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The Application of Regional Coordinate in the Relatively Heavily Polluted Area of Chromium in Water of the Hun River, Northeast China

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Abstract

The aim of the present investigation was to research the relatively heavily polluted area of chromium in water of the Hun River. According to variance analysis, the concentrations of chromium in water showed significant differences at different sampling stations. In addition, we obtained the static concentration function of chromium in water by using a curve-fitting tool and the measured data. It was clear that the static concentration function perfectly revealed the change in regulations between the concentration of chromium in water and spatial coordinates. We furthermore determined the relatively heavily polluted area of chromium in water by using a regional coordinate formula. The results indicated that the relatively heavily polluted area of chromium in water was from H1 to H2, which was highly consistent with the measured data. It is clear that the determination of the relatively heavily polluted area of chromium is helpful to the comprehensive treatment of chromium pollution. The static concentration function and the regional coordinate of the relatively heavily polluted area of chromium in water comprehensively describe the distribution characteristics of chromium in water, which provide a scientific basis for water environment improvement and risk management in the Hun River.

Keywords

Heavy Metal Pollution, Mathematical Model, Risk Evaluation

1. Introduction

Chromium is one of the essential microelements for humans and organisms. However, chromium is also a highly toxic heavy metal in the ecosystem. Chromium pollution refers to environmental pollution caused by chromium or its compounds

(Rahman, Balkhoyor, & Asiri, 2017). Previous studies showed that industry, agriculture, livestock and poultry industry and transportation industry contributed large amounts of chromium pollution to water, soil and atmosphere (Latu-Romain, Parsa, Mathieu, Vilasi, & Wouters, 2018). Ultimately, chromium may accumulate in humans and organisms through food chains and other ways. Excessive chromium will endanger humans and organisms (Dotaniya, Meena, Rajendiran, Coumar, Saha, Kundu, & Patra, 2016). For example, a high incidence of lung cancer is closely related to a high intake of hexavalent chromium (Abreu, Ferreira, Alpoim, & Urbano, 2014).

Hun River is located in Liaoning Province, Northeast China. Hun River originates from Gunmaling Mountain near Qingyuan City and flows into Liaodong Bay near Yingkou City. Hun River has a total length of approximately 415 km and a drainage area of 25,000 km^2 (Zhang, Su, Liu, Song, & Feng, 2017). Hun River has been seriously polluted by various heavy metals. Therefore, it is necessary to research the distribution characteristics and migration regulation of heavy metal pollution in the Hun River. Mishra et al. assessed the heavy metal contamination in Kali River by using heavy metal pollution index, hierarchical cluster analysis and principal component analysis (Mishra, Kumar, Yadav, & Singhal, 2017). Dotaniya et al. used geo-accumulation index to assess the heavy metals in the soil and groundwater of Kanpur, India (Dotaniya, Das, & Meena, 2014). Huang presented the formulation of a two-dimensional model to describe heavy metal transport transformation in fluvial rivers by considering basic principles of environmental chemistry, hydraulics and mechanics of sediment transport (Huang, 2010). Previous studies mainly focused on the distribution and accumulation characteristics of heavy metals in water, soil and atmosphere. However, there was not enough scientific system to reasonably determine the relatively heavily polluted area of heavy metal, which was not conducive to the analysis of heavy metal pollution sources and the treatment of heavy metal pollution. In this paper, we mainly determined the regional coordinate of the relatively heavily polluted area of chromium in water of the Hun River by using static concentration function, diffusion coefficient and barycenter coordinate formula, which made up for the deficiencies of previous studies and provided a scientific system for the treatment of chromium pollution. The regional coordinate of the relatively heavily polluted area of heavy metal provides a new perspective to study the comprehensive treatment of heavy metal pollution, which has important theoretical and practical significance for the treatment of heavy metal pollution.

2. Materials and Methods

The research mainly investigates the impact of industrial and agricultural production on chromium pollution and establishes the regional coordinate of the relatively heavily polluted area of chromium in water of the Hun River. Therefore, we choose from Zhangdang Bridge to Nanyanghu Bridge as the research area (Figure 1). The research area is one of the important grain production bases in the northeast of China. In addition, the research area traverses the heavy industrial areas of Fushun and Shenyang City. The geographic coordinates of the research area are 41.73920˚ - 41.89940˚N, 123.34794˚ - 124.07538˚E (Table 1). Twelve water sampling stations were chosen to research the distribution characteristics of chromium in water in 2017. According to the principle of isometric random sampling, three sampling points (#1, #2 and #3) were determined at each sampling station. Three water samples were collected from the Hun River at a depth of approximately 5 - 10 cm below the surface water by polyethylene acid-washed containers at each sampling point (Zhang, Su, Liu, Song, & Feng, 2017). The concentration of chromium in water sample was determined by inductively coupled plasma-mass spectrometry (ICP-MS) (Zhang & Feng, 2023). The analytical procedures were subjected to Water Quality-Determination of 65 Elements-Inductively Coupled Plasma-Mass Spectrometry (HJ700-2014) of China. The statistical analysis was done by Matlab.

