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Land use changes and socio-economic development strongly deteriorate river ecosystem health in one of the largest basins in China

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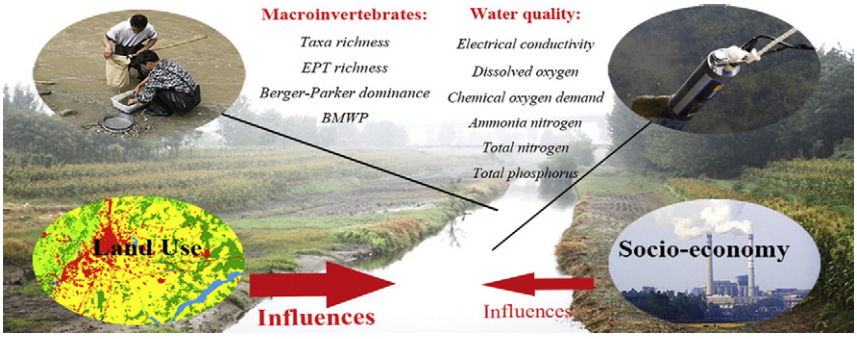
HIGHLIGHTS

- Ecosystem health was assessed in a temperate-monsoon and high human-disturbed basin.
- 148 river sites were sampled during the pre- and post-rainy seasons.
- Ecosystem health was quantified by water quality and macroinvertebrates.
- Land use intensity contributes more to river ecosystem health than socio-economy.

GRAPHICAL ABSTRACT



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ABSTRACT

It is important to assess river ecosystem health in large-scale basins when considering the complex influence of anthropogenic activities on these ecosystems. This study investigated the river ecosystem health in the Haihe River Basin (HRB) by sampling 148 river sites during the pre- and post-rainy seasons in 2013. A model was established to assess the river ecosystem health based on water physicochemical, nutrient, and macroinvertebrate indices, and the health level was divided into "very poor," "poor," "fair," "good," and "excellent" according to the health score calculated from the assessment model. The assessment results demonstrated that the river ecosystem health of the HRB was "poor" overall, and no catchments were labeled "excellent." The percentages of catchments deemed to have "very poor," "poor," "fair," or "good" river ecosystem health were 12.88%, 40.91%, 40.15%, and 6.06%, respectively. From the pre- to the post-rainy season, the macroinvertebrate health levels improved from "poor" to "fair." The results of a redundancy analysis (RDA), path analysis of the structural equation model (SEM), and X-Y plots indicated that the land use types of forest land and grassland had positive relationships with river ecosystem health, whereas arable land, urban land, gross domestic product (GDP) per capita, and population density had negative relationships with river ecosystem health. The variance partitioning (VP) results showed that anthropogenic activities (including land use and socio-economy) together explained 30.9% of the variations in river ecosystem health in the pre-rainy season, and this value increased to 35.9% in the post-rainy season. Land use intensity was the first driver of river ecosystem health, and socio-economic activities was the second driver. Land use variables explained 20.5% and 25.7% of the variations in river ecosystem health in the pre- and post-rainy season samples, respectively, and socio-economic variables explained 12.3% and 17.2% of the variations, respectively. The SEM results revealed that urban land had

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the strongest impact on water quality health and that forest land had the strongest impact on macroinvertebrate health. This study has implications for the selection of appropriate indicators to assess river ecosystem health and generated data to examine the effects of anthropogenic activities on river ecosystem health in a fast-growing region.

1. Introduction

The water and associated ecosystem services of rivers play key roles in human health and social and economic development. The concept of river ecosystem health was first proposed in the US Clean Water Act in 1972, which referred to "the chemical, physical, and biological integrity of the nation's waters" (Act, 1972). Among other crucial ecosystem services, river ecosystems provide vital water resources for humans (Meng et al., 2009); therefore, the health of river ecosystems is of great importance to human life. Due to extensive human interventions, such as alterations of land cover in the river catchments from the clearing of forests for agricultural activities and residential areas (Jayawardana et al., 2017), river ecosystems have shifted from healthy and sustainable to unsustainable (Nandi et al., 2016). The deleterious effects of pollution, channelization and river regulation usually reduce the biological diversity of aquatic ecosystems (Maddock, 1999).

