-300 m from the lake edge and the adjacent urban land space up to a distance of about 1-2 km or equivalent to 15-20 minutes' walking distance[7]-[8]. Besides, lakes are also defined as water bodies by some limnologists.

Research problem and value of this research

This study defines its research scope as "urban lakeside area". With focused and precise research scope, its findings are of higher practical value and pertinence. Wuhan is endowed with a favorable urban pattern of interconnected and densely distributed lakes and rivers with abundant water resources due to Wuhan's special historical geomorphic features. Wuhan has the highest number of lakes located at central urban area compared to other cities in China. Nevertheless, due to the city's fast urbanization and soaring population, its lakes are reduced drastically in

both quantity and water surface area in recent years. In addition. serious siltation is also occurred, which causes some lakes become swamps. Wuhan's lakes have high research value because of the stark contrast between their congenital excellent geomorphological features and its current conditions.

This study summarizes laws governing the land-use changes of Wuhan's lakeside areas and the internal mechanisms driving the changes through GIS quantitative data analyses of Wuhan's lakeside areas at three-time points (1989, 2000 and 2009). Therefore, the findings presented in this paper provides useful information for decision support and a scientific basis for Wuhan's future urban development and lakeside land use.

Domestic and international research trends

Waterfront land-use pattern and waterfront urban planning pattern have been studied intensively by scholars from many countries in recent years, with many papers published every year. Many urban development researchers have proposed the planning of waterfront land-use and urban patterns. For example, Liu Binyi and Zhou Jiang[9]-[10] from Tongji University proposed the concepts of urban waterfront attraction, waterfront vitality, waterfront carrying capacity and waterfront landscaping. Besides, Weng Yicheng[11] summarized the urban-design approaches for achieving sustainability of urban waterfront. Qiu Qiang and Xu Qianli[12] proposed a land-use planning guide for waterfront spaces of mountainous areas. Zeng Zhongping, Lu Xinmei[13] analyzed the temporal-spatial changes of Wuhan's lakes using remote sensing technology. Zhu Jianhong, Tang Xianli and Guo Zonglou[14] proposed appraisal of the urban waterfront landscape environment on the basis of fuzzy mathematic. Lastly, Liu Yaobin, Wang Qifang and Chen Hongmei[15] from China University of Mining and Technology analyzed the changes of Wuhan's lakes and the internal drive mechanisms governing these changes.

Some studies around this research topic started earlier in abroad. For example, Randall Thomas[16] studied energy-saving systems of urban waterfront areas. While Joan Roelofs[17] summered relevant factors and technical measures for water body implementation in green cities. Susan & Geoffrey Jellicoe[18] proposed the significance of the harmonious relations between water and nature and between water and people by studying the central urban waterfront landscape of Hadrian's Vila located in Tivoli, a lakeside city in Italy. L.Azeo Torre[19] summed up the positive and negative impacts of marginalization of water bodies and locating water bodies at urban centers on landscape benefits and economic benefits and conducted a comparative analysis by case studies of New Orleans waterfront, Port Louis sailing Village and Sea Florida, from the perspective of marginalized water. Apart from these, Ann Breen & Dick Rigby[20] summed up the waterfront's regional relations, planning and extension design from the perspective of urban waterfront culture, waterfront environment, waterfront history, mixed waterfront and re-shaped waterfront. Roy B. Mann[21] summarized ten recommendations for urban waterfront rehabilitation and its sustainable development. Jose Edgardo Abaya Gomez[22] proposed the possibilities and feasibility of waterfront design without the orientation of policy provisions. M. Davidson[23] summarized waterfront's post-industrial development and regional planning changes and proposed the interrelations between waterfront environmental resources and economic benefits. Lastly, Michelle E. Portman, Di Jin and Eric Thunberg[24] presented segmentation and assessment methods for waterfront land use and environmental resources.

1 Current problems of Wuhan's lakeside regions

Dramatic urban sprawl, population growth and accelerated economic development lead to increased demands for land. These changes have increasingly intensified the conflicts between the population and urban land shortage. Wuhan's lake areas and ecological environment have undergone a dramatic change under the influence of natural factors and human activities. Its lakes are encroached and filled continuously for agricultural, industrial and residential applications as well as for road traffic. The land use changes contribute to a decline in the natural, social and economic values of the lakes, which in turn endangers them to encounter further encroachment and ultimately their destruction.

