Aquatic Ecological Function Regionalization in the Hai River Basin Based on Terrestrial-Aquatic Ecosystem Coupling: Postprint

Authors: Sun Ranhao, Cheng Xian, Chen Liding

Date: 2018-01-09T00:00:00+00:00

Abstract

Water ecological function zoning is a division of terrestrial ecosystems based on characteristics of water ecosystems, providing ecological background and fundamental units for watershed water ecological management. Terrestrial-water ecosystem coupling constitutes the core of water ecological function zoning, yet it mostly remains at the stage of theoretical discussions in individual small watersheds, with few practical cases in large watersheds. A three-level indicator system for water ecological function zoning is proposed specifically for the unique climate, geomorphology, hydrology, and human activity characteristics of the Haihe River Basin. The first- and second-level zones employ a "top-down"zoning approach based on climate, geomorphology, and hydrological background, while the third-level zones adopt a "bottom-up" zoning method focusing on the impacts of human activities on water resources, water environment, and habitats. Ultimately, the Haihe River Basin is divided into 6 first-level zones, 16 second-level zones, and 73 third-level zones. This study fully embodies the fundamental principle of "determining land by water and controlling water by land," as well as the advantages of both "bottom-up" and "top-down" zoning methods. The results can provide a scientific basis for water ecological management in the Haihe River Basin, and serve spatial allocation and rational utilization of water resources, industrial structure layout, and regional coordination.

Full Text

Preamble

ACTA ECOLOGICA SINICA (ChinaXiv Partner Journal)
Vol. 37, No. 24, December 2017
DOI: 10.5846/stxb201705190925

Coupling Terrestrial and Aquatic Ecosystems to Regionalize Eco-regions in the Haihe River Basin, China

Sun Ranhao[1], Cheng Xian[2], Chen Liding[1]
[1]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

Water ecological function zoning represents a division of terrestrial ecosystems based on aquatic ecosystem characteristics, providing an ecological background and fundamental units for watershed ecological management. The coupling of terrestrial and aquatic ecosystems constitutes the core of water ecological function zoning, yet most studies remain at the theoretical exploration stage for individual small watersheds, with few practical cases implemented in large-scale basins. Addressing the unique hydrological and human activity characteristics of the Haihe River Basin, this study proposes a three-level indicator system for water ecological function zoning.

The results can provide a scientific basis for water ecological management in the Haihe River Basin, serving water resources spatial allocation and rational utilization, industrial structure layout, and regional coordination.

Keywords: ecological function; ecosystem services; regionalization; water quality; Haihe River Basin

---

1. Study Area Overview

The Haihe River Basin includes three major river systems: the main Haihe River, the Luan River, and the Tuhai-Majia River. The plain areas can be broadly divided into piedmont alluvial-pluvial plains, central river floodplains, and coastal plains. The widely distributed Loess Plateau lies to the north of the basin. From east to west, the zonal vegetation transitions sequentially. The northwestern part of the basin predominantly features calcic soils, the north-central part leached soils, the south-central part semi-leached soils, the central-eastern part hydromorphic soils, and the eastern coastal area saline soils.

Annual precipitation in the Haihe River Basin is concentrated in the flood season, decreasing gradually from southeast to northwest. The main river channels experience annual drying periods averaging 3.7×10^{4} km. 4,000 km of river channels remain dry year-round. The average population density is 1.09×10^{4} people/km^2. The basin represents a typical water-deficient region. As one of the country' s major grain production areas, it supports a large population with less than 1.3% of the nation' s water resources.

2. Level 1 and Level 2 Water Ecological Function Zones

The Haihe River Basin completed its Level 1 and Level 2 water ecological function zoning [23-24]. This paper focuses primarily on Level 3 zoning. Hydrological factors serve as Level 1 zoning indicators, while soil factors serve as Level 2 zoning indicators. Based on basin characteristics, a targeted indicator system was established. According to the spatial heterogeneity characteristics of geomorphological types, aridity index, and runoff depth, interpolation methods were used to separately map to obtain vector zoning maps, which were overlaid to form the Level 1 zone map. Soil types and vegetation cover types underwent spatial clustering.

3. Data Collection and Processing for Level 3 Zoning

Level 3 zoning uses small watersheds as the basic unit. The sub-watersheds were extracted using a model, utilizing existing river network data as the base. In plain areas, preprocessing such as depression filling was performed. The average watershed area is 105 km^2.

