Exploitation of the Lakeshore Districts under the Guidance of Healthy Lake Concept—The Case of the Wutong Lake Eco-city Project

Kai Peng, Junqing Zhou and Junlei Yang

Architecture and Urban Planning School, Huazhong University of Science and Technology, Wuhan 430074, China

Abstract: On the basis of the concept of “lake ecosystem health”, the paper proposes that the planning and development of lakeside regions shall be oriented towards the core target of preserving “healthy lake” and all the construction work in lakeside regions shall be conducted within the ecosystem carrying capacity limits that the lakes can withstand. To achieve this core target, the paper first identifies main indicators describing healthy lake ecosystem and defines the external factors that can influence the health of lake eco-system. Then based on this, two kinds of urban planning methods are proposed to maintain the stability of lake eco-system health through controlling the external factors that can affect the health of lake eco-system. The first is to propose controlling factors in urban planning, such as division of ecological sensitive zones, controlling the development intensity, population capacity and types of industry in the lakeside regions and the second is to construct a monitoring and early warning system for lake eco-system health. The theories and methods mentioned in this paper have been applied to the planning of Wuhan Wutong Lake eco-city.

Key words: Healthy lake, lakeshore districts, Wutong Lake eco-city project.

1. Introduction

Since the reform and opening up in 1978, China has made great advancement in urbanization: The urbanization rate has soared from 17.92% in 1978 to 44.99% in 2007 [1], the number of cities has increased dramatically, totaling 661 by the year of 2007 [2]. Several large-scaled and well-connected metropolitan agglomerations have been formed, such as the Yangtze River Delta, the Pearl River Delta and the Jing-Jin-Ji Area.

The urbanization is a process closely associated with population agglomeration and industry agglomeration. The generation mechanism of urbanization includes the increase in the number of agglomeration points and the expansion in the area of agglomeration points.

Either forms of agglomeration will bring about double effects: On one hand, it accelerates rural-urban

migration, and the scale effect brought about by the concentration and interaction of all kinds of activities can boost regional economy; but on the other hand, frequent and intense human activities involved in urbanization may bring damages to natural resources and ecology.

Lakes, which provide human beings with resources necessary for survival and sustainable development, are the most fragile ecosystems in the nature [3]. With the acceleration of China’s industrialization and urbanization, the invasion of human activities, particularly the development of lakeside regions, have aroused serious environmental concerns, such as water pollution, eutrophication, etc.. These problems break the ecological balance of lakes and degrade their natural functions. It is unrealistic to ban all development activities for the purpose of protecting environment because residents near the lakeside harbor depends on lake resources for economic development and improvement of living standards. Therefore, to the problem of reconciliation of

Corresponding author: Kai Peng, Ph.D. candidate, research fields: urban and regional planning. E-mail: pengkai83@gmail.com.

urbanization with the protection of population, resource and environment, as well as initiate construction projects within the carrying capacity of lake eco-system to bring the value of resources into full play without violating natural rules and stability is the focus of this paper. In order to address this problem, the paper introduces the concept of “lake eco-system health” to serve as a guiding principle that must be observed in the planning and construction of lakeside regions. To achieve this core target, the paper first identifies main indicators describing healthy lake ecosystem and defines the external factors that can influence the health of lake eco-system. Then based on this, two kinds of urban planning methods are proposed to maintain the stability of lake eco-system health through controlling the external factors that can affect the health of lake eco-system. The first is to propose controlling factors in urban planning, and the second is to construct a monitoring and early warning system for lake eco-system health.

2. Literature Review

Ecosystem Health was popularized in 1980s' North American countries as a response to the deteriorating global natural ecosystem at that time. It is an interdisciplinary theory developed on the basis of natural science, social science and health science [4, 5]. A number of different definitions [6-10] and indicators [6, 8, 10-12] have been proposed in the literatures. Generally speaking, ecosystem health is an interdisciplinary science integrating researches on human activity, social organization, natural system and human health. The concept of ecosystem health emphasizes the stability, sustainability and vigor of ecosystem, which can be manifested by the ability of an ecosystem to recover automatically after external shocks [5, 13-15]. The aim to conduct ecosystem health researches is to prevent the ecosystem from “falling ill” by evaluating and diagnosing the state of an ecosystem and by locating warning indicators suggesting the poor health state of an ecosystem [5, 13].