1.1 Lake area reduction

The fast development of Wuhan is due to the congenital advantageous urban pattern of abundant lakes, rivers and water resource. Recent demands for land because of economic development and urban construction have led to the encroachment of most Wuhan's lakes to varying degrees, sharply dropping lake quantity and area, and disordering the lake development and utilization. According to relevant data, Wuhan had 127 lakes at its urban area in the

early 1950s with a water surface area of 273 km2. However, in early 1990s, a drastic decrease of 55% lead to only 38 lakes remained with a total area of 122 km2 in its central urban area[25]. As of November 30, 2001, Wuhan's Regulation on Lake Protection[26] refers 27 lakes at its urban area with a surface area of 59.9 km2. During the past 50 years, approximately 100 lakes in Wuhan's urban area were filled, with a reduction of lake surface area by more than 200 km2 and two lakes disappearing averagely each year. Under this critical situation, determining the specific causes behind this change of lake quantity and surface area is the focus of this study.

1.2 Disappearance of lake functions

Lakes have a natural function of flood storage. Repeatedly shrinking lake area elevates water level, reducing the flood storage and retention function of the lakes. The shoal and wetland areas of lakes are critical habitats for aquatic plants and animals and contain a wealth of species. Lake reclamation gradually deprives their ecological functions, damaging species diversity, aquatic habitats, water resources and bio-environment of the lakes. At the same time, the disorderly construction of urban infrastructure facilities, dams, bridges and roads weaken the functions of lakes, completely breaking and severing the interconnection among rivers, lakes and canals. It can be said that most of Wuhan's lakes are suffering from straightened and hardened shorelines, and following deterioration in ecological functions including biodiversity, degradation of contamination, water storage and drainage, as well as abating urban heat island effect. In fact, Wuhan's lakes are confronted with an unprecedented challenge.

1.3 Methods for extracting remote-sensing data

In the field of land-use suitability assessment, GIS techniques are acknowledged to be a powerful tool as implied by recent studies. The thesis takes advantage of remote image processing technology to deal with data of the main districts in Wuhan in 1989, 2000 and 2009. It finishes complete spatial data processing by means of geometric correction, pixel coordinate changing, resample, resolution merge, radiometric enhancement, supervised classification, visual decode and manual extraction. According to "Wuhan Lake Protection Regulations" objects for the research are determined as 27 lakes in the main districts of Wuhan with the details as shown in Table 1.

Table 1. List of 27 lakes in the main districts of Wuhan

Hankou（10）	West Lake, North Lake, Huanzi Lake, Jiqidangzi Lake, Lingjiao Lake, Houxiang Lake, Little South Lake, Tazi Lake, Zhuye Lake and Zhang Lake
Hanyang（7）	Moon Lake, Lianhua Lake, Moshui Lake, Longyang Lake, South Prince Lake, North Prince Lake, and Sanjiao Lake
Wuchang（10）	Dong Lake, South Lake, Yezhi Lake, Shuiguo Lake, Neisha Lake, Waisha Lake, Shai Lake, Simei Pond, Ziyang Lake and Yanchun Lake

Data adapted from: "Wuhan Lake Protection Regulations"

Within the scope of individual lake determined in Table 1, the thesis rapidly adds up data representing changes of lake areas in 1989, 2000 and 2009 by using ArcGIS Desktop software platform. It can then obtain the quantitative data representing the lake filling condition directly from the analysis of data extracted.

