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Identifying and validating freshwater ecoregions in Jinan City, China

Songyan Yu [a], Zongxue Xu [a,b,*], Xingcai Liu [c], Tongwen Dou [d], Chen Xu [e]

[a] College of Water Sciences, Beijing Normal University, Beijing 100875, China
[b] Joint Center for Global Changes Studies, Beijing 100875, China
[c] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[d] Jinan Survey Bureau of Hydrology and Water Resources, Jinan 250013, China
[e] School of Civil Engineering and Environmental Sciences, University of Oklahoma, Norman, OK 73019, USA

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SUMMARY

Freshwater ecoregion is currently widely used by biologists, conservators and resource managers. Most of ecoregion delineations are developed at the basin scale and are not fully adapted in a practical manner because operational water resources management is primarily conducted by political administrative departments. In this study, an ecoregion delineation framework was proposed to classify three-level ecoregions in Jinan City with geographic information systems and cluster analysis. The first level ecoregion was composed of three watersheds (a part of the Yellow River, Xiaoqing River and Tuhaimajia River) plus the urban area, which was primarily determined on the basis of the city administrative divisions and river watersheds. The classification of the second level ecoregion is primarily based on the spatial heterogeneity of land use. The third level ecoregion was delineated for each second level ecoregion by using the cluster analysis on water quality. At the same time, administrative boundaries were used to rectify the boundaries of each ecoregion in this study to facilitate the administration of each ecoregion. Furthermore, ecological health assessment (IBI) based on fish communities were employed to validate the freshwater ecoregion. The results demonstrated that 73.3% of ecoregions were in line with the distribution of fish IBI, indicating that the freshwater ecoregions are acceptable for future water resources management.

1. Introduction

Ecoregions are large geographical regions that include multiple ecosystems, often with similar functions (Bailey, 1983), and have been widely used in resources management since they were issued (Omernik, 1987). Ecoregion delineation initially focused on terrestrial ecosystems, and Omernik (1987) expanded it to aquatic ecosystems. Aquatic ecosystem delineations are based on the assumption that freshwater ecosystem processes are systematically influenced by environmental processes operating at the landscape scale (Maxwell et al., 1995; Soranno, 2010), Therefore, aquatic ecoregions is the unit that includes the homogenous freshwater ecosystems and related surrounding lands. The development of freshwater ecoregions has many potential uses for biologists, conservators and resource managers in conservation and management of water resources (Kennard et al., 2010), aquatic species (Abell et al., 2008), aquatic ecosystems and habitats (Munne and Prat, 2004), and also in water quality monitoring (Ravichandran et al., 1996) and river health assessment (Binckley et al., 2010).

Many aquatic ecoregion delineation systems have been developed in the world (Kennard et al., 2010), including North America (Omernik, 1987) and Australia (Davies et al., 2000). However, two distinct problems still exist for further applications in modern water resources management. First, many previous attempts to delineate ecoregions corresponded approximately to a drainage basin. In fact, the fundamental aquatic ecosystem management unit at least in China is the Water Department within a city, which means it is also necessary to perform aquatic ecoregion delineations within the city scope; on the other hand, previous ecoregion delineations may lead to management confusion. For aquatic ecosystem conservation, the reason for degradation may be from the surrounding environmental factors or the upper basin in another administrative unit. To identify the relationship between the power and the responsibility, aquatic ecoregion delineation needs to be performed, not only in a drainage basin but also within a city.

* Corresponding author at: College of Water Sciences, Beijing Normal University, Beijing 100875, China.
E-mail address: zongxuexu@vip.sina.com (Z. Xu).

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The second problem, the subjective and intuitive ecoregions resulting from different selected indicators instead of repeatable selecting methods, has prevented ecoregion delineation from being derived from a framework of regulated indicators. Because the spatial pattern of any particular variable might correspond to certain eco-regional characteristics when it was applied to identify ecoregions, different ecoregions will vary in their degree of homogeneity, and the change at the boundaries between different ecoregions could fluctuate in a manner specific to the locality (Jenerette et al., 2002). To guarantee the relative stability of borders and even the formality of aquatic ecoregions, a repeatable indicator framework should be developed (Kong et al., 2013).

Terrestrial processes were recognized to have a significant influence on the state of water body (Peterjohn and Correll, 1984; Summer et al., 1990). Particular variables such as physiography, soil characteristics, and land uses were found to be important to affect water quality and even aquatic ecosystem health (Geleta et al., 1994; Jenerette et al., 2002; Shirmohammadi et al., 1997). Aquatic ecoregions could be identified according to the spatial patterns of the driving factors (Bailey et al., 1985; Bailey, 2005; Graef et al., 2005; Omernik and Griffith, 1991). Most studies focused on aquatic ecoregions within a whole watershed or country, rather than in a city. Considering the water resources management practice in China, Jinan City was selected as a case study to delineate three-level aquatic ecoregions which may moderate the conflict of interest between different authorities in watershed management.