Rapport [14] put the problem of ecosystem health under the spotlight by drafting a chart illustrating the influence of human activity on ecosystem and human health.

Rapport, Cech and Costanza [5, 6] identified vigor, resilience and organization as three important standard factors assessing ecosystem health:

(1) Vigor is indicative of the function of the ecosystem, and can be measured in terms of metabolism or primary productivity;

(2) Resilience is also called as resistance and is indicative of a system's capacity to maintain structure and function in the presence of stress;

(3) Organization refers to the complexity of a system and can be measured in terms of the diversity and number of interactions between system components. The more complex the organization is, the healthier the ecosystem will be Ref. [5, 13, 14].

Since the concept of ecosystem health emerged in the 1980s, a number of programs have been made to address lake eco-system health issues [16-18]. “Lake health” is the extension of the concept of ecosystem health to the sphere of lakes. It has two theoretical foundations, one is the ecosystem health theory and the other is the theory of material circulation of lake ecosystems [6, 19, 20]. The researches on the “lake ecosystem health” mainly revolved around the identification of assessment indicators and the introduction of assessment approaches. So far as assessment indicators are concerned, a number of indicators for lake eco-system health assessment has been proposed, e.g., the GEP (gross ecosystem product) [11], ecosystem stress indicators [12] and comprehensive index system integrating biological, ecological, socioeconomic and human health factors [21]. When it comes to the assessment approaches, Jorgensen [22] proposed a tentative procedure for lake ecosystem health assessment, Xu [20, 23] proposed the DMM (direct measurement method) and an EMM (ecological modeling method). The paper differs from previous studies which put an emphasis on assessment

index systems and assessment methods. Drawing on the ecosystem health theory, the paper introduces a new concept “healthy lake”. Taking the lake and its ecosystem as an organism, the state of being healthy refers to a state in which a balance is kept between the economic benefits and the ecological returns. In other words, the lakeside regions can not be overdeveloped beyond the ecological carrying capacity limits of the lake, all the activities should be carried out on the premises of guaranteeing ecosystem health.

The paper first conducts a quantitative analysis of the lake ecosystem health by using three assessment indicators—vigor, resilience and organization and then defines main external factors that can affect the lake ecosystem health, including the pollutants being discharged, population capacity, the types of agricultural and industrial activities, etc.. Then based on this, a series of urban planning measure are proposed to control these external factors influencing the lake ecosystem health, and ultimately to maintain the stability of indexes of the lake ecosystem health and achieve the core target of “health lake”.

3. Methodology

Human activities in various forms, such as waste emission, non-point source pollution, overfishing and land reclamation from lakes, are the major causes undermining the stability of ecosystem health. Therefore, introducing the concept of “lake ecosystem

health” into urban planning, to be specific, the planning of lakeside regions, suggests a transition from old human-centered planning conception to lake-centered conception. In fact, human-centered planning and lake-centered planning are not two concepts in stark opposition. As shown in Fig. 1, human being is the integral part of ecosystem, so the impact of human activities on ecosystem will eventually find a way to act upon human being. Therefore, to prevent the performance of indexes of ecosystem health from changing drastically and to achieve the ultimate target of “healthy lake” by adopting urban planning measures to control the external factors influencing lake health (such as controlling pollutant discharged) is theoretically feasibly. These urban planning measures include limiting population capacity, dividing lakeside regions into different ecological sensitive zones, regulating developing intensity and introducing industries with little impact on lake environment, etc..

In the past, the urban planners were often stuck in a dilemma of balancing economic benefits and ecological efficiency in developing lakeside regions. They either took a compensation scheme in developing lakeside regions by first deciding the industrial development pattern and then making efforts to restore ecological system or went to the other extreme by refraining any kind of construction work by the lakeside to “protect” the ecological

Fig. 1 Linkages between human activity and ecosystem health [14].