The static concentration function refers to a concentration function that is only related to spatial coordinates and not to time coordinates. The diffusion coefficient is one of the important tools for studying the diffusion of heavy metals. The center of gravity coordinate is one of the important mathematical tools,

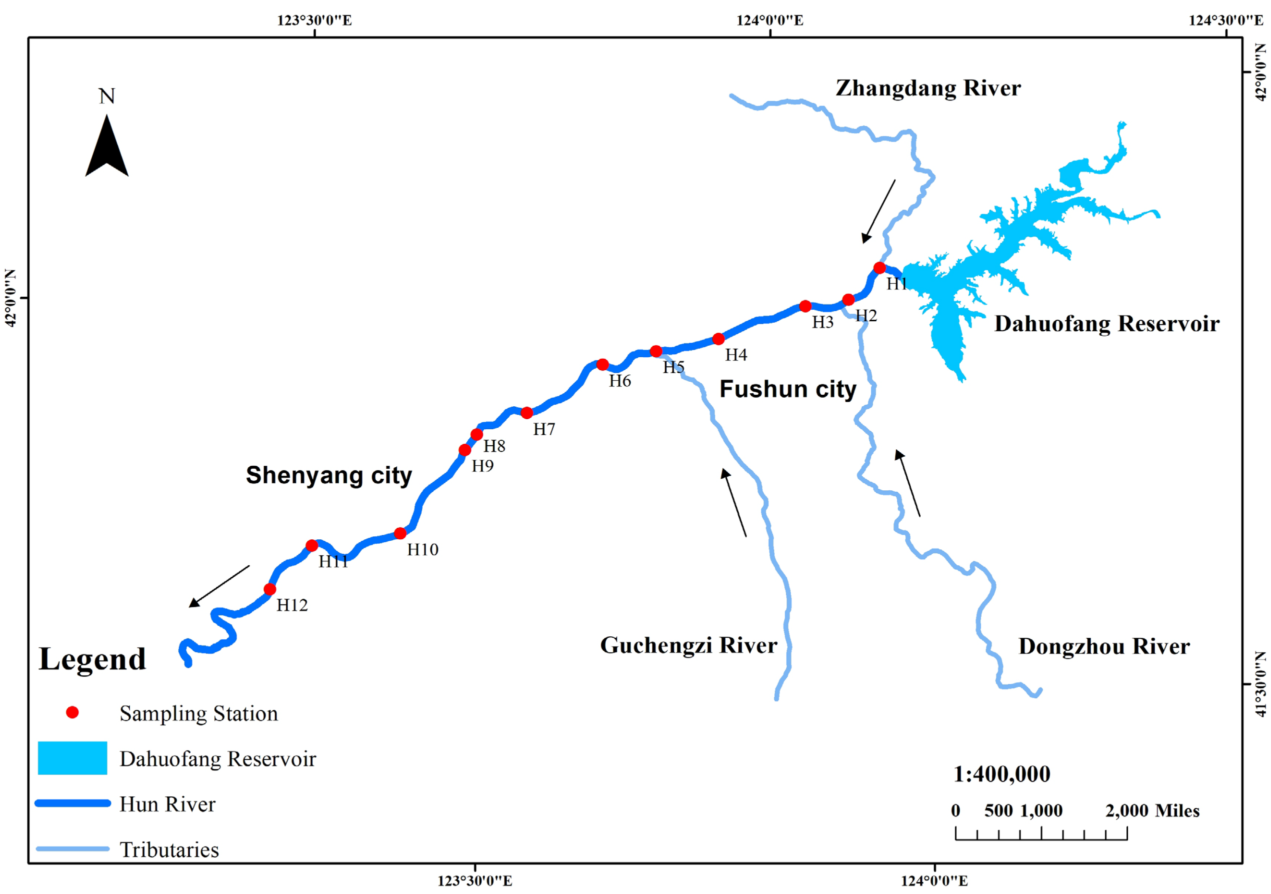

Figure 1. The sampling station along the Hun River.