2 Remote-sensing analysis of Wuhan's lakeside land use

2.1 The nature of land use of Wuhan's occupied lakeside region

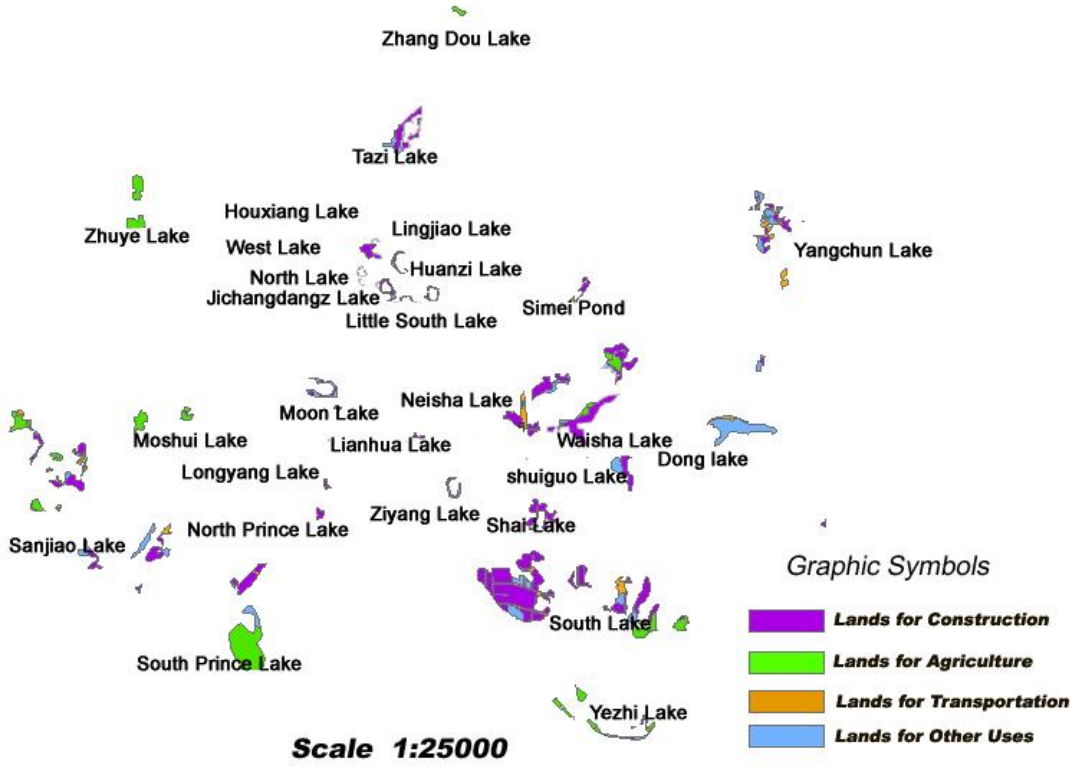
This study conducted a quantitative analysis of the land use types of land reclaimed from Wuhan's lakes at three-time points of 1989, 2000 and 2009 based on the relevant image data and various conflicts between Wuhan's lakes and urban development. Wuhan's lakes have undergone a massive reclamation and encroachment since 1989. In this situation, what land use encroached on lakeside land? Were there any temporal and regional differences among the changes of land use? This study revealed the intrinsic motivations for the encroachment and land use changes of Wuhan's lakes by answering these two questions. This study classified the uses of land

reclaimed from lakes into three categories, including land for construction (LC), land for agricultural use (LA) and land for transportation (LT) to analyze their impacts on lake evolution.

According to analysis on data obtained from two periods, 1989-2000 and 2000-2009, land reclaimed from Wuhan's lakes was mainly changed to LC. The land use types of land reclaimed from Wuhan's lakes during 1989-2009, respectively is displayed in Figure

1. Data analysis demonstrated that Wuhan's lakes were encroached continuously during Wuhan's urban sprawl and changed to other land uses, among which LC and LA were the most prominent.

Figure 1. Distribution of types of land use of land reclaimed from Wuhan's lakes during 1989-2009.



2.2 Conversions of different types of land uses

2.2.1 Land for agricultural use (LA)

Encroaching and filling Wuhan's lakes for LA has never been reduced. Among the lake changes in Wuhan's three towns, Wuchang and Hanyang was seriously encountered the problem of lake filling for LA from 1989 to 2000 (Table 2). The most prominent lake filling appeared around Sha Lake where about 16.62 hm2 of lakeside area was converted to LA. This ranking is followed by South Lake in Wuchang, where it lost about 20 hm2 of its water body due to agricultural reclamation, specifically from Chuxiong Avenue to the east on Guanshanyi Road. With the condition that Wuhan's urban centers gradually affected Hanyang, Hanyang was a key development area for lake filling as LA. Hanyang's lake areas suffering from reclamation included the northwest of Moshui Lake, the east of Longyanghu, and the south of South Prince Lake, as well as the west of North Prince Lake. South Prince Lake suffered the most followed by Moshui Lake. They lost about 157.61 hm2 and 31.41 hm2 of surface area, respectively. These lakes were prone to encroachment because they were far from Wuhan's urban developmental centers. Wuchang suffered the most from lake reclamation followed by Hanyang in 2000 to 2009. Wuchang's reclamation during this period mainly occurred at South Lake where a large area of water body was filled for LA, which had closed ties with the rise of lakeside fish farming. Hanyang's lake reclamation occurred mainly in South Prince Lake where 13 hm2 of water surface area was reclaimed as LA.

