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Multivariate statistical evaluation of dissolved trace elements and a water quality assessment in the middle reaches of Huaihe River, Anhui, China

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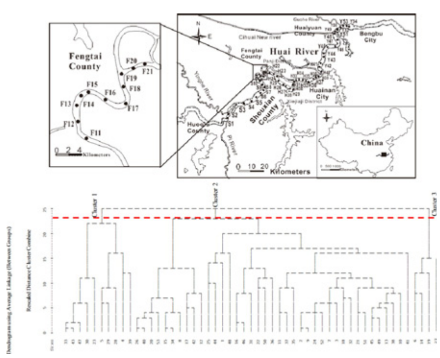
HIGHLIGHTS

- Zn, Cd and Pb were identified as the dominant pollutants in the water body.
- Approximately 96% of the waters in the Huaihe River were unsuitable for drinking.
- Co, Cd and Pb in the river could pose potential non-carcinogenic effects on human health.

GRAPHICAL ABSTRACT



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ABSTRACT

A total of 211 water samples were collected from 53 key sampling points from 5–10th July 2013 at four different depths (0 m, 2 m, 4 m, 8 m) and at different sites in the Huaihe River, Anhui, China. These points monitored for 18 parameters (water temperature, pH, TN, TP, TOC, Cu, Pb, Zn, Ni, Co, Cr, Cd, Mn, B, Fe, Al, Mg, and Ba). The spatial variability, contamination sources and health risk of trace elements as well as the river water quality were investigated. Our results were compared with national (CSEPA) and international (WHO, USEPA) drinking water guidelines, revealing that Zn, Cd and Pb were the dominant pollutants in the water body. Application of different multivariate statistical approaches, including correlation matrix and factor/principal component analysis (FA/PCA), to assess the origins of the elements in the Huaihe River, identified three source types that accounted for 79.31% of the total variance. Anthropogenic activities were considered to contribute much of the Zn, Cd, Pb, Ni, Co, and Mn via industrial waste, coal combustion, and vehicle exhaust; Ba, B, Cr and Cu were controlled by mixed anthropogenic and natural sources, and Mg, Fe and Al had natural origins from weathered rocks and crustal materials. Cluster analysis (CA) was used to classify the 53 sample points into three groups of water pollution, high pollution, moderate pollution, and low pollution, reflecting influences from tributaries, power plants and vehicle exhaust, and agricultural activities, respectively. The results of the water quality index (WQI) indicate that water in the Huaihe River is heavily polluted by trace elements, so approximately 96% of the water in the Huaihe River is unsuitable for drinking. A health risk assessment using the hazard quotient and index (HQ/HI) recommended by the USEPA suggests that Co, Cd and Pb in the river could cause non-carcinogenic harm to human health.

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1. Introduction

Intensification of industrial and urban development as well as agricultural activities has severely degraded surface water quality worldwide; in particular, trace elements have increased in the aquatic system (Li et al., 2011; Islam et al., 2015). Natural processes, such as volcanism and bedrock weathering, and anthropogenic activities, such as metallurgy, mining, coal combustion, and metal smelting, largely release trace elements into the fluvial aquatic system (Meng et al., 2016; Krishna et al., 2009; Kumar et al., 2017; Wang et al., 2015a). Enrichment of toxic metals in water systems results in the water being unsuitable for drinking as well as for different industrial and agricultural purposes (Nazeer et al., 2014; Zhang et al., 2009). In addition, dissolved trace elements in the water system can be absorbed by organisms through the food chain, causing severe health risks (Pekey et al., 2004). It has been reported that considerable metal intake can lead to life-threatening cancers and mental disease (Li et al., 2011). Potential threats to human health and aquatic ecosystems make trace element pollution of water systems an ongoing environmental problem (Farahat and Linderholm, 2015; Giri and Singh, 2013). Therefore, it is important to understand the trace element concentration, distribution, sources, and health risk levels, as well as water quality, to protect water resources and control water pollution (Islam et al., 2014; Xiao et al., 2014).

Multivariate statistical approaches, such as correlation analysis, factor/principal component analysis (FA/PCA), and cluster analysis (CA), are powerful tools for environmental studies. They offer a better understanding of water quality and possible sources that affect the studied system by identifying hidden relations between variables and reducing huge and complex chemical datasets to a small number of factors without much information loss (Ali et al., 2016; Banerjee et al., 2016; Bilgin and Konanç, 2016; Khound and Bhattacharyya, 2016; Kuang et al., 2016; Singh et al., 2004; Zhang et al., 2015).

In China, research on trace element contamination in surface river water mainly concerns trace metals in the Changjiang River and Huanghe River (Li and Zhang, 2010a, 2010b). Little information on trace element contamination, source identification, health risk evaluation, or water quality assessments in the Huaihe River is available, although such information is critical for water management. The Huaihe River, the fifth longest river in China, not only serves as the main source of drinking water for riverside cities but also provides water for hydroelectric energy generation and agricultural and industrial development. Abundant coal reserves in two major coalfields located in the middle reaches (Anhui Province) of the Huaihe River have driven various industrial activities. In recent decades, extensive mining activities, domestic sewage, runoff from agricultural land, and sustainable industrial growth have severely deteriorated the water quality in Huaihe River. Such activities have contributed to the increasing metal pollution of the Huaihe River (Wang et al., 2016).