Table 1. The geographical coordinate of sampling station.

Code	Sampling station	Latitude (˚) N	Longitude (˚) E
H1	Zhangdang Bridge	41.89940	124.07538
H2	Dongzhou River estuary	41.86278	124.03941
H3	Tianhu Bridge	41.87897	123.98159
H4	Jiangjun Bridge	41.86784	123.89459
H5	Guchengzi River estuary	41.85411	123.82820
H6	Hunhe Bridge	41.86089	123.75568
H7	Gaokan Bridge	41.83457	123.66621
H8	Xinkaihe dam	41.82669	123.59500
H9	Dongling Bridge	41.81242	123.58177
H10	Changqing Bridge	41.75611	123.49733
H11	Nanjing Bridge	41.75906	123.39559
H12	Nanyanghu Bridge	41.73920	123.34794

which can be used to study the distribution characteristics of heavy metals. By using static moment and moment of inertia theory, a new type of diffusion coefficient was introduced for obtaining accurate migration regulation of chromium. The diffusion coefficients of chromium in horizontal and vertical directions were respectively defined by

$$DC_x = \frac{\iint_D x^2\theta(x,y)\mathrm{d}x\mathrm{d}y}{\iint_D x\theta(x,y)\mathrm{d}x\mathrm{d}y} \quad (1)$$

and

$$DC_y = \frac{\iint_D y^2\theta(x,y)\mathrm{d}x\mathrm{d}y}{\iint_D y\theta(x,y)\mathrm{d}x\mathrm{d}y}. \quad (2)$$

3. Results and Discussion

3.1. The Distribution Characteristics of Chromium

According to the Environmental Quality Standards for Surface Water (GB 3838-2002), the critical concentration of chromium in water is 10 μg/L. The concentration of chromium in water of the research area was from 0.1059 to 1.2883 μg/L. However, previous studies indicated that low concentration of chromium might also cause serious harm to humans and organisms after its accumulation (Wimalawansa, 2016). Therefore, it is necessary to take effective measures to control chromium pollution for ensuring ecological safety and human health of local residents. According to variance analysis, the concentrations of chromium in water showed significant difference at different sampling stations ($P = 0.000 < 0.01$). Therefore, the different control measures should be adopted for controlling chromium pollution at different sampling stations. For example, reducing chromium pollution caused by the heavy industrial areas of Fushun City is the main measure to reduce chromium pollution near H1. However, reducing chromium pollution caused by industrial and agricultural production along the Dongzhou River is an important measure to control chromium pollution near H2. The highest concentration of chromium in water of the research area appeared at H53 (**Figure 2**), which was mainly attributed to electroplating, metal processing and agriculture along the Guchengzi River (Wang, Cao, Li, & Zhang, 2017). In addition, the average concentrations of chromium in water at H1, H2 and H5 were much higher than those at other sampling stations (**Figure 2**). However, the concentrations of chromium in water decreased sharply from H5 to H6 (**Figure 2**). It was reasonable to speculate that chromium at H5 migrated to sediment and organisms of the Hun River in various ways (Zhao, Chang, Liu, Zhang, & Ma, 2018). Therefore, the concentration of chromium in water at H5 failed to form the relatively heavily polluted area based on the concentrations of chromium from H4 to H6. Therefore, the measured data showed that the relatively heavily polluted area of chromium was from H1 to H2 (**Figure 2**).

3.2. The Static Concentration Function of Chromium

The concentrations of chromium in water at H51, H52 and H53 might be omitted by using descriptive statistics (**Figure 3**). The results indicated that the removal of the concentration of chromium in water at H5 did not affect the study of the regional coordinate of the relatively heavily polluted area of chromium in water. Of course, the sources and control measures of chromium in water near H5 need to be further studied for fully understanding the current situation and development trend of chromium pollution in water. Field research indicated that the length and breadth of the research area were approximately 72 km and 0.6 km, respectively. In order to simplify the calculation, the horizontal coordinate 0 km < x < 72 km was converted into 1 km ≤ x ≤ 11 km, and the vertical coordinate 0 km ≤ y ≤ 0.6 km was converted into 1 km ≤ y ≤ 3 km by using data