Table 2. Reclamation of Wuhan's lakes for LA in 1989-2009 (unit: hm^2)

Zoning	Name	1989-2000	2000-2009
Hankou District	Zhang Dou Lake		
	zhuye Lake	9.15	6.95
	North Lake	27.54	22.61
	West Lake		
	Littele South Lake		
	Huanzi Lake		
	Tazi Lake		
	Jichangdangzi Lake		
	Lingjiao Lake		
	Houxiang Lake		
	Total	**36.69**	**29.56**
Hanyang District	Moon Lake		
	Lianhua Lake		
	Longyang Lake		
	North Prince Lake		
	South Prince Lake	13.25	
	Moshui Lake	14.11	157.61
	Sanjiao Lake		31.41
	Total	**27.36**	**189.02**
Wuchang District	Ziyang Lake	28.09	
	Simei Pond		
	Yangchun Lake		
	South Lake		
	Yezhi Lake	52.12	
	Dong Lake	12.33	20.12
	Neisha Lake		
	Waisha Lake		
	Shuiguo Lake	16.07	16.62
	Shai Lake		
	Total	**108.61**	**36.74**
Total		**172.66**	**255.32**

2.2.2 Land for construction (LC)

LC occupied the biggest share in land use of land reclaimed from Wuhan's lakes and has the fastest development among the three types of land use. It can be clearly found from the evolution of Wuhan's urban pattern that Wuhan's urban construction spread from the two banks of the Yangtze River to its peripheral areas and that lakes were inevitably sacrificed due to the city expansion. In 1989 to 2000, Hanyang's Moon Lake, Longyang Lake, Lianhua Lake, Sanjiao Lake, South Prince Lake and North Prince Lake underwent filling and reclamation for LC. North Prince Lake suffered the most, where its filled area was changed to LC by 22.54 hm2. Longyang Lake and Sanjiao Lake had also lost 10.74 hm2 and 10.24 hm2 of surface area to LC, respectively (Table 3).

Table 3. Reclamation of Wuhan's lakes for LC in 1989-2009(unit: hm^2)

Zoning	Name	1989-2000	2000-2009
	Zhang Dou Lake		
	Zhuye Lake		
	North Lake	0.43	
	West Lake	1.8	8.71
	Littele South Lake	6.52	2.37
Hankou District	Huanzi Lake		7.6
	Tazi Lake	35.2	17.73
	Jichangdangzi Lake	0.63	
	Lingjiao Lake	4.3	4.96
	Houxiang Lake	1.15	16.6
	Total	**50.03**	**57.97**
	Moon Lake	8.51	2.19
	Lianhua Lake	1.68	3.47
	Longyang Lake	11.14	10.74
Hanyang District	North Prince Lake	40.46	22.54
	South Prince Lake	38.66	2.4
	Moshui Lake	4.35	
	Sanjiao Lake	11.89	10.24
	Total	**116.69**	**51.31**
	Ziyang Lake	1.54	
	Simei Pond	9.49	9.49
	Yangchun Lake	32.78	
	South Lake	361.15	35.37
	Yezhi Lake	9.58	
Wuchang District	Dong Lake	35.35	26.86
	Neisha Lake	6.72	21.08
	Waisha Lake	148.31	44.46
	Shuiguo Lake		
	Shai Lake	10.15	33.86
	Total	**615.07**	**171.12**
Total		**781.79**	**280.4**

Comparatively, 170.99 hm2 of lake area in Wuchang had converted to LC, where it experienced the most significant urban sprawl among the three towns. Next, Shai Lake and Waisha Lake underwent prominent filling and encroachment. Lake filling reduced their surface areas by 44.46 hm2 and 33.86 hm2, respectively. Moreover, significant lake filling appeared in Wuhan's two biggest lakes, namely Dong Lake and South Lake, whose surface areas reduced by 26.86 hm2 and 35.37 hm2, respectively. During this period, Wuchang converted about 615 hm2 of its lake area into LC. The speeds of land use change and involved lake area were unparalleled in Wuchang and even Wuhan.

