Research on Spatial Development Control Zoning for Water Ecosystem Health Protection: A Case Study of the Chaohu Lake Rim Area (Postprint)

Authors: Haixia Zhao, Xiaowei Jiang, Yan Liu

Date: 2018-02-01T00:00:00+00:00

Abstract

Water ecological health has become a new objective of regional environmental management and a research hotspot in the field of ecology and environment both domestically and internationally. Driven by rapid industrialization and urbanization, the Chaohu Lake circum-lake area has experienced water ecological health issues such as water quality deterioration, vegetation disappearance, and ecosystem function degradation, aiming to address the relationship between development and protection through spatial development control zoning in the circum-lake area, and to achieve sustainable and healthy development of the water ecosystem in the circum-lake area. Using the ArcGIS spatial analysis platform, a zoning evaluation index system composed of water ecological sensitivity and water ecological pressure was constructed, with 500 m × 500 m grids as evaluation units. Through comprehensive evaluation of single and multiple factors, and with the aid of two-dimensional correlation matrix analysis, spatial development control zoning was conducted, and accordingly, differentiated regional development and ecological environment protection orientations were proposed. The results indicate that the Chaohu Lake circum-lake area can be identified as four types of zones from a spatial unit perspective: low-sensitivity low-pressure zones, low-sensitivity high-pressure zones, high-sensitivity low-pressure zones, and high-sensitivity high-pressure zones; areas along both sides of the main inflow rivers of the lake with high water ecological sensitivity should focus on strengthening ecological restoration and environmental protection; the northern part of Binhu New District, Chaohu City proper, and the centers of various towns have high water ecological pressure, urgently requiring transformation and upgrading, and the implementation of strict environmental access conditions and pollution emission standards; although most areas of the circum-lake towns and townships have relatively low water ecological sensitivity and water ecological pressure, and can rely on local advantageous resources to develop according to local conditions and in a dislocated manner, strictly controlling

new pollutant emissions and maintaining healthy water ecological development is the primary task.

Full Text

Preamble

ACTA ECOLOGICA SINICA ChinaXiv Partner Journal
Vol. 38, No. 3, Feb. 2018
DOI: 10.5846/stxb201610132467

Spatial Management Zoning Based on Water Eco-Health: A Case Study of the Areas Around Chaohu Lake

ZHAO Haixia, JIANG Xiaowei, LIU Yan
State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
Jiangsu Provincial Academy of Environmental Science, Nanjing 210036, China
University of Chinese Academy of Sciences, Beijing 100049, China

---

Abstract

Water eco-health has become a new objective for regional environmental management and a prominent research focus in ecological and environmental fields both domestically and internationally. Driven by rapid industrialization and urbanization, the areas around Chaohu Lake have experienced water ecological health issues including water quality deterioration, vegetation loss, and ecosystem function degradation. This study aims to address the relationship between development and protection through spatial development regulation zoning in the lake-adjacent areas, thereby achieving sustainable water ecosystem health. We constructed a zoning evaluation index system composed of water ecological sensitivity and water ecological pressure, using 500 m × 500 m grid cells as evaluation units. Through comprehensive evaluation of single and multiple factors using ArcGIS, we propose differentiated regional development and ecological environmental protection strategies. The areas around Chaohu Lake can be spatially classified into four types via two-dimensional correlation matrix analysis: low-sensitivity and low-pressure areas, high-sensitivity and low-pressure areas, high-sensitivity and high-pressure areas, and low-sensitivity and high-pressure areas, representing 63.87%, 20.46%, 2.66%, and 13.01% of the total area, respectively. Differentiated measures are proposed for each zone. Firstly, the areas around Chaohu Lake should generally adopt low-density development policies prioritizing ecological and cultural protection. As important drinking water sources and ecological barrier zones for Chaohu and Hefei cities, these areas require strict protection of natural reserves, existing mountains, water bodies, wetland landscapes, forest parks, scenic areas, and lake shelterbelts. Secondly, learning from development models of lakeside districts in other regions, the de-

velopment approach should suit local conditions: belts along major inflow rivers have high water environmental sensitivity and are unsuitable for large-scale development, requiring strengthened ecological restoration and environmental protection. Thirdly, the northern Binhu New District, Chaohu City, and various town centers face high water ecological pressure from high-density development activities and urgently need industrial transformation, upgrading, and implementation of strict environmental access conditions and pollution emission standards. Lastly, although most lakeside towns have relatively low water ecological sensitivity and pressure, they must strictly control new pollution while leveraging local resources, as maintaining healthy water ecological development remains the primary task.