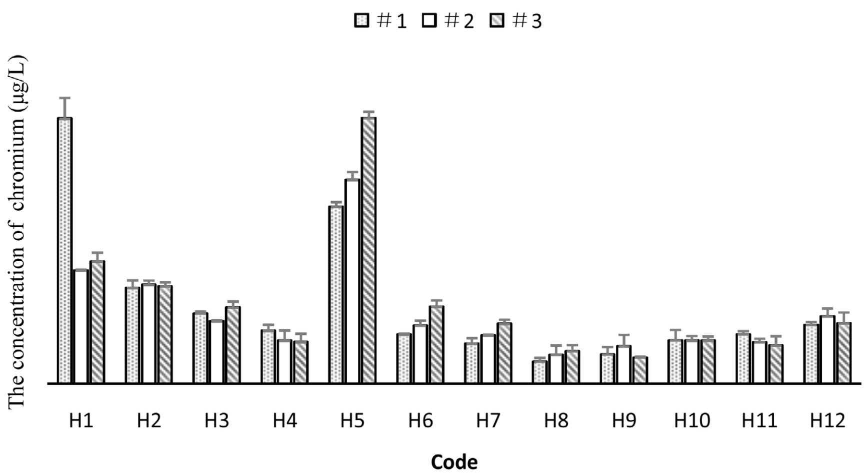

Figure 2. The concentration of chromium at each sampling point.

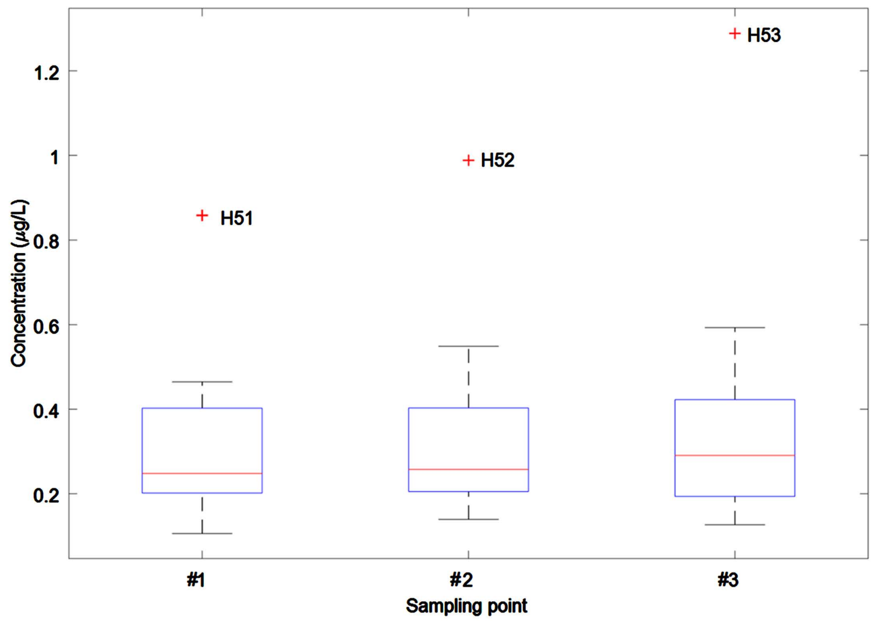

Figure 3. The box diagram of chromium.

standardization. By using a curve-fitting tool in Matlab, the concentrations of chromium in water at sampling points were fitted on the premise of ensuring the fitting accuracy. Therefore, the static concentration function $\theta(x,y)$ of chromium was obtained by

$$\theta(x,y)=15.28xe^{-2.241x-0.4456y^2}+0.0001491x^2y^3-0.001826x^2y^2 +0.1365x+0.09998 \quad (3)$$

$$R^2=0.9323.$$

The average absolute error between the static concentration function in Formula (1) and the measured data was 0.0441 μg/L. Therefore, the static concentration function of chromium in Formula (3) has high fitting accuracy and may be used for subsequent research. It is clear that the static concentration function of chromium in Formula (3) can effectively investigate the concentration of chromium at discrete sampling point. In addition, the static concentration function perfectly reveals the change regulations between the concentration of chromium with spatial coordinate. By Formula (3), it was clear that the static concentration function $\theta(x,y)$ was continuous function on the research area $D=\{(x,y)|1\le x\le 11,1\le y\le 3\}$. The continuity of the static concentration function $\theta(x,y)$ theoretically guaranteed the existence of double integral, which provided a theoretical premise for subsequent research. Therefore, the static concentration function of chromium in Formula (3) plays an irreplaceable role for obtaining the relatively heavily polluted area of chromium.

