Study on treatment effect assessment of heavy metal pollution in Taihu Lake Sediments Based on the rapid development of Yangtze River Delta Urban Agglomeration in China

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Graphical abstract
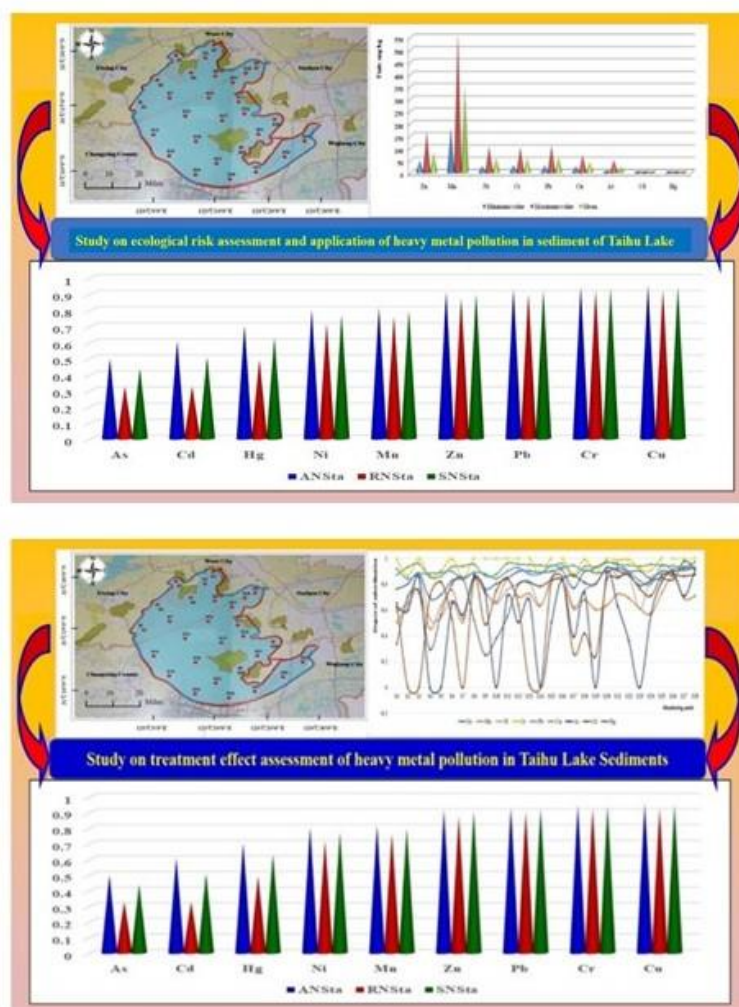
Abstract

In order to explore an effective assessment method for the treatment effect of heavy metal pollution in the sediment of Taihu Lake in China, based on the research background analysis and literature review, this paper reconstructs the spatial niche suitability model and applies it to the effect assessment of heavy metal pollution treatment in Taihu Lake sediment. The study found that the pollution degree of heavy metals in Taihu Lake sediment is as follows: North water area, West water area, South water area and East water area. The assessment results of the effect of heavy metal pollution treatment in Taihu Lake sediment by using SNSM are as follows: $As > Cd > Hg > Ni > Mn > Zn > Pb > Cr > Cu$. The four heavy metals that pose the greatest threat to the effect of Taihu Lake sediment are As, Cd, Hg and Ni; in particular, As and Cd are carcinogenic heavy metals, which the management authorities should pay special attention to. The research results of this paper are of great significance in supporting the government to formulate relevant policies for treating Taihu Lake and helping the management departments improve the treatment effect of heavy metal pollution in Taihu Lake sediments.

