Science of the Total Environment 496 (2014) 594–606

Contents lists available at ScienceDirect

Science of the Total Environment

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

Water quality variation in the highly disturbed Huai River Basin, China from 1994 to 2005 by multi-statistical analyses

Xiaoyan Zhai [a], Jun Xia [a,*], Yongyong Zhang [b]

[a] State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China
[b] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Science and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

HIGHLIGHTS

- Spatio-temporal trend of water quality and effects of anthropogenic activities were detected by multi-statistical methods.
- Spatial autocorrelation existed in CODMn and NH3-N, not DO, and the structure varied.
- High pollution cluster center aggregated at Fuqiao, Huangqiao and Jialuhe station in the 2000s.
- Water quality was mainly influenced by point source emission, flow regulation, water temperature and land use variation.

ARTICLE INFO

Article history:
Received 24 December 2013
Received in revised form 23 June 2014
Accepted 23 June 2014
Available online xxxx

Editor: Eddy Y. Zeng

Keywords:
Seasonal Mann–Kendall
Moran's *I*
Regression analysis
Water quality trends
Huai River Basin

ABSTRACT

Water quality deterioration is a prominent issue threatening water security throughout the world. Huai River Basin, as the sixth largest basin in China, is facing the most severe water pollution and high disturbance. Statistical detection of water quality trends and identification of human interferences are significant for sustainable water quality management. Three key water quality elements (ammonium nitrogen: NH_3-N, permanganate index: COD_{Mn} and dissolved oxygen: DO) at 18 monitoring stations were selected to analyze their spatio-temporal variations in the highly disturbed Huai River Basin using seasonal Mann–Kendall test and Moran's *I* method. Relationship between surrounding water environment and anthropogenic activities (point source emission, land use) was investigated by regression analysis. The results indicated that water environment was significantly improved on the whole from 1994 to 2005. COD_{Mn} and NH_3-N concentrations decreased at half of the stations, and DO concentration increased significantly at 39% (7/18) stations. The high pollution cluster centers for both NH_3-N and COD_{Mn} were in the middle stream of Shaying River and Guo River in the 2000s. Water quality of Huai River Basin was mainly influenced by point source pollution emission, flows regulated by dams, water temperature and land use variations and so on. This study was expected to provide insights into water quality evolution and foundations for water quality management in Huai River Basin, and scientific references for the implementation of water pollution prevention in China.

1. Introduction

Water environment deterioration is a prominent issue in river basin management throughout the world, which has become a serious threat to water security. Surface water was gradually polluted due to natural and anthropogenic activities (Sundaray et al., 2006), such as water–rock interactions (Li et al., 2013), industrial and municipal wastewater emissions (Vega et al., 1998), nutrient losses (Zhu and Wen, 1994), excessive dam and sluice constructions (Zhang et al., 2010). In 2012, water quality inferior to Grade IV (GB 3838-2002) occupied approximately 31% of the national monitoring stations for the seven largest rivers in China (China Environment Bulletin, 2012), in which over 50% of the stations in Huai River were severely polluted. The assessment of long-term water quality trend can excavate potential water quality problems, and identify probable causes such as natural variations and human interventions, which will provide information supports and references for sustainable water resources management.

Based on observed time-series data, statistical detection on the spatio-temporal variation of water quality and influencing factors, is a core task of current water environment research. Trend detection techniques have been applied in numerous water quality issues, in which non-parametric tests with few assumptions about data structures became increasingly popular. Yu et al. (1993) detected downward trends of 13 variables for 15 stations in the Arkansas, Verdigris, Neosho and Walnut basins using four non-parametric methods, which might be related to discharge increase and pollution source decrease. Robson and Neal (1996) applied the seasonal Kendall test to examine the

* Corresponding author. Tel.: +86 02768773772.
E-mail address: xiaj@igsnrr.ac.cn (J. Xia).

http://dx.doi.org/10.1016/j.scitotenv.2014.06.101
0048-9697/

trend of upland stream and water quality in Plynlimon, mid-Wales, and suggested that dissolved organic carbon increased significantly. Antonopoulos et al. (2001) used the non-parametric Spearman's criterion to analyze the temporal trends of 15 variables between 1980 and 1997 for the Strymon River in Greece, and indicated that political status transition influenced water quality status. Libiseller and Grimvall (2002) performed partial Mann–Kendall test on water discharge and permanganate consumption for the Dalälven River in Sweden from 1970 to 1995, and pointed out that the technique could detect the complex relationship between water discharge and water quality, and handle numerous data for temporal trends. Chang (2008) examined the spatial trends of eight parameters for 118 sites by the seasonal Mann–Kendall test in the Han River Basin of South Korea, and explained the relation between water quality and land cover.