Keywords: water eco-health; water ecological sensitivity; water ecological pressure; spatial management zoning; areas around Chaohu Lake

---

1. Study Area Overview

Chaohu Lake, located in central Anhui Province within Hefei City, is the fifth largest freshwater lake in China. The lake has a catchment area of 9130 km^2, measures 54.5 km in length and 21 km in width, and receives inflow from rivers including the Hangbu, Fengle, and Zhegao before discharging through the Chaohu Sluice into the Yangtze River via the Yuxi River. The total storage capacity is 7.69 billion m^3. The study area encompasses all townships adjacent to Chaohu Lake, including Binhu New District, covering 1775 km^2 (excluding the water area of Chaohu Lake itself) [Figure 1: see original paper].

---

2. Database and Evaluation Units

Through field surveys, we collected topographic data, water environmental quality data, economic statistics, population data, and maps for the study area. Using ArcGIS software for map registration and calibration, we established spatial attribute databases for water ecological sensitivity and pressure elements. To accurately express spatial heterogeneity and facilitate single-factor and multi-factor comprehensive evaluation, we selected 500 m × 500 m grid cells as the basic evaluation units. Socioeconomic and cultural element evaluations were based on township administrative units segmented into grid cells, while natural element evaluations used natural boundaries converted to grid units through polygon-to-grid transformation. The conversion formula is:

$$D_i = \frac{\sum_{j=1}^{n}(N_j \times A_{ij})}{A_i}$$

where D_i represents the natural element evaluation index for grid unit i, A_{ij} is the area of the j-th level natural element within grid unit i, A_i is the total area of grid unit i, and N_j is the weight of the j-th level natural element. Spatial overlay analysis was used to unify evaluation units, and effective evaluation units were merged to determine the spatial development regulation zoning scheme.

---

3. Evaluation Indicators and Weights

To comprehensively reflect the natural ecological conditions, environment, and socioeconomic characteristics of the lake-adjacent areas, the zoning evaluation primarily selected two categories of indicators: water ecological sensitivity and water ecological pressure. Water ecological sensitivity reflects the integrity and security of the aquatic ecosystem itself—the higher the sensitivity, the stronger the constraints on development. Water ecological pressure reflects the stress from human activities on the water ecosystem, mainly manifested in land use patterns and pollution intensity—the greater the pressure, the greater the threat to water ecological health. Indicator selection considered stability, scalability, and availability while avoiding overlap to fully reflect spatial differences in development suitability.

Water ecological sensitivity zoning was evaluated based on ecological importance, natural disaster susceptibility, and water pollution risk [Figure 2: see original paper]. Water ecological pressure zoning considered the degree of socioeconomic development stress on water ecological health, including development intensity and pollution emission intensity. Indicators included the proportion of construction land, population density, per capita GDP, and industrial wastewater discharge per unit land area.

Weight determination considered both differences and importance. To ensure accuracy and scientific rigor, we employed the Analytic Hierarchy Process (AHP) to quantify pairwise indicator importance through judgment matrices. Based on Chaohu Lake' s water ecological characteristics, we used AHP to obtain initial factor importance, then collected expert scores through questionnaires. After validity and convergence analysis, weights were refined through iterative feedback until high satisfaction was achieved. Finally, the entropy method determined final indicator weights .