All lakes located in Wuhan's three towns, such as Wuchang, Hankou and Hanyang, were filled and encroached for LC to varying degrees in 2000-2009 when Wuhan proceeded comprehensive construction. Nevertheless, lake encroachment during this period was obviously abated compared to the timeframe 1989-2000. Wuhan's overall lake-area reduction in 2000-2009 was only a quarter of that in 1989-2000. Although lake encroachment was abated, it was still serious. Specially, Hanyang's seven lakes and

Wuchang's 10 lakes were encroached for LC without exception. In Hanyang, South Prince Lake and North Prince Lake suffered the most, in which their lake areas were changed to LC by 40.46 hm2 and 38.66 hm2, respectively. In addition, Longyang Lake and Sanjiao Lake in Hanyang also reduced the surface area to about 11.14 hm2 and 11.89 hm2, respectively. Unfortunately, Wuchang encountered the worsen condition compared to Hanyang in lake encroachment in 2000-2009. Wuchang underwent the most lake encroachment among Wuhan's three towns. Specifically, each of Wuchang's lakes excepting Simei Pond lost more than 20 hm2 of surface area. Waisha Lake and South Lake suffered the most comparatively because their surface areas were encroached by 44.46 hm2 and 35.37 hm2, respectively. Encroachment occurred around Waisha Lake whereas lake filling took place at the eastern and northern coasts as well as between Chuxiong Avenue and Minyuan Road of South Lake. LC still contributed the most in lake encroachment in an abated way in 2000-2009 compared to 1989-2000.

2.2.3 Land for transportation (LT)

LT made a smaller contribution in encroaching Wuhan's lakes compared to LC, but the two change types are clearly related. LT included land reclaimed from lakes for roads and bridges building. Hankou's Houxiang Lake was encroached by 0.58 hm2 for building Qingnian Avenue (Youth Avenue) in 1989-2000. Besides, Zhangdou Lake was filled by 1.22 hm2 for two cross-lake roads construction. Hanyang's North Prince Lake was expropriated by 6.57 hm2 because the urban ring road went through it. Next, Wuchang's Simei Pond, South Lake, Dong Lake, Yezhi Lake and Yangchun Lake also suffered from encroachment for building roads and bridges. Specifically, a small amount of Dong Lake's surface area was expropriated for building Zhuodaoquan North Road; Chuxiong Avenue took up a small amount of South Lake since it intersected with South Lake. In addition, a small part of Simei Pond was filled for building the Second Yangtze-River Bridge. A small part of Yangchun Lake was encroached for building low-level urban roads. Among Wuhan's three towns, Wuchang suffered the most in terms of encroaching water bodies. Specifically, Wuchang had 115.66 hm2 of lake surface area changed to LA, 55 times as that of Hankou and 6 times as that of Hanyang (Table 4).

Table 4. Reclamation of Wuhan's lakes for LT in 1989-2009 (unit: hm2)

Zoning	Name	1989-2000	2000-2009
Hankou District	Zhang Dou Lake	1.22	
	Zhuye Lake		
	North Lake		
	West Lake		
	Littele South Lake		
	Huanzi Lake		
	Tazi Lake	0.28	
	Jichangdangzi Lake		
	Lingjiao Lake		2.35
	Houxiang Lake	0.58	
	Total	**2.08**	**2.35**
Hanyang DIstrict	Moon Lake		
	Lianhua Lake		
	Longyang Lake		0.8
	North Prince Lake	6.57	6.89
	South Prince Lake	3.63	
	Moshui Lake	1.35	
	Sanjiao Lake	5.86	
	Total	**17.41**	**7.69**
	Ziyang Lake		
	Simei Pond	1.26	1.26

Wuchang DIstrict	Yangchun Lake	21.84	
	South Lake	66.29	2.36
	Yezhi Lake	1.72	
	Dong Lake	24.55	
	Neisha Lake		16.27
	Waisha Lake		13.47
	Shuiguo Lake		0.78
	Shai Lake		3.09
	Total	**115.66**	**37.23**
Total		**135.15**	**39.58**