environment. Seldom have they considered the possibility that multifaceted interests could be balanced so long as the development activities are conducted within the ecological carrying capacity and resilience limits of lakes. It is for the purpose of addressing this dilemma that the paper proposes to take the “healthy lake” as the starting point and core target in organizing and guiding development planning near lakeside. Fig. 2 is the technology roadmap of planning and construction of lakeside region with the core target of maintaining healthy lake. As can be seen in this figure, the first step is to set up a core target, to which other economic and social objectives are subordinate. The core target in the urbanization process of lakeside regions is to maintain lake eco-system health. The second step is to conduct quantitative assessment of lake eco-system health with three key assessment indicators—vigor, organization and resilience. The indicator of vigor assesses the mass circulation capability of ecosystem. The indicator of organization assesses the biodiversity of an ecosystem. The more complex the organization is, the healthier the ecosystem will be. The indicator of resilience assesses the system’s capacity to maintain structure and function in the presence of stress. The ecosystem under stress is less resilient than that free from stress. The third step is to define the external factors that affect lake eco-system health, including pollutants discharged into the lake, population capacity and industrial and agricultural production. The last step is to take urban planning measures to control the abovementioned three external factors, and ultimately achieve the core target.

4. The Case of the Wutong Lake Eco-city Project

4.1 An Overview of Planning Area

The Wutong Lake eco-city project is located within Liangzi Lake District inside Erzhou City, Wuhan urban agglomeration (Fig. 3). Wuhan urban

agglomeration was approved as national comprehensive experimental zone supporting the building of resource-saving and environment-friendly society. Its establishment aims at strengthening regional cooperation and removing regional barriers within the sphere of agglomeration and at boosting regional integration in the aspects such as industry layout, infrastructure construction, rural and urban development, market construction and ecological environment protection [24]. The establishment of Wuhan urban agglomeration provides a favorable policy environment for the building of Wutong Lake eco-city project.

Fig. 2 Technology roadmap of planning and construction of lakeside region with the objective of maintaining healthy lake.

Fig. 3 The site of Wutong lake eco-city.

Fig. 4 Location map of Wutong lake eco-city.

Liangzi Lake, the second largest freshwater lake in Hubei Province, is located in the southeastern part of Hubei and situated in the south bank of the middle reaches of Yangtze River. It passes through the central part of Wuhan urban agglomeration (Wuhan, Erzhou, Huangshi and Xianning), with a drainage area of 2,085 km² [25].

The Wutong Lake eco-city project is bounded by Changgang town to the east, Liangzi Lake to the south, Honglian Avenue (Connecting Miaoling Town and Liushi Village of Donggou District) to the north, and Fenglian Avenue (Connecting Phoenix Mountain and Liantai Bank in Wuhan) to the west (Fig. 4). Administratively, the planning area covers four villages Yueshan, Liushi, Zhazhou, Dalong in Donggou town, with an area of 41.23 km².

The condition of land resource in the planning area is superior, with no liability for geological hazard. The land resources available mainly include basic farmland, general farmland, woodland, garden plot, construction land in villages and towns, reclamation area.

Lying south to the Wutong lake and north to the Liangzi lake, the planning area is integral in lake ecosystem, rich in biodiversity and superior in water quality. It is also an important habitat for many rare and endangered wild aquatic animals and plants. Many national first-class and second-class protected animals inhabit here, such as Chinese merganser,

ring-necked pheasant and four kinds of plants under special state protection grow here, which are flora of China, floating fern, wild water chestnut and lotus. Therefore, it satisfies all the conditions required for experimental resource-saving and environment-friendly development zone.

There are still some existing problems in the planning area: The first problem is that the industries in the planning area are unevenly developed, with the primary industry well developed, while secondary and tertiary industry relatively backward; Secondly, though located in the hinterland of Wuhan-Ezhou corridor and Linking industrial zone along Yangtze River and Wuhan East Lake high-tech zone, the unique geographic advantage of the planning failed to stimulate the economic development effectively for so long.

4.2 Implementation of Technology Roadmap

4.2.1 Setting up Core Target

The orientation of developing an innovative and ecological new city is in consistency with the ultimate objective of maintaining “healthy lake”. “Innovative city” highlights the pioneering and creative developing ideology incorporated in the planning of Wutong Lake eco-city, and “Ecological city” is a manifestation of the priority given to the “healthy lake” in the process of lakeside region development.

4.2.2 Analysis of Current Lake Ecosystem Health State and External Influencing Factors

The first step of analysis is to assess the ecosystem health state of Liangzi Lake by use of abovementioned three indicators—vigor, organization and resilience.