---

4. Spatial Control Zoning Evaluation

After standardizing and weighting factor scores for each grid unit, we used hierarchical clustering and convergence analysis to classify both water ecological sensitivity and pressure indices into high, medium, and low levels. A two-dimensional correlation matrix was constructed with water ecological sensitivity index (low to high) as rows and water ecological pressure index (low to high) as columns. Based on this matrix, the study area was divided into four zones:

high-sensitivity high-pressure, high-sensitivity low-pressure, low-sensitivity high-pressure, and low-sensitivity low-pressure. Notably, medium and higher levels of water ecological pressure and sensitivity were classified as high-pressure and high-sensitivity zones, respectively, to better facilitate water ecosystem health maintenance.

Standardization formula:

$$X_{ij} = \frac{x_{ij} - x_i^{\min}}{x_i^{\max} - x_i^{\min}}$$

where $x_i^{\max}$ and $x_i^{\min}$ are the maximum and minimum values of indicator i, x_{ij} is the initial value of indicator i in unit j, and X_{ij} is the standardized value.

Weighted summation formula:

$$A_i = \sum_{j=1}^{n} X_{ij} \times P_j$$

where A_i is the water ecological sensitivity index or water ecological pressure index for indicator i, X_{ij} is the standardized value of indicator i in unit j, and P_j is the weight .

---

5. Data Sources and Processing

Data included spatial vector data, socioeconomic statistics, and environmental information. Spatial vector data were derived from 1:50,000 topographic maps and 10 m resolution remote sensing imagery. Socioeconomic data (population, etc.) came from 2013 township records. Pollution discharge data were estimated based on industrial output value proportions. Water environmental quality data were obtained from the 2013 Hefei Environmental Quality Report. Additional sources included the Chaohu Lake Basin Water Pollution Prevention Plan, Hefei Urban Master Plan, Scenic Area Plan, lakeside township plans, Anhui Provincial Important Ecological Function Zoning, and Anhui Provincial Geological Disaster Prevention Planning.

---

6. Water Ecological Sensitivity Evaluation

Ecological Importance: This reflects ecosystem structure and function stability. Higher ecological importance indicates greater protection value and stronger constraints on development. Indicators included nature reserves, important wetlands, and drinking water source protection zones. Using supervised classification of remote sensing imagery and referencing the Anhui Provincial Important Ecological Function Protection Plan, we digitized these areas in ArcGIS. Comprehensive evaluation revealed higher ecological importance in Tongda Town (southwest), Yicheng Town (northwest), and the mountainous hilly region southeast of Chaohu City, with other areas relatively lower.

Natural Disaster Susceptibility: Based on actual conditions, we selected flood disasters and geological hazards (collapse, landslide, debris flow). Hazard levels were assigned values: high-risk debris flows as level 1; floods and expansive soil as level 2. Except for Baita and Baishan Towns, most lakeside townships showed high disaster susceptibility.

Water Pollution Risk: Increased pollutants are the dominant factor causing Chaohu Lake water quality deterioration. Controlling major inflow rivers is crucial for pollution prevention. Based on water quality targets, risk levels were classified: Class III and above rivers had moderate risk (value 2); Class IV-V rivers had highest risk (value 3). Using 1:50,000 topographic maps and ArcGIS buffer tools, areas within 50 m of major inflow rivers were designated as primary water ecological safety control zones, and 50-200 m as secondary control zones. Analysis showed high pollution risk along major inflow river corridors [Figure 3: see original paper].

Through comprehensive indicator evaluation and clustering analysis, high water ecological sensitivity areas were identified in Yinping Town, Xiage Town, the northern mountainous hilly region of Chaohu City, and along the Nanfei and Yuxi Rivers.

---

7. Water Ecological Pressure Evaluation

Development Intensity: Measured by the proportion of construction land area to total territorial area. Higher construction land proportion increases impervious surfaces, reducing water environmental capacity and pollutant dilution capacity. Binhu New District and Chaohu City proper showed high construction land proportions.

Population Density: Measured by resident population per unit construction land area. Higher population density increases water resource consumption and wastewater discharge. Chaohu City proper had the highest density, followed by Binhu New District.

