

Water System Evolution and Influencing Factors in Wuhan City Over the Past 40 Years via Remote Sensing

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Keywords: MNDWI, Water System Evolution, QGIS, Wuhan.


Abstract: Water systems are an essential component of the earth's ecosystem, providing vital resources for living organisms and human beings. Therefore, ensuring the health and stability of water systems is imperative for human life and development. Taking Wuhan City as a case study, this paper utilizes QGIS software to obtain MNDWI classification maps from four remote sensing images captured in 1985, 1990, 2005, and 2020. It discusses the rules governing water system evolution and the influencing factors in Wuhan City over the past four decades. The analysis reveals that rapid urbanization has significantly impacted the river system in Wuhan during this period. Specifically, there has been a noticeable decline in the overall lake area, which can be categorized into three stages: a sharp decline from 1985 to 1990, a continuous decline from 1991 to 2005, fluctuation stage from 2006 to 2020. Urbanization rate directly correlates with its impact on river systems while macro policies have played a significant role at different stages of change. The natural sedimentation of lakes leads to the deterioration of lake ecological environment and affects the biodiversity of lakes. Water resources are reduced, and water environment is deteriorated by filling lakes to make land or constructing ponds, which leads to excessive development and utilization of land resources. The construction of lake filling weakens the ecological service function of the lake and destroys the ecological balance. It is noted that the changes in the lake are caused by multiple factors and evolve with time.

1 INTRODUCTION

The harmonious development of water and city is an important prerequisite for sustainable urban development (Gao, 2021; Zhan et al., 2022; Xie and Ran, 2024). The evolution of urban water system is very important to cities. Urban water system is an important source of urban water supply system. Lakes, rivers and reservoirs provide cities with drinking, industrial and irrigation water; Urban water systems can help mitigate the risk of natural disasters, such as rivers and lakes that play an important role in flood control and drainage; The urban water system is conducive to improving the ecological environment of the city. Water systems such as lakes, rivers and park water bodies can provide ecological landscapes, increase urban green space, promote the ecological balance within the city, and improve the quality of life of urban residents. The urban water system is an important part of recreation, such as the park by the lake, riverside walks and so on. Urban water system

can also enhance the image and attractiveness of the city, many cities by creating the landscape along the city and supporting facilities around the water system to improve the image of the city, attract more tourists and investment. The evolution of urban water system has an important impact on urban development and living environment. Cities should pay attention to the protection and rational utilization of water system, promote the sustainable development of urban water system, meet the needs of urban residents for water resources, and ensure the ecological environment and sustainable development of the city.

Water system evolution research methods mainly include geomorphology research, geological survey technology, numerical simulation, geochronology and environmental geochemical analysis. These methods can directly observe surface geomorphic features, reveal terrain changes, accurately measure surface elevation, and simulate geomorphic evolution in different geological periods. However, they are limited to surface observation and require a large

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amount of field survey and equipment investment, which may lead to measurement errors and other problems. With the development of technology, more scholars gradually use satellite remote sensing means, such as QGIS, to study the evolution law of urban water system by processing remote sensing data. Therefore, based on remote sensing methods, this paper takes Wuhan City as an example, selects remote sensing images of Wuhan city in 1985, 1990, 2005 and 2020, uses Normalized water body Index (MNDWI) for classification, extracts lake water surface information within Wuhan city, and explores the water system evolution rules and influencing factors of Wuhan City in the past 40 years.

