Ecological Indicators 57 (2015) 85–95

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Assessment of river health based on an improved entropy-based fuzzy matter-element model in the Taihu Plain, China

Xiaojun Deng[a,b], Youpeng Xu[a,*], Longfei Han[a], Zhihui Yu[a], Mingnan Yang[a], Guangbo Pan[a]

[a] School of Geographic and Oceanographic Science, Nanjing University, No. 163 Xianlin Avenue, Nanjing, Jiangsu 210023, China
[b] School of Environmental Science and Resources, Guangxi Normal University, No. 15 Yucai Road, Guilin, Guangxi 541004, China

ARTICLE INFO

Article history:
Received 10 June 2014
Received in revised form 16 April 2015
Accepted 16 April 2015

Keywords:
River health
River functions
Improved entropy-based fuzzy matter-element model
Taihu Plain

ABSTRACT

Rivers are valuable to human beings because of their various functions. Unfortunately, ecological integrity of rivers has been seriously threatened by human activities, resulting in poor river functions. It is thus necessary to evaluate and maintain river health. Meanwhile, it is challenging to comprehensively assess river health with a single method alone. It is therefore relevant to combine the advantages of multiple methods in river health assessment. By classifying and characterizing river functions, we first established an indicator system for river health assessment in plain river network regions. We then assessed the health status of the Taihu Plain in terms of an improved entropy-based fuzzy matter-element model. We found that the overall health status of the Taihu Plain is below "good". In particular, the health status of Yang-Cheng-Dian-Mao and Hang-Jia-Hu Region is "moderate"; the Wu-Cheng-Xi-Yu Region displays the poorest natural and social river functions. We also found that flood control is the most important influential factor in river health. Our findings suggest that rivers in the Taihu Plain must be restored to maintain their health, with the Wu-Cheng-Xi-Yu Region that must be restored preferentially, and that the river function of flood control must be improved at the scale of whole watershed. Comparing with other four commonly used comprehensive assessment methods, our improved entropy-based fuzzy matter-element model outperforms in reflecting objective fact and can be applied to river health assessment. Our results are generally consistent with existing studies, confirming that the proposed method for river health assessment is effective and feasible. Therefore, it provides a useful reference for river health assessment in other plain river network regions.

1. Introduction

Rivers are valuable to human beings because of their key roles in irrigation, water supply, transport, purification, regulation, fisheries, and recreation (Doledec and Statzner, 2008; Jia and Chen, 2013). Among ecosystems on the Earth, however, rivers are the most intensively influenced by human activities (Moya et al., 2011). The ecological integrity of rivers has been seriously threatened, resulting in landscape fragmentation, structural modification, environmental pollution, and biodiversity loss over the past few decades (Nilsson et al., 2005; Dudgeon, 2006). Hence, maintenance and recovery of river health is of relevance for river management (Karr, 1991; Hart et al., 1999; Rapport et al., 1999).

To that end, many methods for the characterization and assessment of river health have been developed in the fields of ecology and environmental science (Norris and Thoms, 1999; Karr, 1999; Pinto and Maheshwari, 2011). These methods are typically based on various biological indicators such as algae, fishes, and invertebrates among others, mainly because the structure and function characteristics of river biology can reflect the cumulative effects of many kinds of ecological stress on the aquatic environment (Patrick, 1973; Karr, 1981; Barbour et al., 1999; Smith et al., 1999; Doledec and Statzner, 2008). Commonly used biological methods include the Index of Biotic Integrity (IBI) and the River Invertebrate Prediction and Classification System (RIVPACS). In recent decades, many mathematical approaches have also been extensively developed (Wu and Chau, 2006; Shrestha and Kazama, 2007), such as analytic hierarchy process (Ramanathan, 2001), multivariate statistical analysis (Petersen et al., 2001; Chau and Muttil, 2007), data envelopment analysis (Zhao et al., 2006), artificial neural network (Xie et al., 2006), fuzzy comprehensive assessment (Zhao

---

* Corresponding author. Tel.: +86 2589685069.
E-mail address: xuyp305@163.com (Y. Xu).

http://dx.doi.org/10.1016/j.ecolind.2015.04.020

and Yang, 2009), and matter-element analysis (Liu and Zou, 2012). These mathematical assessments methods are not without limitations. For example, overmuch qualitative analysis may lead to results that are difficult to convince in the application of analytic hierarchy process; multivariate statistical analysis is limited frequently by the requirement of larger samples; data envelopment analysis is sensitive to the abnormal value; artificial neural network lacks to accurately analyze the each performance index; traditional fuzzy comprehensive assessment is weak to distinguish the adjacent characteristic indicators. In addition, it is challenging to comprehensively assess river health with a single method alone. Therefore, improving the disadvantages of each method and combining the advantages of multifarious methods is indispensable in comprehensive assessment (Muttil and Chau, 2006, 2007).

In addition to these biological monitoring methods, comprehensive assessment methods also integrate multiple physical, chemical, and biological indicators for river assessment, such as Riparian, Channel, and Environmental inventory (RCE), River Habitat Quality (RHQ), and Index of Stream Condition (ISC) (Petersen, 1992; Ladson et al., 1999; Raven et al., 1998). Aforementioned river health assessment methods played an important role in river management around the world over the past decades. However, these methods typically overlooked the fact that river system is a complex ecosystem composed of natural ecology and social economy subsystems.