Keywords: Effect assessment; heavy metal pollution; Taihu Lake sediment; spatial niche suitability model

1. Introduction

Taihu Lake is China's third-largest freshwater lake and is located in the core area of the Yangtze River Delta, between Jiangsu and Zhejiang provinces. Through Taihu Lake, Yangtze River water flows into the East China Sea. The sediments at the bottom of Taihu Lake are gradually generated by the flow deposition of the Yangtze River, containing a large number of viruses, bacteria and harmful elements (Xue et al., 2020；Yu et al., 2021). In particular, the heavy metal pollution treatment in the sludge at the bottom of the lake poses a specific poison threat to the organisms and animals in the lake, the residents around Taihu Lake, people exposed to lake bottom sediments, and consumers of aquatic products (Cao et al., 2018; Wu et al., 2019；Wu et al.，2020). As the water resources of the Yangtze River flow through Taihu Lake, the heavy metal pollutants in the sediments at the bottom of Taihu Lake will flow out of the lake area and cause pollution to the lower reaches of the Yangtze River (Ohore et al., 2019; Niu et al., 2020). The content of heavy metals in the sediment of Taihu Lake is an important indicator of lake water pollution, which reflects the water quality of Taihu Lake to a great extent (Ma et al., 2015; Chen et al., 2019). The

potential effect of heavy metal pollution in Taihu Lake sediments directly or indirectly poses a significant threat to the quality of lake water, the surrounding ecological environment, and the health and even life of relevant people (Wu et al., 2017；Liu et al., 2020). According to the latest research results, the content of heavy metals in lake sediments is cumulative, and its concentration is dozens or even hundreds of times that of heavy metals in lake water (Wang et al., 2020). As Taihu Lake is located in the core area of the Yangtze River Delta urban agglomeration, the heavy metals in the lake sediments are   derived primarily from emissions from the consumption of petrochemical fuel for industrial production around Taihu Lake, exhaust emissions from motor vehicles passing through Taihu Lake, heavy metals in atmospheric sediments, and the accumulation of heavy metals in the water flow in the upper reaches of the Yangtze River (Ti et al., 2018；Zhou et al., 2020). According to the findings of Chinese researchers, over half of the total amount of harmful elements in the sediments of Taihu Lake are deposited from the atmosphere by precipitation; air deposition has become the principal method of heavy metal pollution treatment in Taihu Lake sediments (Duce et al., 1991; Chen et al., 2019; Zhang et al., 2020).

The rapid economic development of cities around Taihu Lake has promoted the scale of petrochemical energy consumption (Jiao et al., 2015；Yuan et al., 2019；He et al., 2020). With the rapid development of urban agglomeration in the Yangtze River Delta, the wastewater, waste gas, and waste residue discharged by energy consumption, as well as industrial wastewater from tanning, electroplating processing, papermaking, printing and dyeing, smelting, and chemical industry, have promoted the continuous increase of heavy metal content in the sediment of Taihu Lake (Qin et al., 2012; Rajeshkumar et al., 2018; Zhou et al., 2021). Besides, the phenomenon of direct or indirect inflow of domestic wastewater from residents around Taihu Lake increases the pollution (Dong et al., 2019). More importantly, these pollutants contain many heavy metals, significantly increasing the content and pollution degree of heavy metals in Taihu Lake (Wu et al., 2020). Taihu Lake is the primary source of domestic water, agricultural irrigation, aquaculture, and industrial development in surrounding cities (Fang et al., 2018; Xu et al., 2021). Domestic and foreign experts and scholars have studied Taihu Lake and found that heavy metals in the sediment of Taihu Lake are significantly higher than the background value in the crust, which has specific biological toxicity and environmental pollution on Taihu Lake (Qin et al., 2012; Xu et al., 2020).

73　　With the deepening pollution degree of Taihu Lake, the issue of environmental pollution and its

74　　treatment effect assessment has been proposed and attracted increasing attention from people

75　　(Huang et al., 2019).