Our study was conducted as a preliminary survey on water contamination by 13 selected trace elements in the middle reaches (Anhui Province) of the Huaihe River with the objectives of (1) analyzing the spatial distribution patterns of dissolved trace elements in river water; (2) exploring trace element sources using multivariate statistics; and (3) evaluating the river water quality and hazard impacts on human health posed by trace elements by using the Water Quality Index (WQI) and Hazard Quotient/Index (HQ/HI), respectively. The results can be applied to increase water management efficiency to help protect water resources as well as prevent hazardous trace element contamination to the public through the water sources.

2. Materials and methods

2.1. Study area

The Huaihe River, located between the Yellow River and Yangtze River in eastern China, has a basin area of 270,000 km^2. It originates from Tongbai Mountain in Henan Province and flows eastward for approximately 1000 km through five provinces (Henan, Hubei, Anhui, Jiangsu and Shandong) before joining the Yangtze River in Sanjiangying (Jiangsu Province). Two-thirds of this basin area is occupied by flatland, and the remainder is mountainous area or hills; the northwest part of the basin is higher than the southeast part. The relatively small average river slope (approximately 0.02‰) and slow water current result in the Huaihe River having a weak self-purification ability. The river is situated in a climate transition zone in China. The north part of the river belongs to the warm, temperate, and semi-humid region, and the south part of the river is subject to a subtropical, humid climate. The annual average temperature and rainfall range from 11 to 16 °C and 600 to 1400 mm, respectively.

Anhui Province, which is located in the middle reaches of Huaihe River, covers a total area of approximately 66,900 km^2 and flows for 430 km (43% of the total extent). In the present study, a total length spanning 131.5 km of the river (32°34′9″–32°57′32″N; 116°39′47″–117°15′40″E) in Anhui province was studied, from the town of Zhengyangguan to the Bengbu sluice, across four major riverbank districts (Shou County, Huoqiu County, Fengtai County and Huainan City), which directly discharge industrial effluents and domestic wastewater into the river. Huainan coalfield, ranked as the fifth largest coalfield in China, is located in Huainan City, where mineral resources, such as coal, are abundant (Chen et al., 2011; Sun et al., 2014). Several large-scale power stations (e.g., Fengtai, Pingwei, Tianjia'an and Luohe power plants) have sprung up eastward along the river bank since the 1940s (Tang et al., 2013). Therefore, the Huaihe River (Anhui Province) likely receives a pollution load from the power plant effluent and deposition of coal combustion flue gases released by these power stations.

2.2. Sample collection and preparation

Samples from 53 sites, labeled S_{1-10}, F_{11-21}, H_{22-41} and Y_{42-53}, that reasonably reflect the water quality throughout the Huaihe River in Anhui Province were collected from Shou County, Fengtai County, Huainan City and Huaiyuan County, respectively, during 5–10th July 2013 (summer, wet season, Fig. 1) for assessment of the trace element characteristics. At each site, vertical water samples from four different depths of < 8 m (approximately 0 m, 2 m, 4 m, 8 m) in the river were collected by using a water sampler and stored in pre-cleaned 1-L high-density polyethylene (HDPE) plastic bottles. Three water samples were collected from site 35, excluding H_{35d} because of the lower river depth. Ultimately, a total of 211 water samples (labeled $S_{1a\ (b,\ c,\ d)}$ - $Y_{53a\ (b,\ c,\ d)}$) from the 53 sites were pretreated for laboratory analysis. To avoid contamination of dissolved trace elements, the instruments were rinsed three times with river water before sample collection (Chen et al., 2007).

For determination of dissolved trace elements, water samples were filtered through a 0.45-μm filter membrane. The initial 50 mL of filtrate was discarded, and the following 50 mL was stored in pre-cleaned polyethylene bottles. The filtrate was acidified to pH ≤ 2 using ultra-pure concentrated nitric acid. The remaining unfiltered water samples were also acidified to pH ≤ 2 by using sulfuric acid to determine the total phosphorous (TP), total nitrogen (TN) and total organic carbon (TOC). All samples were stored at approximately 4 °C before analysis. The water temperature (T, °C) and pH were determined in situ by using portable electronic instruments (XB89-M267, Midwest, China).

2.3. Physicochemical determination

2.3.1. Total phosphorous and total nitrogen

The total phosphorous (TP) and total nitrogen (TN) in the water samples were determined by strictly following the Chinese standard methods provided by China EPA (1990a, 1990b). TP was analyzed by the ammonium molybdenum ascorbic acid method, with water samples digested using mixed concentrated nitric and perchloric acids