The organization index can reflect the community structure of aquatic organisms inside the lake. According to the Liangzi Lake ecological environment protection plan (2010-2014), the Liangzi Lake well conserves the rich biodiversity and genetic diversity and is a habitat for many rare species. There are more than 280 kinds of vertebrates and about 92 advanced aquatic plants in the lake. It can be assessed that the organizational structure of Liangzi Lake is stable.

If the energy and matter of a natural ecosystem can provide sufficient sustenance for organisms living in the system, and can repair and adjust automatically to maintain dynamic balance, it can be said that this system has a high level of resilience and vigor. Thanks to the low exploitation rate and the abundant water grass, the water pollution of Liangzi Lake is not severe and the self-purification capability of water is high. The water quality of the eastern part of the Liangzi Lake, where the planning site is located, reaches the third class. The trophic state of Liangzi lake has degraded from oligotrophic level to mesotrophic lake, with part of water area even approaching eutrophic level. It thus can be judged that the resilience and vigor of planning area is in generally good state, but has a tendency toward worsening. Taking the above analysis together, it can be concluded that the ecosystem in the Liangzi Lake is good on the whole, but it is necessary to guard against the risk of deterioration.

Currently the factors that influence the ecosystem health in planning area include:

(1) Increase of pollutant emission from land

As most of small towns along Liangzi Lake do not have standard domestic sewage treatment facilities and waste landfills, large quantity of domestic sewage

organic waste was discharged into nearby rivers and finally flowed into Liangzi Lake;

(2) Undesirable effect of agricultural production

On the farmland within the Liangzi Lake, fertilizers and pesticides are used excessively. As a result, when the rain falls, pollutants like nitrogen and phosphorus will flow into Liangzi Lake with surface runoff, resulting in the high concentration of nitrogen and phosphorus in the lake;

(3) Dispersed pollution sources

Alongside the Liangzi Lake scattered a number of small towns. Because of the lack of proper industrial and domestic sewage treatment facilities, these towns have become hotbed for multi-point pollution sources.

4.2.3 Controlling Measures in the Planning of the Wutong Lake Eco-city Project

4.2.3.1 Preventive Controlling Measures in the Planning Stage

(1) Division of ecological sensitive zones and control of development intensity

An ecological sensitive area is a designation for an area which is of great significance for urban ecological environment because it has ecologically important elements or entities, which needs special protection because of its comparatively poor capability to counter against external disturbance and poor self-restoring capability [26]. Considering the following factors like the distance to the lake, the self-restoring capacity, the distribution of population aggregates, and the distance to the major transport corridor, the planning area has been divided into extremely sensitive area, sensitive area, less sensitive area and insensitive area. What is more, by giving full consideration to the ecological environment conditions in lakeside regions, the potential and availability of water resource and the actual economic development demand, the authors make an initial decision about the development intensity and industry patterns allowed by areas with different sensitive degrees in Table 1.

Table 1 Grade and construction suggestion of lakeside sensitive area.

Grade of sensitive area	Categories	Scope	Land planning	Construction industries	Exploitation intensity
Extremely sensitive	Absolute protection area	-	Water area	No industry suggested	Preservation first, development banned
Sensitive	Key protection area	< 0.3 km	Water area, garden, land for tourism and sightseeing, land for touring facilities	Eco-agriculture, eco-tourism	Plot ratio < 0.6
Comparatively sensitive	Preservation area	0.3-1.5 km	Land for urban residential area can be added, land for public facilities, land for service industries	Agriculture, tourism, scientific and educational industry, low-density residence	Plot ratio < 1.2
Insensitive	Key developed area	> 1.5 km	The first class of industrial land can be added, land for commercial service	Clean industry and cultural creative industry	Plot ratio < 2

Extremely sensitive area should be designated as absolute protection area because of its great ecological significance. These areas include surface of lake, wetland, etc., where development activity of any kind should be strictly prohibited.

Sensitive area should be designated as key protected area. These areas are of medium ecological significance and mainly include the ecological buffer area within 0.3 km around the lake, and the ecological buffer area around mountain and water area. These areas should be moderately exploited for sightseeing and touring, but high-intensity development activities should be banned.

Comparatively sensitive area should be designated as controlled exploitation area. On the premise of controlling exploitation scale and intensity, these areas can be moderately exploited by introducing tourism projects and educational and scientific industries. Besides, domestic and industrial sewages can be centralized for treatment and emission here. These areas can be developed into different functional areas, such as residential area, touring area, sports and leisure activities area and area for modern science and technology exhibitions.