76　　Through the above literature review, it is evident that there are still many deficiencies in the

77　　academic research on the assessment of the treatment effect of heavy metal pollution in Taihu

78　　Lake, mainly because the research methods are predominantly traditional and there has been no

79　　introduction of new methods. There are few studies on the effect assessment combined with

80　　economic development and living conditions of residents around Taihu Lake, and existing study

81　　on the source of heavy gold in the sediment of Taihu Lake is insufficiently comprehensive. This

82　　paper constructs three niche suitability models, trying to solve the problem of potential effect

83　　assessment of heavy metal pollution treatment in the Taihu Lake water area to promote the

84　　sustainable development of Taihu Lake in China.

85　　## 2. Materials and methods

86　　*2.1 Research areas*

87　　In this paper, Taihu Lake, also known as Zhenze, Juqu, Wuhu, or Lize in ancient times. It is

88　　located in the core area of the Yangtze River Delta Urban Agglomeration. It stretches across

89　　Jiangsu and Zhejiang provinces, closing to Wuxi in the north, Huzhou in the south, Yixing in the

90　　west, and Suzhou in the east. Taihu Lake area is 2427.8 square kilometers, sediment is 2338.1

91　　square kilometers, and the total length of the lake shoreline is 393.2 kilometers (Zhang et al.,

92　　2019). Taihu Lake is close to two prefecture-level cities in Jiangsu with a GDP of more than a

93　　trillion yuan, namely Suzhou and Wuxi. In 2020, the total GDP of the two cities was 3.2541

94　　trillion yuan, the total GDP of cities surrounding Taihu Lake exceeded 5 trillion yuan, and the

95　　total number of urban residents around Taihu Lake exceeded 10 million (Zhang and Teng, 2020).

96　　Heavy metal pollution treatment in Taihu Lake affects the weather and air quality of cities around

97　　the lake and the residents' health to a great extent. Therefore, the effect of heavy metal pollution

98　　treatment in Taihu Lake is closely related to green economic development and the health status of

99　　surrounding urban residents.

100　　*2.2 Collection of heavy metal detection samples*

101　　Heavy metals are metals with a density greater than 4.5g/cm^3. According to the actual situation of

102　　Taihu Lake, a total of 9 harmful heavy metals such as *As, Zn, Mn, Cr, Cu, Ni, Pb*, *As, Cd,* and *Hg*

103　　are selected in this paper. Among them, *As*, a non-metal with comparable qualities to heavy metals,

104 is classified as heavy metal under the Chinese government's standard for the treatment of heavy

105 metal pollution. In order to study the problem of effect assessment from heavy metals pollution in

106 Taihu Lake sediments, we set up a research group to investigate the heavy metals content in Taihu

107 Lake sediment. The survey lasted one year, from June 2019 to June 2020. We also investigated

108 the domestic and foreign research results of pollution and effect assessment of Taihu Lake

109 sediment, visited, and consulted the experts of Taihu Lake research in Jiangsu universities and

110 research institutions. The purpose of the field investigation is to obtain the basic data of the

111 research. According to the survey results, we decided to obtain samples from Taihu Lake sediment

112 to detect heavy metals content. On this basis, on-site sampling was conducted at 28 planned

113 sampling points in Taihu Lake from June 5 to 15, 2020. The distribution of sampling points

114 determined the sampling point of this harmful element according to the research scheme is shown

115 in figure 1.