Economic Development Level: Measured by per capita GDP. Greater economic development increases pressure on water ecosystems. Binhu New District showed the highest values, followed by Hualin Town, with other townships relatively lower.

Pollution Emission Intensity: Industrial wastewater discharge per unit land area directly reflects water pollution levels. Comprehensive analysis of these indicators showed highest pollution emission intensity in Binhu New District and Chaohu City proper, with relatively high pressure in town centers of lakeside townships [Figure 4: see original paper].

8. Spatial Development Control Zoning

Through comprehensive evaluation and clustering, grid units were classified into high, medium, and low categories for both sensitivity and pressure. Based on the two-dimensional matrix analysis, four zones were delineated [Figure 5: see original paper]:

High-Sensitivity High-Pressure Zone (2.66% of total area): Areas with both high water ecological sensitivity and pressure, mainly Chaohu City proper and surrounding regions (47.27 km^2). Local water environmental capacity is already overloaded. Due to strict constraints from ecological protection and drinking water sources, development of pollution-intensive industries (chemicals, paper) is inappropriate. Future focus should be on modern services, logistics, and high-tech industries, accelerating industrial transformation and upgrading with strict environmental access and emission standards.

High-Sensitivity Low-Pressure Zone (20.46% of total area): Areas with high sensitivity but low pressure (363.26 km^2), including Yinping Town, Xiage Town, northern mountainous areas, and major inflow river corridors. While socioeconomic development lags and ecological stress is limited, sensitivity is high. These areas should develop low-pollution, high-benefit characteristic industries suited to local conditions, strengthen ecological restoration and environmental protection, and protect nature reserves, water sources, and wetlands. Areas like Huanglu can develop tourism services leveraging lakeside scenery.

Low-Sensitivity High-Pressure Zone (13.01% of total area): Areas with low sensitivity but high pressure (231.10 km^2), mainly in northern Binhu New District and southern Chaohu City. These zones should accelerate sewage treatment facility construction, enhance treatment capacity, implement appropriate environmental access thresholds, promote clean production, and strengthen environmental law enforcement to control new pollution sources. Binhu New District can leverage its industrial base to develop new energy and new materials industries.

Low-Sensitivity Low-Pressure Zone (63.87% of total area): Areas with both low sensitivity and pressure (1134.19 km^2), primarily in most lakeside townships. With large environmental capacity and strong pollutant assimilation capacity, these areas have significant development potential and represent the main future development space. However, as Chaohu Lake is a critical drinking water source and ecological barrier, development should prioritize ecology and culture with low-density approaches. Townships should leverage local resources and ecological advantages to accelerate specialized industrial parks while strictly controlling impacts on the Chaohu Lake ecosystem.

9. Conclusions and Discussion

This study employed spatial analysis techniques with grid-based evaluation units to conduct spatial development regulation zoning for the Chaohu lakeside zone under the dual constraints of water ecological sensitivity and pressure. Drawing on domestic and international lakeside development models, we identified appropriate development patterns including pure ecological protection, low-density recreational development, and urban development types. The zoning provides theoretical support for coordinating spatial development and ecological protection in the Chaohu lakeside area.

Areas with high water ecological sensitivity, including the region surrounding Chaohu City and major inflow river corridors, are unsuitable for large-scale development and require strengthened ecological restoration and environmental protection. Economic development zones like northern Binhu New District and town centers face high water ecological pressure and urgently need transformation, upgrading, and enhanced sewage treatment facilities with strict environmental access conditions. Areas with low sensitivity but high development demand should moderately control population density and development intensity to become lakeside urban and ecological industrial zones.

This research provides a beneficial exploration of spatial regulation zoning for the Chaohu lakeside region. However, the scientific reliability of zoning results depends heavily on indicator selection. Current indicator systems need further improvement, particularly by adding biodiversity and other ecosystem function indicators in water ecological pressure evaluation. Additionally, this study treated the lakeside zone as a closed system, while actual water ecological conditions are also influenced by upstream areas of the Chaohu Basin and industrial layout/pollution discharge in Hefei City. Developing water ecological spatial regulation analysis methods at larger scales requires further investigation.