Insensitive area should be designated as key development areas because these areas face few ecological constraints, have strong development demand and convenient transport facilities. These areas can be developed into business conference center and enterprise incubators.

Taking the scope of different sensitive areas as the radius of buffer area and using the buffer and overlay tool of ArcGIS software, the distribution map of sensitive areas of different grades is painted in Fig. 5. The crossover of roads and residential areas are also marked in the painting to provide convenience for the planning of industry layout and control of development intensity in the future;

(2) Estimation of proper population size in the planning area

Ecological environment is the biggest advantage boasted by Wutong Lake eco-city, but it is also extremely fragile, and the pollution resulted from large-scale population aggregation will pose severe environmental risks. Therefore, it is of necessity to estimate proper population size in the planning area.

In this paper, the domestic sewage discharge limitation in the residential district will be taken as the primary factor determining population size estimation. Based on the environmental capacity taken up by the domestic sewage in the residential district, and by referring to relevant indexes in the discharge standard of pollutants for municipal wastewater treatment plant, the domestic sewage discharge amount allowed in residential area could be decided. According to the fixed domestic sewage discharge amount regulated in the planning area, the population carrying size could be calculated with the following formula:

$$N = \frac{q_v \times 24 \times 3600}{q_{vn} \times K}$$

Fig. 5 Dividing of lakeside sensitive area.

where, N is the population carrying size in the planning area (person), q_v is the domestic sewage discharge amount allowed in residential area (L/s), q_{vn} is the fixed domestic sewage discharge amount regulated in the planning area (L/person-d,) and K is the general variation coefficient, which is decided by the discharge amount of domestic sewage in the residential area.

According to the actual situation in the planning area and the relevant regulations in China, the q_{vn} in the above equation shall be set as 270 L/person-d and K shall be 1.3.

The domestic sewage discharge amount allowed in residential area is determined by the environmental capacity taken up by domestic sewage discharge in residential area and the maximum permissible emission concentration ratio of basic control item stipulated in the discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002).

In the planning area, the farmland, sports park and

residential and office area is most susceptible to pollution. The environmental capacity of domestic sewage of residential area is: COD (chemical oxygen demand) = 21.5 t/d, NH_3-N (ammoniacal nitrogen) = 0.6 t/d. In these areas, the eutrophication phenomenon is apt to occur as a result of the abundant supply of nutrient elements N and P. Therefore NH_3-N shall be taken as the control factor to decide the population size of Wutong Lake eco-city project.

Therefore, the total environmental capacity shall be set as 0.6 t/d and the maximum permissible emission concentration of basic control items shall be 5 mg/L, 8 mg/L and 25 mg/L, respectively (Table 2).

With different drainage amount, the population size in the planning area should be controlled within the range of 68 to 340 thousand people (Table 3).

According to the discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002), the water discharged from urban sewage treatment plant should fall into Grade III surface water (drinking water source zone and

Table 2 Maximum allowed discharge concentration of basic control items (mg/L).

Basic control items	First-class standard		Second-class standard	Third-class standard
	A standard	B standard		
Ammonia nitrogen (N)	5	8	25	-

Source: Discharge standard of pollutants for municipal wastewater treatment plant (GB 18918-2002).

Table 3 Estimation of population carrying size in different cases of sewage discharge.

Sewage discharge condition and standard	Third-class standard	Second-class standard	First-class standard	
			B standard	A standard
Population carrying size (10,000)	-	6.8	21	34

swimming pool excepted), and should be treated by first class B standard. By this standard, the population size in the planning area should be controlled below 210,000.