To determine indicators of river health assessment, we must first understand river functions because rivers are considered healthy when their social and natural functions are either balanced or compromised in corresponding periods (Liu and Liu, 2008). Furthermore, human demands-related river functions vary across different river health criteria. Therefore, major river functions must be identified prior to river health assessment. According aforementioned analysis, river health is an obscure and fuzzy concept because it depends on human demands and self-identities, and many elements in river health assessment are nonlinear and indeterminate (Karr, 1999; Norris and Thoms, 1999). Therefore, using fuzzy comprehensive assessment method to assess river health is acceptable because it can investigate objectively as possible various obscure and indeterminate issues (Zhao and Yang, 2009). On the other hand, river functions are interacted in that these functions may impair one another when they run simultaneously. Similarly, matter-element analysis method can be used to assess river functions because of its efficiency in solving incompatible problems (Cai, 1999). However, in order to more objectively assess river health, fuzzy comprehensive assessment and matter-element analysis method must be improved and combined due to their inherent disadvantages, such as the correlation function of matter-element analysis cannot be calculated when any measured values exceed the controlled field (He et al., 2011). In this study, to develop and validate a new and quantitative method of river health assessment in plain river network regions, focusing on the Taihu Plain, we first selected a suite of river function indicators to establish the indicator system for river health assessment based on major characteristics of plain river network regions; we then applied an improved entropy-based fuzzy matter-element model to evaluate the health status of the Taihu Plain.

This paper proceeds as follows: Section 2 briefly introduce the study area and data sources, and details description of the developed indicator system and improved entropy-based fuzzy matter-element model; the results of river health assessment are presented in Section 3; detailed discussions concerning the establishment of indicator system and comparisons of different methods are presented in Section 4; we conclude the study in Section 5.

2. Materials and methods

2.1. Study area

The Taihu Basin is located at the center of the Yangtze River Delta. This region has the highest urbanization level and the fastest economic development in China, and contains numerous large and medium-sized cities, including Shanghai, Suzhou, Wuxi, Changzhou, Zhenjiang, Hangzhou, Jiaxing, and Huzhou. Because of the spread of the various rivers and lakes across the region, it contains a water surface area of 5551 km^2 with water surface ratio of 15%. In total, river length is 120,000 km, and river density is 3.3 km/km^2. The Taihu Basin can be divided into eight water resource zones according to the landform condition and river system distribution: the mountain regions of Zhe-Xi and Hu-Xi, the plain river network regions of Wu-Cheng-Xi-Yu, Yang-Cheng-Dian-Mao, Hang-Jia-Hu, Pu-Dong, and Pu-Xi, and the lake region of Taihu (Fig. 1). Here, we focus on the Taihu Plain (including three plain river network regions of Wu-Cheng-Xi-Yu, Yang-Cheng-Dian-Mao, and Hang-Jia-Hu), which cover a total area of 15,757 km^2 and accounts for 42.7% of the whole basin. The Taihu Plain remains approximately natural before the 1960s. Since 1980s due primarily to the rapid urbanization over this region, however, ecological and environmental problems have worsened, reflected by river shrinkage, water pollution, shortage of water resources, flood disaster and biodiversity loss.

2.2. Data sources

River system data are derived from a Digital Line Graphic at a scale of 1:50,000 in 2014. The water system is derived from the topographic map based on image registration, digitization, mosaic, and overlay. Elements of the water system are represented by polygons or polylines according to their characteristics. Rivers wider than 20 m are represented as polygons, whereas its central lines and other rivers are denoted by polylines. Rivers wider than 40 m are viewed as the primary rivers, rivers with width are between 20 m and 40 m as secondary rivers, rivers with width ranging from 10 m to 20 m as tertiary rivers, and those less than 10 m wide as quaternary rivers. Data about river biology are collected from the recent benthic macroinvertebrate investigation conducted at 120 sampling sites in the Taihu Basin (Huang et al., 2015). The latest data related to hydrology, water environment, and social economy are obtained from the Taihu Basin Authority of the Chinese Ministry of Water Resources and the local government of the Taihu Plain.

2.3. Indicator system

2.3.1. Classification of river functions

River functions can be divided into natural and social functions according to their attributes. Natural functions indicate the contribution of the river to the river ecosystem, which is an important indicator of vibrant river life (Liu and Zhang, 2006). Social functions reflect the degree to which the river supports the human socioeconomic system and are the original motivation for humans to maintain river health. Natural functions can be further classified into secondary functions, such as landform generation, material transportation, climate regulation, water purification, habitat provision, and biodiversity conservation (Costanza et al., 1997; Yang et al., 2013). Likewise, social functions can also be further classified into secondary functions, including water supply, flood control, inland navigation, provision of aquatic products, tourism and entertainment, and cultural education. Here we ignore the secondary function of hydroelectric power because of the flat topography and the small fall in plain river network regions.