Lake filling at Hankou, Hanyang and Wuchang in 2000-2009 was also presented. Lake filling disappeared at Hankou, excepting that Lingjiao Lake was filled by 2.35 hm2 for LT for building Xinhuaxialu Road. Lake filling at Hanyang for LT was in continuously decrease, where only North Prince Lake and Longyang Lake were filled by 6.89 hm2 and 0.80 hm2, respectively. While Lake filling at Wuchang was still the most serious comparatively. Neisha Lake and Waisha Lake were further filled due to the demands of urban development, reducing their water surface areas by 16.27 hm2 and 13.47 hm2, respectively. They were expropriated for building Liyuan Road on the east of Neisha Lake, Youyi Road and Heping Road between them, and roads extending east. South Lake, Shuiguo Lake and Shai Lake were expropriated by 2.36 hm2, 0.78 hm2 and 3.09 hm2, respectively for building low-level urban roads. Wuchang's lakes still suffered the most from expropriation for LT in 2000-2009. Lake expropriation reduced somewhat in 2000-2009 compared to 1989-2000. However, Wuhan's lakes were still being changed to other land uses.

Throughout the entire research timeframe of 1989-2009, Wuhan's urban spatial morphology changes basically followed four modes, such as leap-type development, axial advancement, ring-shaped filling, enclosure-type extension, which appeared simultaneously or alternately four during the various stages of Wuhan's urban development[27]. The direction of a city's spatial morphology can be described by the trajectory of its sprawl and expansion. The impacts of urban sprawl on urban lakes are obvious and dominant. Wuhan's lakes reclaimed for LC were mainly distributed in the direction of Wuhan's urban sprawl, which was the most apparent in Wuchang. Nevertheless, reclaiming lakes for LA contributed the most to lake encroachment in Hanyang, which is an economically less developed area. In short, Wuhan's lake reduction due to urban expansion had not decreased until 2009 and was in continuing evolution. Therefore, summarizing the various reasons behind and proposing pertinent countermeasures are a priority.

3 Some implications of lakeside land use change

Wuhan's lake changes did not happen overnight. They occurred because of urban construction and development through a gradually evolving process driven by responses to national policies in different stages of urban construction. They resulted from the combined effect of various processes, including urbanization, population growth, urban economic growth and policy changes, reflecting changing concepts and ideas of good city form. Wuhan's lakes are in continuous reduction and shrinkage, mainly due to inherent contradictions between the national and local governmental policies and people's behavior patterns. Although the national and local policies are regulatory, some groups usually do not follow the policies so as to maximize their economic benefits. This disobedience slowly reinforced the power of these groups, which further caused a variety of unbalances. Then, the national and local governments would adjust their policies to eliminate these imbalances, resulting in a general trend promoting the society to continue moving forward. Therefore, Wuhan's lake changes are a causative product of both parties, such as national and local governments and the disobeying groups.

3.1 Construction of urban infrastructure

Since Wuhan is in fast urbanization, thus urban population soars with rapid urban and economic development. As a result, there are increasing demands for land in urban areas. This situation intensifies the conflicts between population explosion and urban land shortage. With the review and approval of

Wuhan Municipal Government, some lakes are partly converted to LC including urban traffic roads and municipal facilities, such as The Second Yangtze-River Bridge encroaching Simei Pond, Youyi Avenue encroaching Sha Lake, Moon Lake Bridge encroaching Moon Lake, Jiangcheng Road encroaching Moshui Lake and South Prince Lake, Qingnian Lake Avenue encroaching Houxianghe andWest Lake Substation encroaching West Lake. The above lake fillings with governmental approval is legitimate.

3.2 Changes of land system

Since China implemented the system of land leases, land value has rediscovered, and land's asset character has recognized. As a result, an "enclosure movement" swept China, with booming land development and real estate development throughout China. Given that it is more economical to expropriate lakes than vegetable plots and farmland, land users and real estate developers have filled a large amount of lake area for greater economic gains.

