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A water quality management strategy for regionally protected water through health risk assessment and spatial distribution of heavy metal pollution in 3 marine reserves

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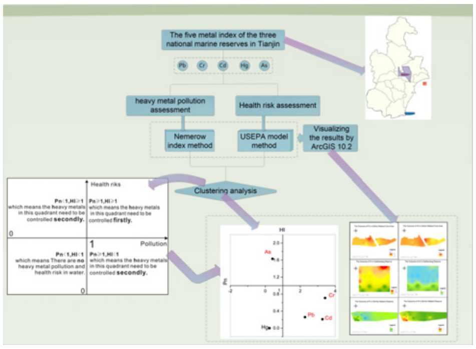
HIGHLIGHTS

- A watershed management method is explored to assess the heavy metal pollution and human health risk in water.
- Nemerow and USAEPA models were used to evaluate the pollution and health risk of three natural reserves in Tianjin.
- Cluster analysis and GIS can determine the sequence and location of pollution treatment.
- Reserves are subject to varying degrees of pollution or health risks.
- A new perspective of water quality oriented watershed management is advised at the regional scale.

GRAPHICAL ABSTRACT



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ABSTRACT

Severe water pollution and resource scarcity is a major problem in China, where it is necessary to establish water quality-oriented monitoring and intelligent watershed management. In this study, an effective watershed management method is explored, in which water quality is first assessed using the heavy metal pollution index and the human health risk index, and then by classifying the pollution and management grade based on cluster analysis and GIS visualization. Three marine reserves in Tianjin were selected and analyzed, namely the Tianjin Ancient Coastal Wetland National Nature Reserve (Qilihai Natural Reserve), the Tianjin DaShentang Oyster Reef National Marine Special Reserve (DaShentang Reserve), and the Tianjin Coastal Wetland National Marine Special Reserve (BinHai Wetland Reserve) which is under construction. The water quality and potential human health risks of 5 heavy metals (Pb, As, Cd, Hg, Cr) in the three reserves were assessed using the Nemerow index and USEPA methods. Moreover, ArcGIS10.2 software was used to visualize the heavy metal index and display their spatial distribution. Cluster analysis enabled classification of the heavy metals into 4 categories, which allowed for identification of the heavy metals whose pollution index and health risks were highest, and, thus, whose control in the reserve is a priority. Results indicate that heavy metal pollution exists in the Qilihai Natural Reserve and in the north and east of the DaShentang Reserve; furthermore, human health risks exist in the Qilihai Natural Reserve and in the BinHai Wetland Reserve. In each reserve, the main factor influencing the pollution and health risk were high concentrations of As and Pb that exceed the corresponding standards. Measures must be adopted to control and remediate the pollutants. Furthermore, to protect the marine reserves, management policies must be implemented to improve water quality, which is an urgent task for both local and national governments.

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1. Introduction

Environmental pollution by heavy metals has attracted much attention worldwide because they rapidly accumulate in the natural environment (Kavcar et al., 2009; Mahato et al., 2014; Tiwari et al., 2015; Nguyen et al., 2016). Heavy metals in aquatic environments enter the ocean by direct emissions or by surface runoff and can come from natural sources, such as geologic weathering and atmospheric inputs, or from human activities, such as industrial and agricultural sewage discharge (Bradl, 2005; Sharifi et al., 2016; Tiwari et al., 2016a, 2016b; Tiwari et al., 2016a, 2016b; Tiwari et al., 2017). Furthermore, some heavy metals such as mercury, cadmium, chromium, lead (Campbell and Gailer), and metalloid arsenic can transform into persistent metallic compounds with high toxicity (Cao et al., 2016). They are a major source of water pollution and have long been considered critical contaminants in aquatic ecosystems because of their toxicity, persistence, non-degradability and bioaccumulation characteristics. (Page et al., 2014; Spanopoulos-Zarco et al., 2014). Bioaccumulation of these compounds in organisms' results in magnified toxicity along the food chain (Chang et al., 2014), thereby threatening both aquatic ecosystems and human health (Van Hook, 1979). Heavy metals can accumulate in the adipose tissue and livers of humans and animals (Bhuiyan et al., 2010), which adversely effects the nervous, circulatory, and immune systems (Lauwerys, 1979; Straif et al., 2009). Moreover, some heavy metals, such as Cadmium (Mielke and Reagan, 1998) and Chromium (Bonsignore et al., 2016) can be carcinogenic when stored in the body for long periods of time. Due to their damaging effects on the ecological environment and in human health, it is necessary to include heavy metal contamination in aquatic (Zhang, Qin et al. 2014).