2 BACKGROUND OF WUHAN CITY

As the capital of Hubei Province and a national central city in central China, Wuhan is located in the east of Jiangnan Plain, between $113^{\circ}41' - 115^{\circ}05'$ east longitude and $29^{\circ}58' - 31^{\circ}22'$ north latitude. The total area of the main urban area is 678 km^2 (Figure 1). Wuhan sits at the intersection of China's North-South fault belt, where the North China Block, the Yangtze Plate and the southwest Plate meet. Therefore, the geological structure of Wuhan area is complicated and the geological resources are rich, but it is also prone to geological disasters. Wuhan is located in Jiangnan Plain, the terrain is flat, the soil is fertile, and the central part is scattered with residual hills. The Yangtze and Han rivers are the two main rivers in Wuhan. The Yangtze River is the largest river in China and flows through the center of Wuhan. The water system of these two rivers forms the main water network of Wuhan City, which has an important impact on the geological environment and water resources of Wuhan City. Lakes are scattered all around. In the early days of the founding of New China, there were 127 lakes of all sizes in the main urban area, whose water area accounted for about 1/4 of its administrative area, ranking first among similar cities in the country, and known as the "City of 100 Lakes" (Duan, 2013).

With the rapid population growth and economic development in Wuhan, the development of urban construction has been accelerated, and the lakes in Wuhan have fallen into a very embarrassing dilemma: the number of lakes has dropped sharply; The water surface area has shrunk sharply; The lake is seriously silted. Some lakes are gradually swamped, coupled with soil and water loss caused by human factors,

resulting in shallow lakes and reduced storage capacity; A large amount of production and domestic sewage discharge worsens the water quality of lakes (Wang, 2005). As a key component of the urban ecosystem, urban lakes provide an important driving force for sustainable urban development in terms of climate regulation, flood control and water storage, eco-tourism and water supply (Yang et al., 2010). Therefore, it is urgent to research the law of water system evolution and influencing factors in Wuhan City.

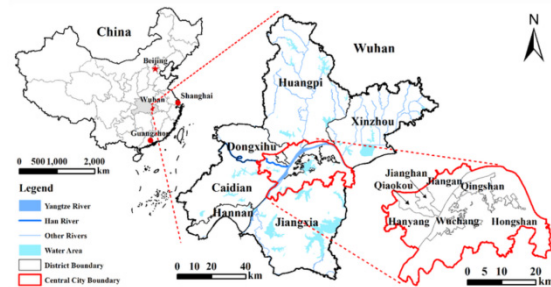


Figure 1: Regional distribution in Wuhan (Cai et al., 2017)

3 METHODS

Using remote sensing data, this paper selects four time points, 1985, 1990, 2005 and 2020, and applies QGIS to restore water body evolution.

3.1 Data Collection

This paper mainly uses the Landsat series remote sensing satellite data from the United States Geological Survey. In order to reduce the influence of flood season water level changes on lake extraction, the time nodes of remote sensing data used in this paper are all from November to March (cold season), and the image quality is intact without cloud cover (Zhan et al., 2022). Landsat-5 satellite remote sensing images were used in 1985, 1990 and 2005, and Landsat-8 satellite remote sensing images will be used in 2020.

3.2 QGIS Modeling

QGIS was used to classify the image data using Modified Normalized Difference Water Index (MNDWI). MNDWI is a remote sensing image processing technology mainly used to distinguish and extract water information on the surface. MNDWI is based on the near-infrared (NIR) and short-wave infrared (SWIR) bands ratio. Because of short-wave

infrared bands, MNDWI can better suppress the influence of soil background, especially in areas with sparse vegetation cover or similar soil colors. At the same time, NIR band has a higher reflection on water bodies, while SWIR band has a lower response to water bodies. This makes MNDWI more inclined to highlight water features, especially in high-resolution images, so as to obtain four images with more prominent water features for comparison and analysis.

4 RESULTS

From 1985 to 2020, the area of 58 key lakes in Wuhan has shown a downward trend, decreasing from 1034.76 km² to 687.66 km², and the water surface has decreased by 33.54% (347.10 km²). Compared

with 1985, the area of each key lake has shrunk to varying degrees (Figures 2, 3).