Socioeconomic statistical data were obtained from the basin' s statistical yearbooks. Since socioeconomic data are mostly based on county-level administrative units while Level 3 zoning is based on small watershed catchment units, we adopted a land use weighting method [25]. For example, agricultural water use and fertilizer application concentrate in farmland, industrial water use and wastewater discharge concentrate in urban land, and livestock breeding concentrates in rural land. After weighting socioeconomic indicators to different land use patches, we could obtain socioeconomic data for each small watershed. Compared with simple area-weighted spatialization of socioeconomic indicators, this method better reflects the main causes and pathways of socioeconomic activities and offers higher precision.

Water quality data were collected using multi-parameter water quality meters (YSI 6600V2, YSI). Algae and fish were the main monitoring targets. Fish were captured using multiple methods including electrofishing.

3.1 Zoning Principles

The purpose of Level 3 zoning is to reveal the carrying functions and stress effects of terrestrial ecosystems on aquatic ecosystems, as well as ecosystem types and their combination characteristics. The basic principles include:

Terrestrial-Aquatic Coupling Principle: Terrestrial ecosystems have direct impacts on aquatic ecosystems, while aquatic ecosystems can influence terrestrial ecosystems through feedback mechanisms. The two interact with each other. Zoning should be conducted through terrestrial indicators that affect the formation and maintenance of aquatic ecosystems, with each indicator having a clear impact on aquatic ecosystems. Through mutual feedback between terrestrial and aquatic ecosystems, the goal is to ultimately achieve ideal terrestrial zoning management and aquatic ecological objectives.

Catchment Unit Integrity Principle: The basic zoning unit for Level 3 zones is the small watershed, reflecting the overall consistency within small watersheds and differences between them.

Dominance of Human Activity Stress Principle: The impacts of human activities and land use need to be particularly characterized. Based on the strong human activities in the Haihe River Basin and the severe stress on water resources and water environment.

River Type and Function Unity Principle: Level 3 zones should reflect differences in river types and variations between upstream/downstream and main tributaries. These differences may affect water quantity river habitats.

3.2 Zoning Indicators

Level 3 zoning indicators need to be temporally stable and primarily address causal relationships of ecological elements.

Water Resources Stress and Carrying Function: Through literature review, a series of alternative indicators were identified. Among them, domestic water use intensity (t/km^2), industrial water use intensity (t/km^2), and agricultural water use intensity (t/km^2) are the most direct factors of water resources stress intensity. Other indicators have more indirect effects. For water resources carrying function, small watershed area and average flow accumulation intensity are direct measures of a small watershed' s water collection capacity, reflecting the support capacity of human engineering measures for water resources and their support for flood regulation and water source conservation.

Water Environment Stress and Carrying Function: Indicators that can characterize water environment carrying function or maintain nutrient cycling capacity include watershed average slope and watershed shape index (LSI). According to literature research, average slope and watershed shape index can affect hydrological conditions. Can serve as mandatory indicators simultaneously.

River Habitat Stress and Carrying Function: Land use intensity represents the stress pressure of human activities on river habitats, particularly the ratio of natural to artificial surfaces. Wetland proportion can reflect the carrying capacity of river habitats within the watershed.

Unity of River Type and Ecological Function: River types are usually combined with specific ecological functions, such as main and tributary streams. River order serves as a representative indicator for the above river type classifications. Different order rivers provide different habitat conditions for aquatic organisms, suitable for different species distributions. To simplify calculation, secondary division of water ecological function zones was performed to form water ecological function zones with relatively consistent river types, setting the impacts of human activities on water resources and habitats as equal weights.

3.3 Spatial Pattern Characteristics

Spatial clustering of Level 3 zone indicators was conducted within each Level 2 zone. The selection principle tries to maintain continuity of Level 3 zones across different Level 2 zones. Finally, a balance must be struck between classification detail and accuracy.

3.4 Zoning Result Evaluation

To obtain relatively stable aquatic biological indicators, we averaged multiple sampling datasets. Correlations between water ecosystem characteristics and socioeconomic characteristics were analyzed for each sub-watershed. Correlations between zoning indicators and water quality/aquatic biological indicators were statistically analyzed. Table 1 shows that most zoning indicators can reflect the heterogeneity of water ecosystems from different aspects.

Impact on Water Environmental Characteristics: Fertilizer use intensity, forest/grassland proportion, domestic water use intensity, domestic sewage intensity, small watershed area, and slope have relatively significant effects ($p < 0.05$, $p < 0.01$).

Impact on Benthic Animals: Small watershed slope and forest/grassland proportion show significant effects.

Impact on Algae: Industrial sewage intensity, fertilizer use intensity, industrial water use intensity, and small watershed area show relatively significant correlations.

Impact on Fish: Domestic water and sewage intensity have no significant effect on fish communities.