Much of this work – including freshwater ecoregion delineation within a city and a repeatable indicator framework – has not been adequately conducted up to date. Thus, this paper aims to use statistical methods to develop an acceptable indicator framework based on the concept of aquatic ecoregions. Additionally, factors considered during ecoregion delineation in a watershed are quite different from those in a city. Administrative boundaries and rivers often overlap, effectively dividing watersheds (Jenerette et al., 2002), while traditional ecoregions used to include a complete basin for ecological reasons (Bailey, 2005). Additionally, for modern water resources management, freshwater ecoregions in a city are required for local river management. Therefore, we try to identify aquatic ecoregion boundaries according to local political boundaries other than the boundaries of watersheds.

The objective of this study is to use rigorous analysis procedures, especially modern statistical methods, to develop a repeatable indicator framework applied for identifying freshwater ecoregions in Jinan City. Then, the ecoregion results will be assessed for accuracy in describing the homogeneity within ecoregions and maximizing the heterogeneity among ecoregions. Finally, appropriate freshwater ecoregions will be illustrated for water resources management in Jinan City.

2. Materials and methods

2.1. Study area description

Jinan City is located in the warm-temperature and semi-humid continental monsoon district. This city's land consists of three major watersheds, which are the Yellow River watershed, the Xiaoqing River watershed and the Tuhaimajia River watershed, with total areas of 2778 km^2, 2792 km^2 and 2400 km^2, respectively. They have few hydrological connections with each other, and their headwaters come from different districts, so that we could expect there to be a few differences among the three aquatic ecosystems. The part of the Yellow River in Jinan City belongs to its downstream section, which merges into the Bohai Sea in the city of Dongying next to Jinan. The riverbed is quite broad (up to 200 m wide), and interestingly there are only a few branches merging into the Yellow River in Jinan because abundant sediment concentration causes the bottom of the riverbed to be higher than the surrounding ground. The Xiaoqing River, which crosses through the urban area, is important for the urban district, domestic life and industrial development in Jinan. The Tuhaimajia River, which is located in the alluvial plains of the north of Jinan, is regarded as the main water resource for irrigation, as it flows through densely populated areas with a large amount of farmland.

2.2. Freshwater ecoregions delineation

The identification of the freshwater ecoregions included four steps as follows.

Step 1: Environmental data collection and processing

To monitor the water quality of river ecosystems within Jinan City, we conducted three extensive field surveys (Fig. 1): May 1st-20th, August 2nd-21st and November 1st-20th, 2014. Nine representative parameters were selected for the freshwater ecoregion delineation, including electrical conductivity (Ec), dissolved oxygen (DO), total nitrogen (TN), ammonia nitrogen (NH_3-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), permanganate index (COD_{Mn}), biochemical oxygen demand (BOD), and total phosphate (TP). The values of Ec and DO were directly measured in-situ using a YSI-85 multiparameter water quality monitoring instrument. The others were collected at the monitoring sites and tested in the laboratory within 24 h.

Fishes were also collected in the field surveys. Sites were fished for a maximum of 30 min and for no more than 100 m, which represented different types of habitats (i.e., riffle, run, and pool). In wadeable streams, fish were collected by a two person fish collection team, i.e., one individual used the backpack electrofisher with two handheld electrodes and one was responsible for netting fish with dip nets (Wu et al., 2014). In unwadeable streams, seines (30 and 40 mm mesh size) were used for fishing by boat, and electrofishing equipment was used to ensure a good representation of the fish at the site. All fish individuals (with total length longer than 20 mm) collected were identified to species. The ecological health assessment was conducted using the Index of Biological Integrity based on fish community (IBF, see Wu et al., 2014 for details).

A digital elevation model (DEM) at a 30×30 m resolution was used to extract sub-basins by ArcGIS software. The delineated sub-basins were employed for identifying ecoregions using cluster analysis.

Landuse information was obtained from the Resource and Environmental Sciences Data Center of CAS (Chinese Academy of Science). Data were provided in a 30×30 m resolution, and included information from six land use categories (Fig. 2): (1) agricultural land, including paddy field and dry land; (2) forestland, including shrub land and sparse woodlot; (3) grassland, including different coverage types; (4) construction land, including industrial and residential area; (5) water bodies, including rivers, wetlands and sandy beaches; and (6) barren land, including gravel, bare ground and bare rocks. Actually, only forestland and barren land were selected in this study for the following analysis due to their appropriate spatial heterogeneity, while the spatial homogeneity of other land use types were too high or too low to be applied for ecoregion delineation (Fig. 2).

Step 2: Selection of freshwater ecoregion indicators

Selection of indicators is vital in freshwater ecoregion delineations, which should be in accordance with the classification of