116
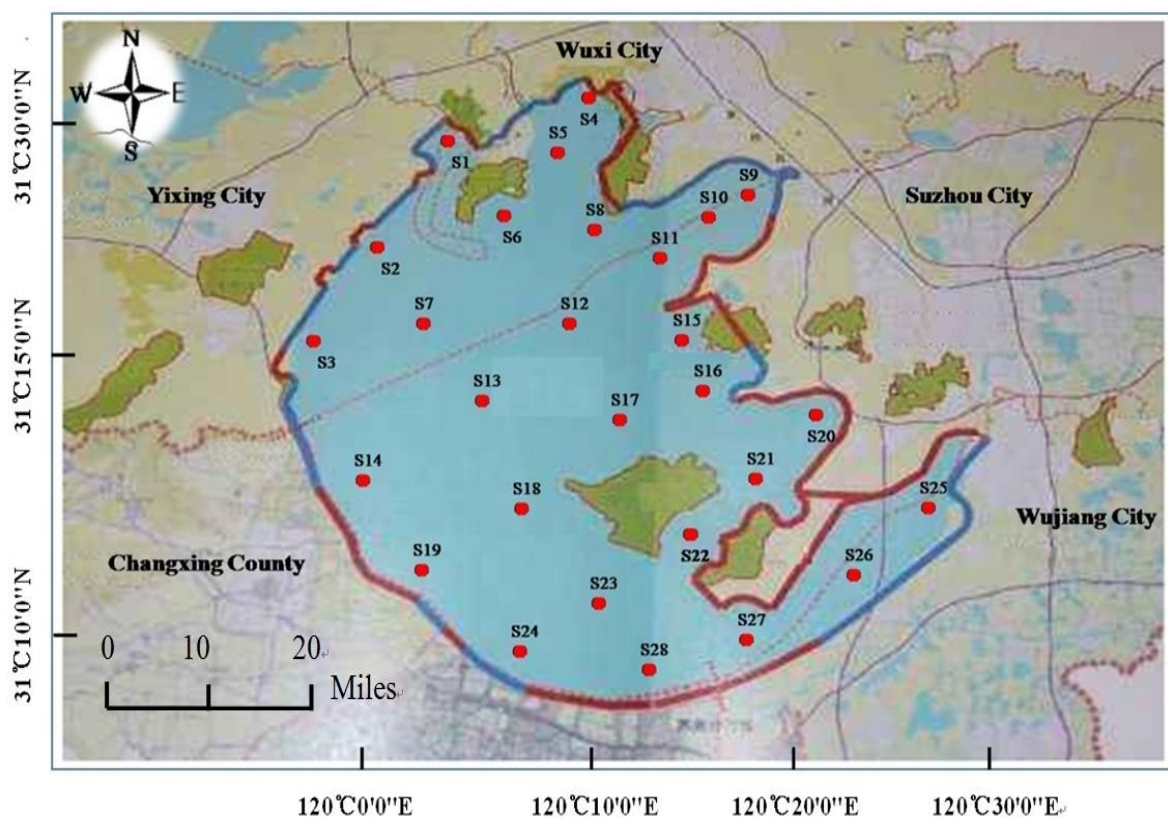
117 Figure 1. Cross section of sampling points for heavy metals detection in sediment of Taihu Lake

118 The sampling tools were a TC-600 gravity grab sediment sampler and GPS recorder, the water

119 depth of the sampling point was 1-2m, and each sediment sample was 1-2L. The test sample is

120 approximately 5-10cm above the bottom sediment sample; the test samples were packaged in

121 plastic bags to minimize loss due to exposure to heavy metals in the sediment; The samples were

122 subsequently provided to the laboratory personnel, who conducted standard detection on the

123 sediment samples of Taihu Lake to obtain the basic data for this paper.

124 *2.3 Detection of heavy metal concentration in sediment samples*

125 In the laboratory, the stratified sample sediment was pretreated by microwave digestion, following

126 which the frozen sample was dried and ground, and the sediment was dried, crushed, and well

127 mixed Then, after screening with a 100-mesh nylon screen, take a 0.2-gram test sample, place it in

128 a polytetrafluoroethylene microwave digestion tube, and add 6mL of nitric acid with a

129 concentration of 65%-68%, 2mL of hydrofluoric acid with a concentration of 40%, and 1mL of

130 perchloric acid with a concentration of 70%-72%. After using the microwave digestion instrument

131 for degradation, place the sample on the heating plate for desilication, and stop adding the solution

132 when the solution becomes viscous. After the solution has cooled, add 1mL of 1% nitric acid and

133 2mL of high-purity water before heating the tube to 100℃ and allowing it to reflux. The

134 samples' content of *Zn, Mn, Cr, Cu, Ni, Pb, As, Cd,* and *Hg* was determined using an American

135 Lee's man ICP-AES Prodigy XP full spectrum direct-reading emission spectrometer. The test

136 error was less than 1%, and the professionals in the laboratory used professional instruments to

137 measure and obtain the heavy metal test results of the test samples. After statistical analysis and a

138 systematic classification of the test results, the test results of the heavy metal content for all

139 samples are shown in Table 1.