The change in lake area has relatively obvious stages, which can be roughly divided into three stages: the first stage (1985-1990) is the sharp decline of the lake area, which decreased from 1034.76 km² in 1985 to 801.01 km² in 1990, a decrease of 233.75 km² (22%). The second stage (1990-2005) was the stage of slow decrease of the lake. From 1990 to 1995, the lake area decreased slightly by about 6 km², and from 1995 to 2005, the lake area decreased continuously, from 794.80 km² to 679.29 km², and the decrease area was 115.51 km², a decrease of about 15%. The third stage (2005-2020) is the stage of the fluctuation of lake area, which increased by about 42.97 km² from 2005 to 2014. Although the lake area decreased from 2014 to 2020, the water area in 2020 was still higher than in 2005. The overall area growth trend was presented (Figure 2).

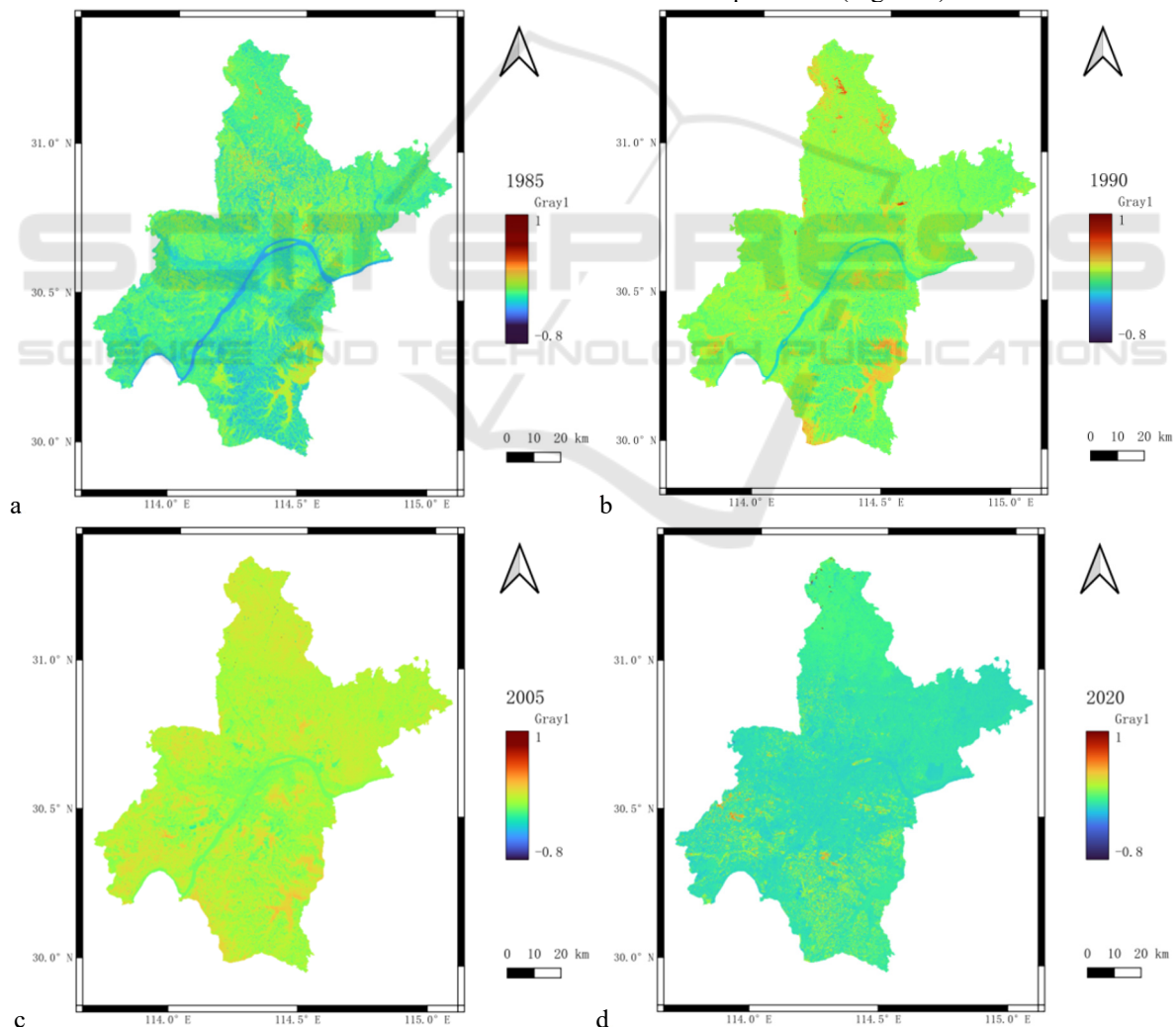


Figure 2: MNDWI graphs in (a) 1985; (b) 1990; (c) 2005; (d) 2020. (Picture credit: Original)

