Spatial-temporal Changes of Urban Wetlands Shape and Driving Force Analysis Using Fractal Dimension in Wuhan City, China

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***Abstract*—Anthropogenic activities play a key role in wetlands evolution during the processing of urbanization. In this paper, Wuhan, which is known as a "Hundred-lake city", was selected as an example for wetlands morphology analysis by fractal. Firstly, the border information of 19 lakes was extracted from two time-series Landsat TM images for the years 1991 and ETM+ 2002.By using GIS tools, the fractal dimension for those wetlands were calculated. Secondly, the relationship between fractal dimension changes and human activities were also analysed. The fractal dimension of the 19 urban lakes was decreased from 1991 to 2002 during the process of Wuhan urbanization. The increasing population, industrial structure boosting and economy development affected the urban land use changes. The infilling of lake which caused the lake loss, was considered to be the primary factor for the lake's fractal dimension decreasing. It states that the human activity contributed much more to lake morphology evolution during the urbanization of Wuhan City**

***Index Terms*—Fractal Dimension; Spatial-temporal Changes; Urban Wetlands; Driving Force**

I. INTRODUCTION

Urban wetlands are important to urban sustainable development since the wetlands ecosystems provide important ecological and economic services for urban development (eg. support biotic diversity, nutrient retention, flood protection, provide some contact with nature and some opportunities for recreations) [1][2].However, in the past several decades, extensive urban wetlands losses have occurred, with many of the original wetlands drained and converted to farmland or residential land[3] [4].The importance of the research on the dynamic changes of wetlands has been widely recognized in order to provide valuable information to protect or restore urban wetlands[5].

Activities resulting in urban wetlands loss include: agriculture; commercial and residential development; road construction; impoundment; resource extraction. Generally, the changing of urban wetlands can be measured by Euclidean geometric parameters such as area, parameter, width, length etc. However, the evolution of urban wetlands is complex and determined by climatic change, biologic disturbances and anthropogenic activities factors. Mandelbrot's fractal theory, as a research fronts coupled with concepts of complexity, criticality, and self-organization, provide a new tool to describe the change of urban lake. Like the coastline of Great Britain, the surface of a lake is also an example of a fractal. As the scale of the ruler measuring the lakeshore becomes smaller, the length of the coastline becomes greater. The purpose of this paper was to examine effect on urban lakeshore shape due to human-related disturbances using fractal dimension. The result will also serve as a major data source for urban wetland protection and management.

II. STUDY AREA

Wuhan, as a famous historical and cultural city of China, is considered as the largest and main economical capital of Hubei province. It is located on latitude 30d34'48''N and longitude of 114d16'12''E and the YangtseRiver and Hanshui River cross each other in the city. In 1991, the urban consisted of three towns (Hankou, Hanyang, Wuchang).Wuhan is known as a "Hundred-lake city with a total number lakes over 200.The total area of lakes amount to 5925.2 km^2 .Therefore, urban lake is viewed as one of the key natural resources need to be protected.

Situated in the center of China, Wuhan is the national hub of communications of railway, waterway, highway, airline, and telecommunication. In the last three decades, especially after 1990, Wuhan has encountered a rapid urban growth movement associated with the increase in population and industry infrastructure. This undergoing growing resulted in the expanding of Wuhan City.

III. DATA COLLECTION AND PROCESSING

The data used in this study were comprised of a time-series Landsat TM images for the years 1991 and ETM+ 2002. The spatial resolution for 1991 satellite digital data was 30 meters, but 15-30 meters in the case of 2002 ETM+ images. The selection of this images covers an urban growth period of eleven years over Wuhan city area. The census land use data were also collected to provide some background information to the study.

Before spectral information in a satellite image can be used in a geospatial analysis, the image should be pre-processed. This includes radiometric and geometric corrections. Radiometric correction is the process of removing spectral influences that alter the measurement of earth object reflectance values. Geometric correction is the process of rectifying an image with another spatial layer so that they geographically coincide. Then, the Landsat images were reprojected from Universal Transverse Mercator (UTM) projection to Gauss-Kruger Projection, Krasovsky Datum, Transverse Mercator projection. The normalized difference water index (NDWI) is derived in order to enhance the lakeshore of Nanhu. A total of 19 lakes were selected lakeshore in 1991 and 2002 are digitized by GIS tools.