140   **Table 1. Statistical table of detection results of heavy metals in sediment samples of Taihu Lake（Unit: mg×kg⁻¹）**

Sample	*Zn*	*Mn*	*Ni*	*Cr*	*Pb*	*Cu*	*As*	*Cd*	*Hg*
S_1	128.2364	522.3626	90.8726	52.2718	53.2642	64.2437	18.2427	0.4128	1.0237
S_2	109.3863	396.2638	77.2738	98.6528	91.2835	41.2738	19.2428	1.0638	0.4936
S_3	68.9827	275.3812	38.3728	41.2738	72.2736	31.2725	10.2836	1.4168	0.4562
S_4	163.6713	568.3217	102.3826	99.6527	70.2837	71.3764	51.4628	0.3627	1.0827
S_5	149.8629	402.3715	99.2731	84.2716	66.2735	68.3728	49.8726	0.2639	0.6972
S_6	96.3847	283.4817	76.2638	51.2727	62.2745	40.2716	17.2837	0.5218	0.3628
S_7	89.2735	496.2717	106.6812	102.1724	90.2628	38.3815	20.3724	1.2427	0.3028
S_8	70.2738	198.2736	42.3726	32.1627	65.7234	33.2719	9.8726	0.2439	0.7626
S_9	128.2734	304.2713	62.3725	42.3816	71.3624	67.3826	14.2739	0.5628	1.1426
S_{10}	108.2736	370.2736	80.2637	31.9728	89.3216	62.3821	40.2638	0.3273	0.9628
S_{11}	87.2731	205.2618	60.2635	33.2817	61.6236	29.3729	15.2438	0.2389	0.7217
S_{12}	62.2635	332.2717	52.2267	45.2732	48.2631	32.2576	22.3824	0.4238	0.3639
S_{13}	60.2716	310.2715	48.3721	48.2836	73.2736	34.2738	16.2839	0.98237	0.3429
S_{14}	66.2716	401.2817	82.2817	92.2718	86.2537	35.8727	50.2837	1.1937	0.3856
S_{15}	61.4826	221.2742	42.2836	38.2625	40.5265	37.8937	22.3418	0.2519	0.3138
S_{16}	59.2731	215.2718	32.1726	34.2735	47.9826	31.2739	10.9827	0.2347	0.2927
S_{17}	125.2732	421.2715	84.2637	93.2735	39.3628	69.0245	26.3826	0.7628	0.2638

S_{18}	59.8726	356.2813	60.4216	52.3817	61.3824	39.48273	14.2739	0.6238	0.3459
S_{19}	68.2832	426.1728	51.2738	89.3281	49.2418	40.2348	45.5927	0.7838	0.3589
S_{20}	62.1725	397.7216	28.0217	51.2834	28.9725	25.4695	9.3728	0.2498	0.1836
S_{21}	48.9725	313.2738	40.2715	55.2136	32.6218	34.3624	17.9827	0.2358	0.2139
S_{22}	62.3826	342.2576	38.3814	53.2816	62.3862	35.2736	27.3847	0.2102	0.2638
S_{23}	60.2615	421.3863	87.2738	79.3523	98.2639	38.9328	51.2837	0.3128	0.3749
S_{24}	89.2638	458.2683	43.2714	83.2739	109.8763	33.2739	20.2817	0.3627	0.3249
S_{25}	61.2736	302.2863	38.2617	36.7823	38.2937	36.3827	11.2837	0.2182	0.2938
S_{26}	62.2739	180.2535	31.2618	32.2716	57.3827	37.2839	8.8376	0.2156	0.3128
S_{27}	50.1257	346.2768	26.4728	42.2718	58.2738	40.3827	15.2837	0.2238	0.1078
S_{28}	51.8926	328.2678	27.9815	30.2639	49.3726	26.0627	8.1629	0.2138	0.1924