Marine protected areas are part of intertidal or sub-tidal environments, and encompass the overlying water; other geographical features, such as the coast, estuarine, wetlands, and islands; and all associated flora and fauna. These environments have been protected by law (Ervin et al., 2010) to conserve and protect marine biodiversity (Gaines et al., 2010); enhance ecological functions(Hastings and Botsford, 1999); reduce the decline of biomass of the oceans (O'Leary et al., 2012); and to ameliorate the negative impacts of human activities(Wells et al., 2007). Protected marine areas in China are divided into marine natural reserves, which are established to protect cherished, primitive marine areas; and marine special reserves (China, 1998), which are established to protect marine ecosystems that are used by people and to develop sustainable utilization practices for the marine resources (Zeng et al., 2016). There are two national marine reserves in Tianjin: the Tianjin Ancient Coastal Wetland National Nature Reserve and the Tianjin DaShentang Oyster Reef National Marine Special Reserve. Another special reserve, known as the Tianjin Coastal Wetland National Marine Special Reserve, is currently under construction. As an important trade port in northern China, Tianjin has a large number of industrial, agricultural and fishery activities that utilize the abundant marine resources in the area (Weizhen, 2016). These activities result in large amounts of heavy metals being discharged into the aquatic environment (Zhang et al., 2016), thereby polluting the seawater and threatening the health of local people and the environmental security in Tianjin's marine reserves (Zhang Qin and Mengxuan, 2015).

To meet the challenge of severe water pollution and resource scarcity, water quality-oriented management and intelligent watershed management are needed in China. It is a new and core watershed management module of water quality-oriented management and intelligent watershed management for the water pollution control strategy of the 13th Five Year planning in China (Zhang, Liang et al. 2014). The total pollutant load control program currently implemented in China will be supplemented by the water quality target-oriented management to form the framework for future watershed management (Sheng et al., 2013). Existing research on water of marine reserves mainly focuses on surface water quality assessment of lake, river, et al. For example, a study was focused on the water quality prediction in Yuqiao reservoir by BP neural network method (Zhao et al., 2007), Wang X et al. investigated the zooplankton and water quality in Tuanbo reservoir (Wang et al., 2008), Cao Z et al. studied the occurrence and distribution of polycyclic aromatic hydrocarbons in reclaimed water and surface water of Tianjin, including the river of Haihe, Beiyun, Ziya, etc. (Cao et al., 2005). Integrated watershed management should be explored to serve the watershed management measures based on water quality monitoring and analysis. Therefore, three marine reserves protected in Tianjin were selected for heavy metal pollution assessment according to their water quality target. And differentiated management measures for different protected marine reserves were explored according to clustered categories based on the heavy metal pollution and health risk index.

Many studies assessing heavy metal pollution in marine reserves concentrate on qualitative and quantitative evaluation of heavy metals in sediments (Caeiro et al., 2005). These studies mainly compare monitoring data with water quality standards and then further analyze the pollution sources and elucidate protection measures by assessing the given results (Hambaryan, 2013), however, they lack adequate assessment of heavy metals to which humans are easily exposed (Bonanno et al., 2017). For example, Mohsen Nowrouzi et al. (Nowrouzi et al., 2014) assessed heavy metal pollution in the sediments of the Iran Halak biosphere reserve and found that the concentration of Al, Zn, Cu and Cr were affected by pH and human activity. David Haynes et al. (Haynes and Johnson, 2000) analyzed the changes in heavy metal concentrations from several sources, such as water, sediment, mangroves and fish, in the Great Barrier Reef Reserve, and found that the primary sources of heavy metal pollution were urban runoff, and agricultural and industrial waste water emissions. Furthermore, many investigations regarding heavy metal pollution in the water and sediment of rivers, groundwater, lakes, and estuaries have been conducted using varying assessment techniques. For example, Nguyen Thi Thuong et al. (Thuong, 2013) assessed the heavy metal pollution in the To Lich River using the single factor index method for water analysis and the geo-accumulation index and enrichment factor methods for sediment analysis. Their results indicate that industrial discharge and the fertilizer application were the main pollution sources; they further concluded that suitable environmental protection regulations were necessary to protect the river environment.

Evaluation methods for aquatic heavy metal pollution mainly include the single factor index method and the comprehensive index method (Chen et al., 2011). The former is a simple method that compares monitoring data to water quality standards (Gummadi et al., 2015). The later considers multiple factors, which mainly include the Nemerow index, grey correlation analysis method, fuzzy comprehensive evaluation method, and principal component analysis (Sönmez et al., 2013; Ali et al., 2016; Yang et al., 2016). The Nemerow index method highlights the role of the maximum and the average index, which can direct focus to the major pollutants (Yan et al., 2016). Grey correlation analysis regards water as a grey box, and evaluates the mutual relationship and influence of various factors on water (Tan et al., 2015). Fuzzy comprehensive analysis classifies the degree of heavy metal pollution, thus determining the extent of heavy metal pollution in the water (Gu et al., 2016). Principal component analysis uses multidimensional factors, which allows for identification of the main contributors to environmental pollution (Yalcin et al., 2016). In this study, the Nemerow index method is used to analyze heavy metal pollution in Tianjin marine reserves because it is simple and flexible, and also reveals the conspicuous role of the pollutants of higher concentration. The health risk assessment aims to correlate human health with water pollution by relating each quantitative index to human health (Li et al., 2014). Currently, the most commonly used method is the human health risk assessment model, as recommended by the U.S. Environmental Protection Agency (USEPA) (Su et al., 2006). Many studies concentrate on assessing the health risk of heavy metals in water, sediments, and fishes, but there are few health risk assessments on heavy metals in marine reserve water (Qi et al., 2014). For example, the USEPA model was used to