To estimate the population size by the environmental capacity taken up by domestic sewage in residential area and for the objective of maintaining lake eco-system health is a new approach attempted in this project;

(3) Choice of industry patterns and layout of Industry distribution

The choice of industry patterns in the planning site must conform to the objective of “healthy lake”. Four industries were chosen as leading industries in the lakeside region, which are the environment protection industry, high science and technology industry, cultural originality industry and tourism industry (Fig. 6):

- Environment protection industry

Environment protection industry engages in a range of activities from the product development, commercial circulation, resource utilization to information service with a purpose of preventing and controlling environmental pollution and improving ecological environment. Wutong Lake eco-city can serve as a pilot area for the development of environment protection industry. In this experimental zone, the production, research and learning processes are integrated to create a win-win situation, with the research and development results of industry being applied to improving lake eco-system directly. As for the businesses run by environment protection industry, besides conventional businesses such as

manufacturing and selling environment protection equipments and providing environment protection services, other forms of business can also be derived such as opening up environment protection exhibition center, etc.;

- Scientific and technological pilot test

As far as the development of Wutong Lake eco-city is concerned, the scientific and technological pilot test can effectively promote the establishment of incubators and attract modern manufacturing and research institutions to join. There are a lot of modern manufacturing enterprises, research institutions and universities located in Wuhan, equipping Wuhan with strong research power. However, due to the lack of communication and cooperation platform for research institutions, universities and enterprises, each unit is conducting scientific and technological pilot tests independently, which is unfavorable for the integration of technology resources. Therefore, establishing the largest scientific and technological pilot test base of central China in Wutong Lake eco-city provides a golden chance to integrate product research and test resources, to organize large research teams to make technological breakthroughs. This is not only conducive for the sustainable development of Wuhan’s modern manufacturing, but also provides a platform to transform research results into productivity as quickly as possible;

- Cultural creative industry

Cultural creative industries refer to a range of economic activities which are concerned with the creation and elevation of cultural resources by high

technologic means and by use of the wisdom, skills and gift of human being and the generation of high-added value products by developing and exploiting intellectual property rights. Internationally recognized as low-pollution and high-profit industry, cultural creative industries can yield great fortunes and create job opportunities, and are thus extremely suitable to be introduced in the lakeside region. Wuhan East Lake high-tech zone and many universities and colleges located near the Wutong Lake area are earmarked to provide specialized talents to promote the development of regular industries like design, advertisement exhibition, software and computer service, theme residence, tourism and specialized service;

- Lake tourism

Taking full advantage of rich lake resources, beautiful natural scenery, unique lake and wetland landscape, and convenient land and water transport conditions inside the planning area, the Liangzi Lake can be developed into a comprehensive recreational and economic site combining vacation resort, water sports industry and special aquatic products

cultivation industry;

4.2.3.2 Establishing Long-Term Monitoring and Early Warning System to Protect Lake Health

In order to maintain the lake health ecosystem, taking cautions in initiating development is not enough, establishing a long-term monitoring and early warning system to assess the impact of the development projects could be essential.

The healthy lake monitoring and warning system consists of the general management and operation system, the health assessment and monitoring system, and the contingency management and operation system (Fig. 7). When a development project is being started, it will follow the basic flow in the general management and operation system, from the approval and initiation of the project to the construction and operation of the project. In the meantime, the health assessment and monitoring system will monitor the operation of each step constantly to assess the impact on lake eco-system. Once any operational link is found to make negative impact on lake eco-system, the contingency management and operation system will be called into

Fig. 6 Industry pattern of Wutong Lake eco-city.

Exploitation of the Lakeshore Districts under the Guidance of Healthy Lake Concept—The Case of the Wutong Lake Eco-city Project

Fig. 7 Healthy lake monitoring and warning system.

play, stopping the project in operation immediately and seeking for possible solutions. Not until the impact is proved to be cleared by the health assessment and monitoring system can the project be resumed. The cooperation and interaction of three systems plays an effective role in monitoring lake eco-system health and sending warning signals.

5. Conclusions

With the rapid urbanization of China, lake environment faces severe ecological challenges. In order to address the contradiction between economic development and lake protection, the paper proposes the concept of “healthy lake”, and uses this concept as

an orientation to direct the planning and construction of lakeside regions. The lake-centered planning mode that differs from the traditional human-centered planning mode complies with the sustainable development conception and can accelerate the transition and development of lakeside regions scientifically and successfully. The Wutong Lake eco-city has now been under construction and the authors will follow the development of the project to make prompt adjustment and modification to the theory and methodology proposed in the paper.