141 Table 1 shows the basic data of heavy metals content in the sediment of Taihu Lake, which
142 reflects the effect degree of heavy metal pollution in the sediment of Taihu Lake. The heavy
143 metals content data measured in the experiment can clearly reflect the distribution of heavy metal
144 content in Taihu Lake's sediment. These primary experimental data are arranged in the order of
145 green to red according to the heavy metal content in Taihu Lake. The distributions are shown in
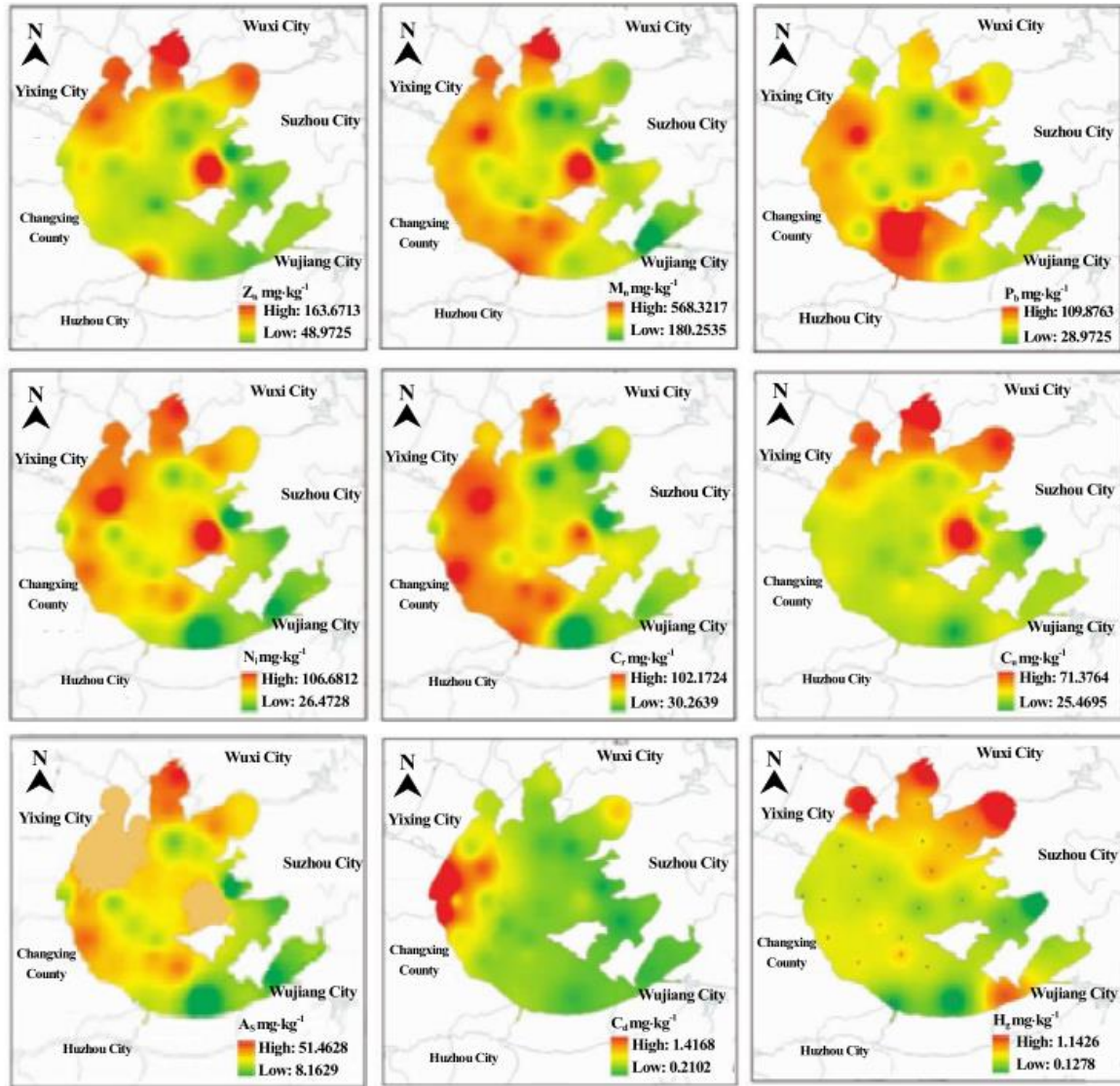146 Figure 2.