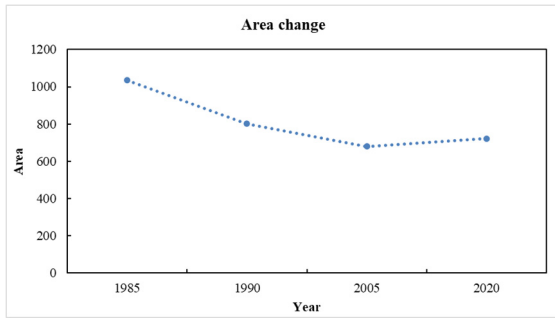


Figure 3: Change line diagram of water system area from 1985 to 2020. (Picture credit:Original).

5 DISCUSSIONS

5.1 Water System Evolution Laws

Through data investigation, it is found that the lake evolution in Wuhan area mainly has the following characteristics:

Lakes with larger areas are relatively stable, while lakes with smaller areas are easy to recede. Hanyang District has the largest decrease in lake area (21.514 km²) from 1985 to 2020. This is mainly due to the large number of lakes in Hanyang District and the relatively small lake area, the extent of natural siltation of small lakes is serious, which is more conducive to reclamation, and most of Hanyang District is a new economic development zone, resulting in serious lake filling phenomenon caused by urban construction. The lakes in Wuchang District and Wuhan district are mainly East Lake, South Lake, Tangxun Lake, Qingling Lake, Huangjia Lake and other large lakes, and the lake area is relatively stable.

The period of lake receding in the remote suburbs (e.g. Dongxihu area) was mainly reflected in the 1980s, and the area decreased by about 12km² from 1985 to 1990. It may have something to do with the policies, the construction of the city. In the 1980s, the economic construction of Dongxihu District became the focus, and the lake land was continuously filled, which led to the artificial reduction of the lake area. From 1990 to 2020, the lake area is relatively stable, and the lake area decreases by about 2.5 km². This is mainly due to the small and small scale of engineering construction in remote areas, and the lake area is relatively stable.

In recent 10 years, the lake area in the central urban area remained relatively stable, while the lake area in the new urban area decreased sharply. In the past 10 years, as the Wuhan Municipal government has strengthened the protection of lakes in the central urban area, it has carried out corresponding

reconstruction work on the lake shoreline, which has remained relatively stable, and the lake water area in the central urban area can be effectively guaranteed. However, due to a large number of engineering construction, road building, new factory building, real estate development, the phenomenon of lake filling occurs from time to time, resulting in a sharp decline in the lake area in the new urban area.

5.2 Influencing Factors of Water System Evolution

As for the reasons for the gradual reduction of the urban lake area in Wuhan, domestic scholars have carried out several studies: Wang (2013) believes that it is mainly caused by the urban economy, the development and construction of traffic, the development and utilization of real estate, flood and blockage, and improper protection and utilization measures; Duan (2013) pointed out that land reclamation and fish farming in lakes in the 1970s and 1980s, municipal construction and real estate development in the 1990s, and the drive of huge profits in recent years were the main causes in different stages. Wang (2005) pointed out that the interest drive in the process of urbanization is the main reason. Zhang et al. (2010) pointed out that in the past 100 years, the main reason for the sharp decline in lake area was the reclamation of lake land.