Furthermore, spatial association identification measures have been widely used to predict and determine the distributions and structures of water ecological or environmental variables (Dormann et al., 2007; Zhou, 2012). Brody et al. (2005) indicated that water quality variables were spatially correlated in the Salado and Leon creeks, which could provide directions for watershed planning and policy. Luo and Luo (2011) performed spatial statistical analysis by global and local Moran's *I* in the Tai Lake, which showed that water quality presented significant spatial autocorrelation and accumulation mode in March, 2000. Besides, regression analysis is a simple but robust statistical technique to investigate the underlying relationships among water quality variations, basin attributes, and anthropogenic interferences (Mueller et al., 1997; Simeonov et al., 2003; Steele and Jennings, 2010). Smith et al. (1997) developed spatially referenced regressions, and showed that surface characteristics significantly influenced land–water delivery of total nitrogen and total phosphorous at 414 stations in the National Stream Quality Accounting Network. Sliva and Williams (2001) determined a correlation between water quality and landscape characteristics using multivariate regression within three local southern Ontario watersheds in Canada, and indicated that urban land use has the greatest positive influences on water quality.

As the sixth largest river in China, Huai River is notorious for its disastrous water issues which have threatened national security and socio-economic development, especially the frequent water pollution incidents. Spatio-temporal statistical detection is an effective approach to evaluate water quality variation, and regression analysis is a simple but efficient tool to identify the correlations between water quality variation and anthropogenic activities. Both of the statistical methods are of great significances for pollution control and should be given priority in implementing integrated river basin management. The paper was organized as follows. Firstly, several statistical methods including the seasonal Mann–Kendall test, Moran's *I* and multiple linear regression model were introduced, as well as the study area and data; secondly, the results of temporal variation of COD_{Mn}, NH_3-N and DO were presented and their spatial structures were evaluated. Thirdly, influences of anthropogenic activities on water environment were explored from the aspect of point source emission and land use. This research was expected to provide insights into water quality evolution, and provide technical foundations for water quality management in the Huai River Basin (HRB) to ensure water security and sustainable development, and scientific references for the implementation of water pollution prevention in the future.

2. Material and methods

2.1. Study area

Huai River Basin (117°36′E–118°57′E, 29°21′E–30°13′E; Fig. 1) is the most crowded in terms of both population and water projects, and heavily polluted basin in China. The population density is 614 persons/km^2 and every 50 km^2 is controlled by one dam. The total storage capacity of dams and sluices accounts for 51% of annual runoff (Zhang et al., 2012a). Point source pollutant is a major pollution source, while the contribution of agricultural non-point source pollution has been growing. The chemical oxygen demand (COD) load discharged into rivers was 0.98 million tons in 2005, which was twice of the targeted

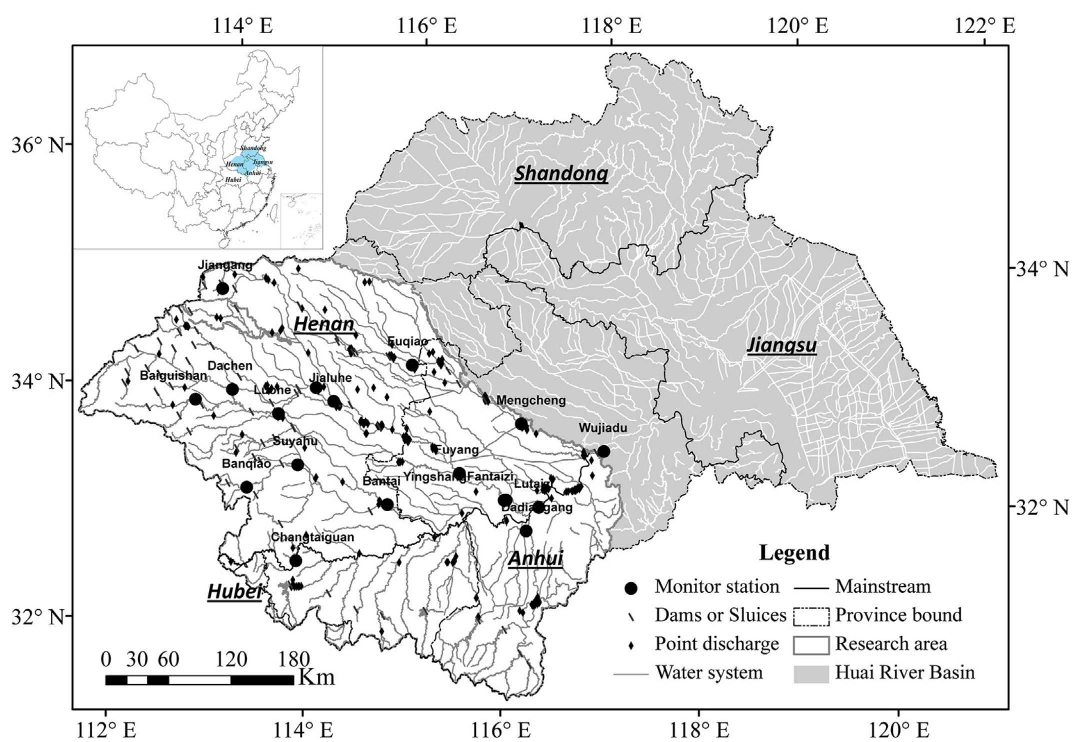

Fig. 1. Location of study area, water quality monitoring stations, dams or sluices and sewage outlets.