The fractal dimension is used as a measurement parameter for fractal analysis. It measures the degree of irregularity at all levels of magnification by how fast the estimated measurement of the fractal increases as the measurement device becomes smaller. When the fractal dimension is greater than the classical geometric dimension of the object, the fractal is more irregular. Several measures of dimension such as the information dimension, capacity dimension, box-counting dimension are often used to calculate the dimensions of fractal sets. A "box dimension" method was used here to calculate the fractal dimension of the lake surface. For a lakeshore curve, the box dimension is the same as the Hausdorff-Besicovitch dimension for 1 <= D <= 2. It is given by (Hausdorff, 1919):

$$D_c = \lim_{t \to 0} \frac{\ln N(\varepsilon)}{\ln(1/\varepsilon)}$$

Dc is the fractal dimension of the projection of the lake into a plane. Box counting consists of superimposing a grid on the lakeshore to be described and determining the number of squares that are needed to cover it. Such a procedure can be performed in a GIS environment. For ARCGIS, an initiate square matching the lakeshore size is firstly generated and a series of half size grid coverages is meshed sequentially. Then an overlay operation for the lakeshore shapefile coverages and different grid coverages is exercised. Thus, the number of squares occupied by lakeshore or not is counted. Two graphs of log(N(ε)) against log(1/ε) along with the equations arising from linear regression.

IV. RESULT

Table 1 shows the results of fractal dimension computation of the 19 lakes in 1991 and 2002.

A. The fractal dimension distribution of lakes in 1991

The fractal dimension values are different and all of them are between 1 and 1.5. In the Wuchang district, the Liangzi lake, the Nanhu lake, the Tangxunhu lake have the higher value. The common characteristics of these lakes are far from the urban center. The Liangzihu lake is the farthest away from the urban center. Those lakes near the city center, such as the Shaihu lake,Xihu lake,Beitaizihu lake, however, have a lower fractal dimension, the fractal dimension value are slightly larger than 1.

According to the population and economic data analysis, it was found that the greater the population density is, the lower the fractal dimension is. Although the fractal dimension

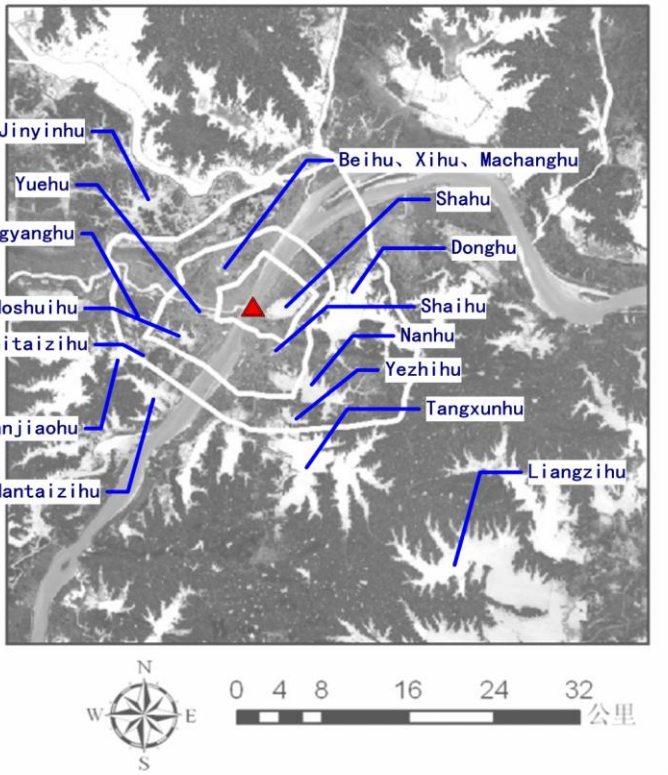

Fig.1 The location of lake in the study

distribution characteristic in 1991 may require a more detail historical data for further analysis, but on the whole, the lakes in the inner ring were the result of urban development and evolution over a long period. The fractal dimension values of these lakes were relatively low. However, the fractal dimension values of these lakes located in the outer ring were relatively larger.

B. The fractal dimension change from 1991 to 2002

The fractal dimension of the 19 lakes in Wuhan city decreased from 1991 to 2002. In Wuchang District,the most change was happened to the Nanhu lake,the variation was 0.158, followed by the Shahu lake, East Lake by 0.118. In Hankou district was Jinyinhu lake,the variation was 0.101.In Hanyang district was Beitaizihu, the variation was 0.108. It seemed that the lakes located between the middle and outer ring of the urban changed more sharply than the inner ring or the outer ring of urban.