3.3 Omissions of management

Wuhan's lakes are of unclear ownership because some issues involved in the historical evolution of Wuhan's lakes remain unresolved. Undefined ownership objectively gives rise to a phenomenon who fills a lake area first is entitled to the ownership of the land reclaimed by filling the lake area. Moreover, there were no enforceable laws and regulations for managing lakes of unclear ownership. For instance, Hanyang's Moshui Lake, South Prince Lake, North Prince Lake and Sanjiao Lake are partly owned by Wuhan Water Authority who receives no funding to manage these lakes, leading to uncoordinated development between lake management and law enforcement.

3.4 Issues concerning management of law enforcement

Wuhan Municipal Government promulgated specific laws and regulations for protecting Wuhan's lakes, including Wuhan's Measures for Protecting Natural Mountainous Lakes in 1999 and Wuhan's Regulations on Lake Protection in 2001. Unfortunately. These acts are still lacked the supporting management and supervisory measures, giving rise to lax enforcement of these enforceable regulations.

3.5 Considerations of economic benefits

Driven by economic interests, some of lakes' owners ignored the social and economic benefits, lowered the cost of reclaiming land from lakes, and filled lakes for self-serving ends in the context of the current lake management negligence.

3.6 Weak public awareness

Although Wuhan is inherently endowed an excellent natural landscape pattern, however, lacking public awareness of lake protection and development led to weak utilization, serious waste and heavy pollution of the water resources. Low yields with high consumption and unconscious destruction caused slow shrinking of Wuhan's lake shoreline.

4 Conclusion

4.1 The future value of Wuhan' riparian areas

Urban Waterfront is one of the most advantageous location with the biggest developmental potential in a city. Wuhan owns the highest number of lakes in China. Wuhan's congenital geomorphic characteristics of interwoven water network featuring the Yangtze River and Han River, and hundreds of lakes have endowed Wuhan with a huge developmental potential. Thus, reasonable development of Wuhan's lakeside space is of great significance for enhancing Wuhan's overall environmental and economic value and for creating more investment opportunities in Wuhan.

4.2 Methodological considerations

What can be done to improve and control Wuhan's shrinking lake area and disappearing lake lakes functions? To address these concerns, much efforts must be first made to combine Wuhan's lakeside development and utilization with its urban development, economic structuring, government decision-making, law enforcement and management, as well as public awareness enhancing, and formulate compre-hensive development goals on this integrated and combination and integration. Specific improvement methods are as follows:

1) Stabilizing the lake area and returning farmland to lakes

- Control lakeside agriculture and fishery considering lakeside industrial restructuring and upgrading.
- Formulate reasonable lakeside land planning according to the actual situation of each lake, clarify its function zoning, and strictly control the scale of farming.
- It is recommended that the governments remove excess lakeside farming to ensure the ecological environment and species diversity of the lakes.
- Return lakeside low-lying farmlands to lakes whenever is possible and feasible to increase lake area, thus enhancing the urban lakes' capacity of

flood regulation and storage.

2) **Stabilizing the lake area and returning farmland to lakes**

● Determine ownership relations of each lake and its management agency, and clarify the management agency's rights, responsibilities and obligations.

● Formulate unified legal provisions for lake management and development so that varied lake managing agencies take unified action.

● Increase funds for lake management to ensure the executive ability of lake-management agencies.

3) **Strengthening legislation and law enforcement**

● Enforce relevant laws, including enforcement Wuhan's Regulation on Lake Protection.

Strengthen the law-enforcement status of the lake-management agencies department based on defined lake management relations.

● Establish a strict system for acquiring lakes for land, clarify the approval procedures and authority of lake expropriation, and increase acquisition cost.

● Expropriated lakes or lake areas must be developed in strict accordance with the requirements of the overall urban planning and land use nature.

4) **Strengthening public participation awareness**

● Enhance the public's awareness of the rule of law, organize publicity and education on protecting lake ecosystems, and encourage the public to participate in lakeside area planning and lake ecological protection.

● Governments should strengthen the public's participation in the whole process of lakeside development projects to ensure that the projects are carried out under the condition of fulfilling public needs.

5) **Proposing integrated development goals**

● The developmental goals of Wuhan's lakeside areas should not be determined from a single perspective, whether economic, ecological or aesthetic, etc.

● Wuhan's lakeside areas should be developed with diversified, comprehensive and integrated goals to realize their historic, economic, ecological, educational and entertaining values and give full play to their characteristics and potentials.

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