References

[1] Water ecosystem health assessment of the Taizi River Basin based on benthic algae. *Acta Ecologica Sinica*, 2012, 32(6): 1677-1691.

[2] Spatiotemporal characteristics and policy implications of water resources development in the Beijing-Tianjin-Hebei urban agglomeration. *Progress in Geography*, 2017, 36(1): 58-67.

[3] Research progress on watershed aquatic ecological function zoning and zoning methods. *Chinese Journal of Ecology*, 2009, 28(3): 542-548.

[4] Snelder TH, Biggsbarry JF. Multiscale river environment classification for water resources management. *Journal of the American Water Resources Association*, 2002, 38: 1226-1239.

[5] Rapport DJ, Costanza R, McMichael AJ. Assessing ecosystem health. *Trends in Ecology and Evolution*, 1998, 13(10): 397-402.

[6] Water ecoregion zoning methods and their application prospects in China. *Advances in Water Science*, 2007, 18(2): 293-300.

[7] Comparative study on ecological zoning systems between China and the USA. *Acta Ecologica Sinica*, 2010, 30(11): 3010-3017.

[8] Secondary zoning technical framework. *Acta Ecologica Sinica*, 2010, 30(17): 4804-4814.

[9] Omernik JM. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers*, 1987, 77: 118-125.

[10] Austrian Standards Institute. Guidelines for the ecological survey and evaluation of flowing surface waters. Vienna: Austrian Standards Norm M 6232, 1997: 38.

[11] Control unit division of Liao River Basin based on aquatic ecological function zoning. *Journal of Meteorology and Environment*, 2013, 29(3): 107-111.

[12] Aquatic ecological function zoning of Taihu Basin. *Chinese Journal of Ecology*, 2010, 29(1): 111-117.

[13] Ecological function zoning of the lower Jinsha River region based on hierarchical analysis. *Acta Ecologica Sinica*, 2016, 36(1): 134-147.

[14] Spatial development function zoning of small watersheds in the lower Huai River: A case study of Jiangsu coastal areas. *Environmental Science and Technology*, 2012, 35(5): 198-201.

[15] Water environmental constraint zoning and industrial access in economically developed areas: A case study of Wuxi City. *Resources and Environment in the Yangtze Basin*, 2011, 20(7): 879-885.

[16] Industrial agglomeration spatial optimization in Taihu Basin under water environmental capacity constraints. *China Environmental Science*, 2012, 32(8): 1530-1536.

[17] Primary and secondary water ecological function zoning of Dianchi Basin. *Journal of Basic Science and Engineering*, 2015, 27(1): 175-182.

[18] Regional pollution load allocation based on macroeconomic optimization models. *Journal of Basic Science and Engineering*, 2003, 11(2): 133-142.

[19] Water environmental constraint zoning and spatial development guidance: A case study of Wuxi City. *Resources and Environment in the Yangtze Basin*, 2008, 20(1): 129-134.

[20] Water environment collaborative constraint zoning and industrial layout guidance: A case study of Jiangsu Province. *Acta Geographica Sinica*, 2010, 65(7): 819-827.

[21] Overview of Chaohu lakeside zone and ecological restoration plan for lake shoreline and water-facing littoral zone. *Resources and Environment in the Yangtze Basin*, 2012, 21(S2): 62-68.

[22] Spatial regulation zoning for economic coordination development in lakeside areas: A case study of the eastern Chaohu section. *Acta Ecologica Sinica*, 2010, 30(22): 6255-6263.

[23] Basic issues in water ecological function zoning research. *Resources and Environment in the Yangtze Basin*, 2012, 21(4): 426-432.

[24] Spatial scale characteristics of watershed environmental elements and their relationship with water ecological zoning scales: A case study of the Liao River Basin. *Acta Ecologica Sinica*, 2012, 32(11): 3613-3620.

Note: Figure translations are in progress. See original paper for figures.