4. Discussion

Existing zoning schemes for the Haihe River Basin can be roughly divided into the following categories: physical geography zoning, ecological function zoning, water function zoning, eco-hydrological zoning, water resources zoning, etc. Through comprehensive comparison of existing zoning schemes in the Haihe River Basin, water ecological function Level 3 zoning shows improvements in several aspects:

Enhanced Terrestrial-Aquatic Coupling: Physical geography zoning considers geomorphology, climate and other natural differences. Ecological function zoning highlights the impact of human activities on ecological environmental problems. Water function zoning divides water body functions based on watershed units, representing only functional classification of visible water bodies. Eco-hydrological zoning emphasizes regional hydrological and water resources characteristics. Most existing schemes focus on either terrestrial or aquatic ecosystems, ignoring their interconnections. Water resources zoning emphasizes socioeconomic indicators. Water ecological function zoning organically combines comprehensive zoning and thematic zoning, which is reflected in multi-level zoning that comprehensively considers various natural environmental factors. Level 1 and 2 zoning belong to comprehensive zoning, while Level 3 zoning belongs to thematic zoning targeting specific water ecological environmental problems.

Differentiated Control Elements at Different Levels: Water ecological function zoning needs to distinguish main control elements at different levels. Based on the basin' s terrain, vegetation and soil ecological characteristics, we divided water ecological function Level 1 and 2 zones. On this basis, considering the stress effects of human activities on water ecosystems, we conducted Level 3 water ecological function zoning. Most existing schemes only target terrestrial or aquatic ecosystems. Considering management needs and indicator stability, the selection of zoning indicators focuses entirely on terrestrial ecosystem indicators without incorporating water ecosystem indicators, which are only used for zoning indicator selection and result validation.

Increased Management Targeting: Existing zoning schemes in the Haihe River Basin include both comprehensive zoning (integrating multiple natural or socioeconomic factors) and thematic zoning (focusing on specific environmental or social factors). For example, water function zoning mainly focuses on water' s service functions to humans. Some zoning schemes related to water ecology strive to break administrative boundaries, mostly using watershed boundaries as zoning scope and dividing according to watershed natural attributes. However, since China implements a management system based on administrative regions, even if a basin-wide coordinating department is established, implementation must ultimately be carried out by various administrative regions. This creates an awkward situation. Therefore, it is necessary to fully integrate natural boundaries and administrative boundaries. Most existing schemes detach from management departments' actual needs in basic zoning units and zoning objectives. This study' s Level 3 water ecological function zoning comprehensively considers both watershed boundaries and administrative divisions, making it easier to formulate targeted management plans.

Integration of Zoning Methods: From the perspective of zoning methods, most schemes adopt hierarchical, top-down zoning techniques that divide lower-level units step by step from higher-level ones. A few schemes adopt bottom-up methods that merge small regional units into larger ones. The Haihe River Basin water ecological function zoning fully absorbs the advantages of both methods. Level 1 and 2 zones use top-down methods, mainly based on regional differentiation laws and macro-scale patterns of water ecosystems, reflecting macro-scale regularities of water ecological functions. Level 3 zones use bottom-up methods, mainly based on classification indicators of ecosystem structure, obtaining zoning results through spatial clustering [39].

5. Conclusion

Level 3 zones can be applied to environmental management at medium and small scales, including providing scientific basis for integrated regional socioeconomic development, determining environmental pollution loads by zoning units, industrial structure layout, and regional coordination.

References (References):

[1] Zhang Y, Fu G, Yu T, Shen M H, Meng W, Ongley E D. Trans-jurisdictional pollution control options within an integrated water resources management framework in water-scarce north-eastern China. Water Policy, 2011, 13(5): 624-644. [2] [Title missing] Research on the concept, characteristics and implementation strategies of watershed water ecological function zones. Environmental Science Research, 2013, 26(5): 465-471. [3] Bailey R G. Ecoregions: The Ecosystem Geography of the Oceans and Continents. New York: Springer-Verlag Inc., 1998. [4] Abell R A, Olson D M, Dinerstein E, Hurley P T, Diggs J T, Eichbaum W, Walters S, Wettengel W, Allnutt T, Loucks C J, Hedao P. Freshwater Ecoregions of North America: A Conservation Assessment. Washington DC: Island Press, 2000. [5] Abell R, Thieme M L, Revenga C, Bryer M, Kottelat M, Bogutskaya N, Coad B, Mandrak N, Balderas S C, Bussing W, Stiassny M L J, Skelton P, Allen G R, Unmack P, Naseka A, Ng R, Sindorf N, Robertson J, Armijo E, Higgins J V, Heibel T J, Wikramanayake E, Olson D, López H L, Reis R E, Lundberg J G, Pérez M H S, Petry P. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. BioScience, 2008, 58(5): 403-414. [6] Frissell C A, Liss W J, Warren C E, Hurley M D. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management, 1986, 10(2): 199-214. [7] [Title missing] Multi-index assessment method for river ecosystem health in the Liao River Basin. Research of Environmental Sciences, 2009, 22(2): 162-170. [8] [Title missing] Research on water ecological function zoning in the Liao River Protection Zone. Chinese Journal of Applied Ecology, 2013, 32(6): 744-751. [9] [Title missing] Progress in watershed water ecological function zoning and zoning methods. Ecological Science, 2009, 28(3): 542-548. [10] [Title missing] Research on water ecological zoning in the Liao River Basin. Acta Ecologica Sinica, 2009, 20(12): 3101-3108. [11] [Title missing] Water ecological function zoning in the Taihu Lake Basin. Acta Scientiae Circumstantiae, 2009, 29(1): 111-117. [12] [Title missing] Research progress in water ecological function zoning. Environmental Science Research, 2010, 23(6): 911-918. [13] [Title missing] Research on ecological function zoning of the Chaohu Lake Basin based on water ecosystem structure characteristics. Science Press, 2015. [14] [Title missing] River ecological health assessment in the East River based on remote sensing. Acta Scientiae Circumstantiae, 2010, 30(22): 6255-6263. [15] [Title missing] Research on water ecological function zoning in China based on Gini coefficient. Acta Ecologica Sinica, 2010, 30(17): 4804-4814. [16] [Title missing] Primary and secondary water ecological function zoning in the Dianchi Lake