According to the research results of this paper, from 1985 to 2020, the three stages of Wuhan water system change are mainly related to macro policies and economic development. The first stage: from 1985 to 1990, the lake area decreased sharply. At this stage, China was in the early stage of planned economy and reform and opening up, cities entered the stage of large-scale development and construction, and urban built-up areas spread rapidly. Due to its large scale and immovable spatial position, urban lakes cannot be economically and compact developed in cities if they are not partially filled with lakes and lakes and rivers under the requirements of urban development and construction. In order to build a good urban development structure, landfilling frequently occurs, such as between sand lake and East Lake, sand Lake and Yangtze River. The second stage: from 1991 to 2005, the lake continued to decrease. On the basis of the established framework of early urban development and construction, real estate developers choose to develop and build lakeside areas with high ecological value and rich landscape resources based on the principle of maximizing economic benefits in the process of urban development. Moreover, due to the imperfect layout

of the transportation network, it is not enough to support the urban enclave construction and development, and the lakeside space in urban built-up areas is further squeezed. The third stage: from 2006 to 2020, the lake area's fluctuation improves. At this stage, the urban development is transforming, the city is renewing, and the urban development area and the far urban area are expanding. On the one hand, lakes close to the city center have been restored by lake connectivity. On the other hand, under the background of high-quality urbanization, lake protection is emphasized in the development process of the new district.

In addition to the impact of macro policies, this paper, combined with the field investigation, believes that there are three reasons for lake receding in Wuhan area:

Natural siltation of lakes occurs due to the drainage of sloping land, waterlogging in fields caused by deforestation and overcultivation, leading to soil and water loss. The sediment carried in the water is deposited in rivers and lakes. Additionally, leaves, weeds, and other debris along the river contribute to constant silt accumulation in riverbeds. Small rivers and lakes with minimal annual flow experience faster sedimentation rates, resulting in yearly silt buildup. Furthermore, inadequate dredging of many lakes exacerbates the serious issue of river and lake siltation. As a consequence, most rivers and lakes are facing extinction as their capacity diminishes annually. Taking the East Lake in Wuhan as an example, the scanning of the underwater topography and silt thickness of the East Lake shows that the maximum silt thickness of the East Lake is 4 m, the average silt thickness is 1.06 m, and the total silt volume reaches 35.22 million m^3 , which is 20% of the storage capacity of the East Lake.

Lakes are being filled for agricultural or pond construction to expand cultivated land areas or promote pond culture. This trend was particularly prominent during the 1980s when reclamation projects addressed food shortages and low grain production. Evidence such as numerous fish ponds and lower-lying farmland surrounding these reclaimed areas supports this observation. Taking Crescent Lake as an example, Crescent Lake is located in Wuhan City, East and West Lake District Zumaling Street thirteen branch ditch, also known as the double lake, in 1958 Zumaling farm, because of the shape of the lake like the crescent, it was renamed Crescent Lake, the initial lake area of about 1200 mu, in the 1980s geological records for more than 700 mu, now only 460 mu, the area reduced by nearly two thirds. At present, the lake has become a private

contract lotus pond, surrounded by fish ponds, the average water depth of about 1 m, poor class V water quality, the function of the lake is gradually disappearing, and there is a danger of extinction (Pei et al., 2018).

Engineering construction to fill the lake. In the urban development and construction, to solve the land shortage problem, large-scale lake filling and land reclamation movement began, especially in plant construction, municipal engineering and real estate development. For example, the North Prince Lake is located at the intersection of Fangcao Road and the Third Ring Road in Hanyang District. The Third Ring Road in Wuhan divides the North Prince Lake into two parts, with an average water level of 20.25 m and an average water depth of 1.8 m. Before the 1960s, the water area of the North Taizi Lake was about 11.33 km^2 . In May 1966, Wuhan City (2014) organized the reclamation of the North Taizi Lake to build farmland. In 1965, four new farms were built, followed by Wuhan seed breeding farms, which only left 0.823 km^2 , and the water area of the lake dropped sharply. After the 1970s, the lake area of Wuhan was relatively stable, and by 2000, the area of North Prince Lake was 0.705 km^2 . In the 21st century, the construction of Wuhan City accelerated the withdrawal of the North Prince Lake, especially the Wuhan Third Ring Road passed through the lake with solid foundation. On the one hand, the road was built to fill the lake directly; on the other hand, the Third Ring Road divided the North Prince Lake into two parts, making the water on both sides unable to flow. At present, the area of the lake on the northeast side of the Third Ring Road has gradually shrunk and has become a pond. Moreover, due to the continuous filling of the lake by the nearby engineering construction, the pond area is getting smaller and smaller, and it has nearly disappeared.