Biological indices are a widely used method to assess river ecosystem health (Meng et al., 2009). For example, aquatic organisms such as macroinvertebrates (Smith et al., 1999), fish (Karr, 1981), algae (Poikane et al., 2016), and plankton (Reynolds, 2003) are commonly used as indicators to evaluate the health of river ecosystems. Macroinvertebrates are functionally important players in river ecosystems that decompose and recycle autochthonous and allochthonous organic matter (Covich et al., 1999), link aquatic and terrestrial food webs (Scharnweber et al., 2014), and form an important source of nutrition for fish communities (Vadeboncoeur et al., 2002). Macroinvertebrates are among the most widely applied biological indicators for river ecosystem health assessments (Birk et al., 2012) because of the advantages they provide, such as their ubiquitous nature, long life cycles, ease of sampling and identification, and sedentary behavior (Shan et al., 2016).

Anthropogenic activities can alter water flow and degrade river habitats and biotic conditions (Aazami et al., 2015), which have great impacts on river ecosystem health. Land use types are closely related to the characteristics of anthropogenic activities, which in turn determine the anthropogenic substances carried into hydrological systems through run-off processes (Lee et al., 2009). Land use intensity is also an important factor that controls the structure of aquatic communities and can be used as a proxy of the composition and structure of macroinvertebrate assemblages (Törnblom et al., 2011). Landscape characteristics are widely accepted as factors that strongly influence stream water quality (Ai et al., 2015; Kändler et al., 2017; Shi et al., 2017). Economic development level also has a strong effect on nutrient pollution (Duan et al., 2009). Population density and industrial development have been considered to be important drivers of water quality deterioration in inland waters (Duan et al., 2009; Zhou et al., 2017). Because administrative units do not encompass the entire watershed in most cases, the number of studies linking socio-economic metrics to water quality are limited (Zhou et al., 2017).

We selected the Haihe River Basin (HRB) as an example to assess the river ecosystem health and its potential drivers. The HRB is one of seven major river basins in China and had a population of approximately 140 million in 2010, accounting for approximately 10% of the national population. Rapid economic development and urbanization have caused significant water pollution in the region (Shan et al., 2016). Water shortages and structural and functional degradation of the rivers are also serious (Yang et al., 2013). In recent years, the health of the river ecosystem in the basin has drawn considerable research attention (Yang et al., 2013; Shan et al., 2016). However, to the best of our knowledge, no studies have focused on the river ecosystem health of the entire HRB. Thus, it is of great importance to assess the river ecosystem health in this basin.

In this study, we assessed the river ecosystem health based on water quality and macroinvertebrate indicators. The objectives of this paper were to (1) identify the spatial and temporal variability of the river ecosystem health in the HRB, (2) explore the relationships between land use and socio-economic variables and river ecosystem health, and (3) quantify the contributions of land use and socio-economic factors to river ecosystem health at the catchment scale.

2. Materials and methodology

2.1. Study area

The HRB is located between 112–120°E and 35–43°N, covering an area of 31.8×10^4 km^2, which accounts for 3.3% of the total land area of China. This basin covers all of Beijing and Tianjin, most parts of Hebei, and parts of Shandong, Henan, Shanxi, and Inner Mongolia. The HRB is bounded by the Mongolian Plateau and Yanshan Mountains to the north, the Yellow River to the South, the Taihang Mountains to the west, and Bohai Bay to the east. The annual average temperature of the HRB is 9.6 °C, and the annual precipitation is approximately 530.3 mm (1951–2007) (Bao et al., 2012). This basin is in a temperate-monsoon climatic region, and 75–85% of the precipitation occurs during the rainy months (June to August). The HRB is located in economically developed areas of China, and the gross domestic product (GDP) in 2006 (the most recent data available) was approximately 12.1% of the total GDP of China. The economic development level differs between the mountainous and plain areas of the basin. Mountains comprise 18.9×10^4 km^2, accounting for nearly 60% of the area, and plains cover 12.9×10^4 km^2, accounting for approximately 40%. However, the plain areas account for approximately 73% of the total population, 65% of the plantations, and 83% of the total GDP.

A total of 132 catchments were selected in this study; the areas ranged from 32.06 to 1017.68 km^2 with a mean of 294.46 km^2 (Fig. 1). In total, 148 sampling sites were distributed across these 132 catchments. Among these, 37 sampling sites were distributed at the outlets of their respective catchments. Previous studies have indicated that river ecosystem health varies annually and seasonally (Parr and Mason, 2003; Hawkins et al., 2010). As the precipitation varies with the season in this monsoon region, each site was sampled twice, once in the pre-rainy season (May 2013) and once in the post-rainy season (September 2013), to explore the seasonal variations in the river ecosystem health.

2.2. Anthropogenic activities

The anthropogenic activities of the catchments included land use types and socio-economic variables (Table 1). Land use interpretation and mapping in the catchments were conducted based on a Landsat Thematic Mapper image (30-m resolution, 2010). The 18 land use types that identified were classified into six groups with a descending order of area as follows: arable land, forest land, grassland, urban land,