Table 1 **The land-use composition(%)of Nanhu from 1991 to 2002**

No.	District	Lake name	Urban ring	Distance(Km)	Year	Dimension	△ D
1	Hankou	Jinyinhu	Outer-ring	14.2	1991	1.312	0.101
					2002	1.211	
2	Hankou	Machanghu	Middle_ring	5.6	1991	1.082	0.047
					2002	1.035	
3	Hankou	Xihu	Middle_ring	4.3	1991	1.025	0.002
					2002	1.023	
4	Hankou	Beihu	Middle_ring	4.9	1991	1.022	0.001
					2002	1.021	
5	Hanyang	Longyanghu	Outer-ring	10.8	1991	1.166	0.037
					2002	1.129	
6	Hanyang	Beitaizihu	Middle-Outer-ring	10.3	1991	1.122	0.108
					2002	1.014	
7	Hanyang	Nantaizhu	Outer-ring	12.3	1991	1.217	0.068
					2002	1.149	
8	Hanyang	Moshuihu	Middle-ring	6.2	1991	1.206	0.092
					2002	1.114	
9	Hanyang	Yuehu	Inner-middle ring	4.3	1991	1.081	0.011
					2002	1.070	
10	Hanyang	Sanjiaohu	Middle-Outer-ring	12.8	1991	1.091	0.031
					2002	1.060	
11	Hanyang	Houguanhu	Middle-Outer-ring	14.4	1991	1.313	0.048
					2002	1.265	
12	Wuchang	Nanhu	Middle-Outer-ring	11.2	1991	1.337	0.158
					2002	1.179	
13	Wuchang	Donghu	Middle-Outer-ring	10.1	1991	1.342	0.118
					2002	1.224	
14	Wuchang	Shahu	Inner-Outer-ring	3.1	1991	1.137	0.118
					2002	1.019	
15	Wuchang	Tangxunhu	Outer-ring	16.7	1991	1.308	0.093
					2002	1.215	
16	Wuchang	Liangzihu	Outer-ring	43.2	1991	1.429	0.005
					2002	1.424	
17	Wuchang	Shaihu	Inner-Outer-ring	5.7	1991	1.071	0.042
					2002	1.029	
18	Wuchang	Yezhihu	Outer-ring	13.1	1991	1.247	0.041
					2002	1.206	
19	Wuchang	Yandonghu	Outer-ring	10.2	1991	1.289	0.076
					2002	1.213	

V. DISCUSSION

Major factors affecting fractal dimension change of Wuhan city lake shore include social, economic, and political backgrounds.

A. Industry rearragement and land use change.

The rearragement of industry forced to change landuses structure. According to the census data, in 1992, the proportion of primary industry of Wuhan city is 11.92%, which decreased to 7.86% in 1998. The secondary industry decreased from 47.98% to 44.66% from 1992 to 1998. However, the third industry increased from 40.10% to 47.48%. The proportion of third industry exceeded that of secondary industry in 1998. Optimization and adjustment of land use structure is the key point to industry rearragement. Much more construction land resource are requried to meet the needs of high-speed urban development.The build-up area around middle ring of the city were growing and the urban growth had a tendency to expand outward.

B. Road infrastructure

Road Development is an important factor for urban development. The road system forms a powerful instrument to allocate economic activities within an area or region. In order to anticipate urban growth, the road infrastructure network had been improved and enlarged in the 1990s. From the beginning of the 1990s, road authorities scrambled to develop properties with good urban roadway access. Several main roads project, such as Luoyu Road - Wu Xian Highway project, the inner ring project, bridge construction project over the Yangzi River was implemented in the 1990s. The rapid development of urban traffic network system promoted the formation process of the circle expanding model structure and speed up the process of urban expansion. The road patterns influence the patterns of land use and its change, especially around middle ring of the city.

C. Population growth

According to the official census data, from 1991 to 2002, the increasing population ratio remained about 5 percent around inner-outer area and the population increased by 144%. In spite of the urban population continued to rise overall, the population increase ratio is not the same. With the urban growth, urban-rural fringe of the urban was becoming population agglomeration. Population growth led to increased demand for residential space. Real estate scrambled to develop properties with good lake view. Parcels near the lake shore can yield handsome profit. Housing construction was one of the main activities that occupy wetlands on the fringe areas of Wuhan city.

As the population increases, the urbanization process going faster and to help to boost economy had been government mission. In the early stages of urbanization, the government and a lot of citizen didn't realize the importance of lake protection. Poor legal ground for wetlands administration, weak law enforcement, and the drive towards fast economic growth were the underlying problems that prevented effective wetlands protection. Since there were no detailed methods and administrative rules for the supervision of the lake protection, much lake converted to built-up area.

The results showed that the wetlands located around the middle ring changed more drastically during Wuhan urbanization.. The results demonstrated that wetlands spatial morphology can be effectively and quantitatively assessed by fractal dimension based on GIS and RS. The fractal dimension can be used to reflect the social-economic change in some extent.

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