3.3. The Regional Coordinate of the Relatively Heavily Polluted Area of Chromium

It is well known that the migration regulation of heavy metal pollution in water may be affected by many influencing factors such as velocity of water flow, temperature and pH and so on (Kanai & Kawahara, 2012). In addition, the diffusion coefficient also has important influence on the distribution and accumulation characteristics of heavy metal pollution in water (Wu & Wu, 2018). By using barycenter coordinate formula and diffusion coefficients of chromium in Formulas (3) and (2), the regional coordinate ($\overline{x}, \overline{y}$) of the relatively heavily polluted area of chromium was defined by

$$\overline{x} = \frac{\iint_D \theta(x,y)\mathrm{d}x\mathrm{d}y \iint_D x^2\theta(x,y)\mathrm{d}x\mathrm{d}y}{\left(\iint_D x\theta(x,y)\mathrm{d}x\mathrm{d}y\right)^2} \tag{4}$$

and

$$\overline{y} = \frac{\iint_D \theta(x,y)\mathrm{d}x\mathrm{d}y \iint_D y^2\theta(x,y)\mathrm{d}x\mathrm{d}y}{\left(\iint_D y\theta(x,y)\mathrm{d}x\mathrm{d}y\right)^2}. \tag{5}$$

By Formulas (1)-(5), it was easy to obtain that

$$\overline{x} = \frac{\iint_D \theta(x,y)\mathrm{d}x\mathrm{d}y \iint_D x^2\theta(x,y)\mathrm{d}x\mathrm{d}y}{\left(\iint_D x\theta(x,y)\mathrm{d}x\mathrm{d}y\right)^2} = 1.1806 \tag{6}$$

and

$$\overline{y} = \frac{\iint_D \theta(x,y)\mathrm{d}x\mathrm{d}y \iint_D y^2\theta(x,y)\mathrm{d}x\mathrm{d}y}{\left(\iint_D y\theta(x,y)\mathrm{d}x\mathrm{d}y\right)^2} = 1.0897\,. \tag{7}$$

By Formulas (6) and (7), the relatively heavily polluted area of chromium was from H1 to H2, which was the same as the measured data (**Figure 2**). Field research indicated that industry and agriculture along the Zhangdang and Dongzhou Rivers contributed large amounts of chromium to water of the Hun River near H1 and H2 (Zhang, Sun, & Zhao, 2012). In fact, Formulas (6) and (7) also indicated that the concentration of chromium at H1 was higher than that at H2, which was the same as the measured data (**Figure 2**). In addition, Formulas (6) and (7) also indicated that the highest concentration of chromium appeared at H11 except for the concentration of chromium at H53, which was the same as the measured data (**Figure 2**). According to different pollution characteristics of chromium at different sampling stations, local government should take different measures to control chromium pollution along the Zhangdang and Dongzhou Rivers to reduce chromium pollution near H1 and H2. For example, the abuse of fertilizer and industrial sewage along the Zhangdang River should be avoided to reduce chromium pollution near H1. However, chromium pollution caused by industrial sewage, livestock and poultry industry and agriculture should be avoided to reduce chromium pollution near H2. In addition, the results showed that the main tributaries of the research area contributed large amounts of chromium to the mainstream of the Hun River. Therefore, the treatment of chromium pollution in main tributaries of the Hun River is the current urgent task. It is clear that the regional coordinate of the relatively heavily polluted area of chromium provides quantitative tool for studying the distribution and accumulation characteristics of chromium.

4. Conclusion

The static concentration function of chromium can grasp the distribution characteristics of chromium in water of the whole research area. In addition, the regional coordinate of the relatively heavily polluted area of chromium in water may help us to find the sources of chromium and take more pertinent measures for controlling chromium pollution. Therefore, the static concentration function and the regional coordinate of the relatively heavily polluted area of chromium may provide a scientific basis for the treatment of chromium pollution. It should be noted that this study does not consider the distribution characteristics of other heavy metal pollutants and their mutual synergy or resistance effects. However, it is important to combine static concentration function and regional coordinate with other influencing factors for obtaining precise migration regulation of chromium pollution. In addition, the limitations, generality, reliability and constraints of the static concentration function and the regional coordinate of the relatively heavily polluted area of chromium need to be further studied for optimizing the study of chromium in water. Therefore, the regional coordinate of the relatively heavily polluted area of chromium can be further optimized for obtaining accurate distribution and accumulation characteristics of chromium.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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