Basin. Environmental Science, 2013, 33(18): 5808-5817. [17] [Title missing] Tertiary water ecological function zoning in the Taihu Lake Basin. Environmental Science Research, 2015, 27(1): 175-182. [18] [Title missing] Technical framework for secondary zoning of water ecological functions. Acta Scientiae Circumstantiae, 2015, 35(7): 2177-2183. [19] [Title missing] Research on primary and secondary water ecological function zoning in the Haihe River Basin. Science Press, 2013. [20] [Title missing] Research on water ecological function zoning in the Haihe River Basin. Environmental Science Research, 2012, 31(11): 1941-1951. [21] [Title missing] Tertiary water ecological function zoning based on water ecosystem structure characteristics in the Dianchi Lake Basin. Environmental Science, 2013, 26(5): 480-486. [22] [Title missing] Ecological function zoning in the lower Jinsha River area based on analytic hierarchy process. Acta Ecologica Sinica, 2016, 36(1): 134-147. [23] [Title missing] Research on water ecological function zoning in the Haihe River Basin. Science Press, 2013. [24] [Title missing] Primary and secondary water ecological function zoning in the Haihe River Basin. Environmental Science Research, 2012, 31(11): 1941-1951. [25] Zhang H P, Chen L D. Using the ecological risk index based on combined watershed and administrative boundaries to assess human disturbances on river ecosystems. Human and Ecological Risk Assessment: An International Journal, 2014, 20(6): 1590-1607. [26] [Title missing] China mountain plant species diversity survey plan and technical specifications. Biodiversity Science, 2004, 12(1): 5-9. [27] Berger W H, Parker F L. Diversity of planktonic foraminifera in deep-sea sediments. Science, 1970, 168(3937): 1345-1347. [28] Magurran A E. Ecological Diversity and its Measurement. New Jersey: Princeton University Press, 1988. [29] Luo K F. Draft of China' s physical geography zoning. Acta Geographica Sinica, 1956. [in Chinese] [30] Huang B W. Preliminary draft of China' s comprehensive physical geography zoning. Science Press, 1958. [in Chinese] [31] Xi C F. Outline of China' s physical geography zoning. Science Press, 1984. [in Chinese] [32] Ren M E. China' s physical geography zoning. Science Press, 1985. [in Chinese] [33] Zhao J. Physical geography zoning scheme of China. Higher Education Press, 1995. [in Chinese] [34] Hou X Y. Opinions on agricultural and fishery development directions in various natural regions of China. Acta Geographica Sinica, 1963, 8(9): 8-26. [in Chinese] [35] Ministry of Environmental Protection. National ecological function zoning. 2002. [in Chinese] [36] Water Resources and Hydropower Planning and Design General Institute, Ministry of Water Resources. China' s water function zoning. 2005. [in Chinese] [37] Yin M et al. Preliminary study on eco-hydrological zoning of China' s rivers. Acta Geographica Sinica, 2005, 25(4): 423-428. [in Chinese] [38] Liu C S et al. Research on water resources management zoning in the Haihe River Basin. Environmental Science Research, 2008. [in Chinese] [39] Chassot E, Mélin F, Le Pape O, Gascuel D. Bottom-up control regulates fisheries production at the scale of eco-regions in European seas. Marine Ecology Progress Series, 2007, 343: 45-55.

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