References

- [1] China Statistical Abstract 2008, National Bureau of Statistics, Statistics Press, Beijing, China, 2008.
- [2] F.C. Lin, The urbanization and urban development in china after the reform and opening-up, *Economic Geography* 29 (1) (2009) 20-24.
- [3] W.Y. Qing, Preface, in: the Proceedings of 13th World Lake Conference, China Agricultural University Press, Beijing, 2009, p. 1.
- [4] A.J. McMichael, B. Bolin, R. Costanza, G.C. Daily, C. Folke, K.L. Kiessling, et al., Globalization and the sustainability of human health: An ecological perspective, *BioSciences* 49 (3) (1995) 205-210.
- [5] D.J. Rapport, R. Costanza, P.R. Epstein, C. Gaudet, R. Levins, *Ecosystem health*, Blackwell Science 372 (1998) 1-356.
- [6] R. Costanza, G.N. Bryan, D.H. Benjamin, *Ecosystem Health: New Goals for Environmental Management*, Island Press, Washington, DC, 1992, pp. 239-279.
- [7] D.J. Schaeffer, E.E. Herricks, H.W. Kerster, *Ecosystem health: Measuring ecosystem health*, *Environ. Manage.* 12 (1988) 445-455.
- [8] J.R. Karr, K.D. Fausch, P.L. Angermeier, P.R. Yant, I.G. Schlosser, *Assessing Biological Integrity in Running Waters: A Method and Its Rationale*, Champaign, Illinois National History Survey, Special Publication 5, Illinois, 1986.
- [9] D.J. Rapport, What constitutes ecosystem health?, *Perspect. Bio. Med.* 33 (1989) 120-132.
- [10] J.J. Kay, A nonequilibrium thermodynamic framework for discussing ecosystem integrity, *Environ. Manage* 15 (4) (1991) 483-495.
- [11] B. Hannon, Ecosystem flow analysis, *Canadian Bulletin of Fisheries and Aquatic Sciences* 213 (1985) 97-118.
- [12] D.J. Rapport, H.A. Regier, T.C. Hutchinson, Ecosystem behavior under stress, *American Naturalist* 125 (1985) 617-640.
- [13] J.J. Cech, *Multiple Stresses in Ecosystems*, Lewis Publishers, Boston, 1998, pp. 53-132.
- [14] D.J. Rapport, R. Costanza, A.J. McMichael, Assessing ecosystem health, *Trends in Ecology and Evolution* 13 (1998) 397-402.
- [15] S. Kristin, Ecosystem health: A new paradigm for ecological assessment, *Trends in Ecology and Evolution* 9 (1994) 456-457.
- [16] S.E. Jorgensen, The application of ecological indicators to assess the ecological condition of a lake, *Lakes Reservoirs: ResManage* 1 (1995) 177-182.
- [17] F.L. Xu, S. Tao, On the study of ecosystem health: State of the art, *J. Environ Sci.* 12 (1) (2000) 33-38.
- [18] J.J. Zhang, Z. Gurkan, S.E. Jorgensen, Application of eco-exergy for assessment of ecosystem health and development of structurally dynamic models, *Ecological Modelling* 221 (2010) 693-702.
- [19] S.E. Jorgensen, *Fundamentals of Ecological Modeling*, Elsevier Science, New York, 1994, pp. 32-41.
- [20] F.L. Xu, S. Tao, R.W. Dawson, P.G. Li, J. Cao, Lake ecosystem health assessment: Indicators and methods, *Wat. Res.* 35 (13) (2001) 3157-3167.
- [21] H. Shear, The development and use of indicators to assess ecosystem health state in the Great Lake, *Ecosystem Health* 2 (2) (1996) 241-258.
- [22] S.E. Jorgensen, Exergy and ecological buffer capacities as measures of ecosystem health, *Ecosystem Health* 1 (3) (1995) 150-160.
- [23] F.L. Xu, R.W. Dawson, S.A. Tao, Method for lake ecosystem health assessment: An ecological modeling method and its application, *Hydrobiologica* 443 (1-3) (2001) 159-175.
- [24] Wuhan Urban Agglomeration Master Planning Outline (2007-2020), Hubei Development and Reform Commission, China, 2007.
- [25] The Ecological Environment Protection Planning of Liangzi Lake (2010-2014), Hubei Government, China, 2010.
- [26] D. Liangjun, L. Lina, L. Wanlian, C. Ming, The definition and types of urban ecological sensitive area with the case study in Pudong New Area, Shanghai, China, *Journal of East China Normal University (Nature Science)* 2 (2004) 97-103.