As for the causes of lake retreat, it is generally the result of the combined action of two or three factors on the above two factors. For example, Shihu, located on the outskirts of Wuhan City, reduced its area by 3.817 km^2 from 1985 to 1990, changed little from 1990 to 2000, and decreased by 2.173 km^2 from 2000 to 2011. Since 1985, the lake's total area has decreased by 5.988 km^2 , or 91%. There is little engineering construction in this area, and the main factors of lake retreat are siltation, land reclamation, pond reclamation and flood control dam construction.

5.3 Suggestions

(1) Through the analysis of the current situation of lake evolution in the study area, it is found that in

recent decades, the number and total area of lakes in Wuhan have dramatically decreased due to unreasonable lake filling, pond building, economic development and natural siltation of sediment, which will inevitably lead to further aggravation of flood disasters in Wuhan, and more difficulties in irrigation and water diversion for residents. The further deterioration of groundwater resources and the obvious change of the environment in Wuhan resulted in a series of consequences. The lake remediation work in Wuhan City is imminent. This study puts forward the following suggestions:

(2) Strengthen the supervision of lake protection. Through the formulation of corresponding laws and regulations on lake protection, to achieve legal compliance, strict law enforcement; It is strictly prohibited to pollute, cut off all pollution sources, and ensure that clean water enters the lake.

(3) Strictly control the development and utilization of lakes and their surroundings. Artificial breeding should be controlled. For lakes in central urban areas, artificial breeding should be prohibited. For lakes in suburban areas, the scale of breeding should be effectively controlled. To prevent any form of lake filling behavior, especially engineering construction, real estate development, etc. is strictly prohibited to fill the lake, and the road through the lake should be passed in the form of viaduct.

(4) Fully carry out lake improvement and protection measures. The fish ponds or reservoirs around the lake should be unified regulation, the lake and the pond should be integrated, and the water area of the lake should be expanded; The lake shoreline should be regulated, the silt should be removed in time, and the landscape road along the lake should be built. More artificial canals should be built where possible to connect lakes in adjacent areas to keep lakes flowing. As social public resources, the Lake shoreline and landscape road along the lake should be independent from the community or private residential areas.

(5) Cultivate public awareness of lake protection. Make full use of various channels such as TV, newspapers, radio and publicity columns to strengthen the publicity of lake protection and improve the awareness of lake protection of Wuhan citizens.

6 CONCLUSIONS

In this study, land use information was extracted from multi-temporal remote sensing images to dynamically monitor the temporal changes of lake

area in Wuhan from 1985 to 2020. Since the 1980s, with the acceleration of urbanization, the water system in Wuhan has been affected by human development and utilization, and the water area has been reduced. During the 45 years from 1973 to 2018, the area of key lakes in Wuhan City showed a downward trend as a whole, shrinking by 33.54% from the original 1034.76 km² to 722.26 km². Among them, the phenomenon of lake filling is more prominent, and some lakes and waters are filled for urban construction and infrastructure construction, resulting in the reduction of the area of lakes and water systems, the destruction of ecosystems and other problems, and the destruction of urban water environment.

The influencing factors include macro-policy, urbanization and industrialization, natural siltation of lakes, lake filling for land or pond building and engineering construction for lake filling. It leads to the deterioration of the ecological environment of the lake, affects the biodiversity of the lake, reduces the water resources and deteriorates the water environment, weakens the ecological service function of the lake, and destroys the ecological balance.

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