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Comprehensive ecological risk assessment for heavy metal pollutions in three phases in rivers

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Abstract: Literature lacked in providing a comprehensive research on heavy metal detection in aquatic, biological and sedimentary states of rivers. The present study was imparted with all these three components of the river. Heavy metal toxicity or pollution index was used as a tool for ecological risk assessment by considering the single state studies conducted by many researchers. An intensive ecological risk assessment model was constructed and heavy metals were indicated as a serious threat to the environment. The model was applied to determining five toxic heavy metals in three states of the Songhua River. According to the ecological risk index, heavy metal pollution in three phases was categorized as aquatic>biological>sedimentary, while the overall descending order of heavy metal ecological risk index was as Cd>Hg>As>Pb>Cr. Cd and Hg were selected as the priority pollutants of Songhua River.

Key words: comprehensive ecological risk assessment; priority pollutants selection; heavy metal; Songhua River

1 Introduction

An increase in industrial production and urbanization was believed responsible for increasing concentration of heavy metals into the natural environment, not only posing serious threat to individuals and species but also causing a negative effect on the ecological system. Excessive amount of heavy metals resulted in severe impacts on human body, such as acute and chronic intoxication, cancer, teratogenesis, and mutations [1]. Currently, heavy metal contamination got great attention by researchers due to its potential hazard to environmental pollution locally and globally [2]. Different methods were adopted and implemented to calculate an ecological risk assessment of heavy metals in Xiawan Port sediments like potential ecological risk index (RI), risk assessment code (RAC) by modifying an index, modified potential ecological risk index (MRI) [3]. Four different methods, named mineralogical analysis, three-stage BCR sequential extraction procedure, dynamic leaching test and Hakanson potential ecological risk index method were used to evaluate the zinc residual leaching and its potential ecological risks on environment [4]. Ten fish species were collected from Bangshi River at Savar in Bangladesh in two different seasons to measure eight heavy metals (Pb, Cd, Ni, Cr, Cu, Zn, Mn, and As) [5]. The water quality index was implemented for heavy metals risk assessment and water quality characterization of River Soan, Pakistan [6]. However, most of the researchers detected heavy metals in single medium only. No intensive research on heavy metal pollution in all aquatic, biological and sedimentary phases of the river was reported. Although many studies investigated screening methods for priority pollutants in aqueous environments, most of them focused on heavy metal contamination of organic matters causing great threat to human body [7]. This was a problem to formulate a scientific evaluation model for determination of heavy metals as priority pollutants for intensive research on target rivers due to the demand of high standard heavy metal detection devices and operators. By considering heavy metal pollution assessment models [8−10] and priority pollutant screening methods [11−13] adopted and observed in different researches, the present study opted relevant indexes to construct a comprehensive ecological risk assessment model to detect heavy metals in aqueous, biological and

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sedimentary phases. Heavy metals with higher ecological risks were selected as the priority pollutants to control heavy metal pollution in rivers.

2 Migration and transmission of heavy metals among three phases in rivers

Heavy metals after entering in any environmental component were easily transmitted and accumulated in food chains [14], same in the case of water bodies, heavy metals eventually entered in human bodies by edible marine food like fish [15]. This process not only poisoned the fish, but also caused the alarming situation towards humans. Moreover, heavy metals in water bodies showed a tendency to react with organic polymers, forming a complex or chelate by adhering to surface of clay minerals. These pollutants were ultimately settled and accumulated in sediments and acted as secondary pollutants in water bodies by undergoing a series of physical, chemical and biological processes [16]. The migration and transmission process of heavy metals in river ecosystem is shown in Fig. 1.

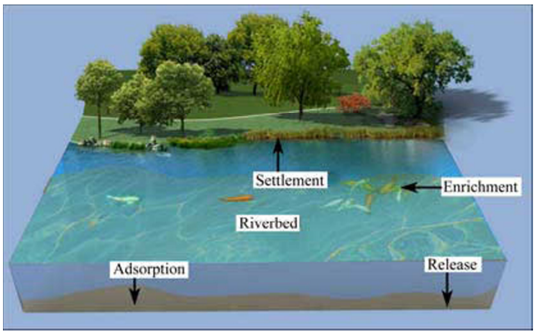

Fig. 1 Simulation of migration and transmission process of heavy metals in river ecosystem

3 Construction of risk evaluation model for heavy metals in three phases in rivers

3.1 Construction of index system

Table 1 shows the major assessment models for heavy metal pollutions locally and globally. Heavy metals pollution in rivers were mainly influenced by biological toxicity, absorption and contamination extent. By keeping in view the model construction concepts in literature, in the current study, toxicity coefficient, pollution index, and detection rate were selected as the key factors to construct the risk assessment model to detect heavy metals in rivers.

3.1.1 Toxicity coefficient of heavy metals (T_r^i)

Toxicity coefficient T_r^i represented the toxicity level and the biological sensitivity for heavy metals. Toxicity coefficients commonly used are shown in Table 2.

3.1.2 Pollution index of heavy metals (C_f^i)

Pollution index C_f^i represented the richness and pollution degree of a single heavy metal, which was denoted in Eq. (1):

$$C_f^i = C^i / C_n^i \tag{1}$$

where C^i is the detected value of a single heavy metal (mg/kg); C_n^i is the background value (mg/kg).

3.1.3 Detection rate of heavy metals (F_s^i)

Detection rate F_s^i symbolized the pollution scale and

Table 1 Main models of heavy metal pollution assessment

Model name	Formula	Indication
Index of geo-accumulation [8]	$I_{geo} = \log_2 \frac{C_n}{kB_n}$	C_n represents the content of element n in sediments; B_n refers to the background value of n in sedimentary rock (regular rock).
Pollution load index [17]	$CF_i = \frac{C_i}{C_{oi}}$ $PLI = \sqrt[n]{CF_1 \times CF_2 \times \cdots \times CF_n}$ $PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times \cdots \times PLI_n}$	C_i is the detected content of element i; C_{oi} is the background value of i; PLI is the pollution bearing coefficient of a certain point; PLI_{zone} is the pollution bearing coefficient of a certain region.
Potential ecological risk index [9]	$RI = \sum_i^m T_r^i \times \frac{C_d^i}{C_r^i}$	C_d^i is the detected concentration of pollutants in sediments; C_r^i is the background value of pollutants in sediments; T_r^i refers to the toxicity coefficient of single factor pollutant.
Excess after regression analysis [10]	$ERA(B) = [E_s - (\beta C_{Mg} + \alpha)] / E_D$, $ERA(A) = (E_s - E_D) / E_D$	E_s is the total concentration of heavy metals; E_D is the background concentration; C_{Mg} refers to the Mg concentration; β represents the regression slope between heavy metals and Mg; α is the regression intercept between heavy metals and Mg.
Sediment enrichment factor [18]	$K_{SEF} = (s_E / s_{Al} - a_E / a_{Al}) / (a_E / a_{Al})$	S_E indicates the heavy metal content in sediments; S_{Al} is the Al content in sediments; a_E is the content of heavy metals in unpolluted sediments; a_{Al} is Al content in unpolluted sediments.