147

148

Figure 2. Distribution of heavy metals in sediment of Taihu Lake

149 According to the basic data in Table 1, the statistical analysis method is used to analyze the central

150 characteristic values of the basic data, including the minimum value, maximum value, mean value,

151 standard deviation, and coefficient of variation. The specific statistics of the heavy metal data are

152 shown in Table 2.

153 **Table 2. List of main statistical indicators of heavy metal data**

Indicators	Zn	Mn	Ni	Cr	Pb	Cu	As	Cd	Hg
Minimum	48.973	180.254	26.473	30.264	28.973	25.470	8.163	0.210	0.108
Maximum	163.671	568.322	106.681	1.0.172	1.9.876	71.376	51.463	1.417	1.145
Mean	82.554	349.879	58.960	58.097	63.417	41.976	23.029	0.506	0.462
SD	31.806	98.576	25.088	24.740	20.433	14.033	14.356	0.363	0.289

CV	0.385	0.282	0.426	0.426	0.322	0.334	0.623	0.719	0.626

In the above table, SD is the abbreviation of standard deviation; CV is the abbreviation of coefficient of variation. The content of heavy metals in Taihu Lake sediment can be used to compare the toxicity of the same harmful element. However, it cannot be used to compare the toxicity of different heavy metals. The comparison of toxicity between different heavy metals needs to be determined according to the assessment criteria and specific assessment results.

2.4 Construction of spatial niche suitability model

The effect assessment of heavy metal pollution treatment in the sediment of super-large lakes in the core area of urban agglomeration is a very important research topic. The degree of heavy metal pollution treatment directly determines the size of the effect (Wang et al., 2020). According to the results of the literature review and the latest research results both domestically and abroad, the actual situation of Taihu Lake is fully considered, and the niche suitability model is constructed in order to explore the effective assessment methods of heavy metals pollution in the sediment of Taihu Lake and its therapeutic effect. A niche refers to the position of a population within the natural ecosystem in time and space, as well as its functional interaction with other populations in the environment that are unaffected by human activity. It represents the minimum habitat threshold necessary for the survival of each organism in the ecosystem. Suppose there are n ecological factors in a region, in that case, the quantized values of these ecological factors are expressed by X_i, the ecological factors matrix can be expressed as X= $\{X_1, X_2, \cdots, X_n\}$. The ecological factors of m regions can form $(n \times m)$ dimensional quantized values matrix of ecological factors (EFM), and the specific expression is as follows:

$$EFM = \begin{pmatrix} x_{1(t_1)} & x_{2(t_1)} & \cdots & x_{n(t_1)} \\ x_{1(t_2)} & x_{2(t_2)} & \cdots & x_{n(t_2)} \\ \vdots & \vdots & \vdots & \vdots \\ x_{1(t_m)} & x_{2(t_m)} & \cdots & x_n(t_m) \end{pmatrix} \quad (5)$$

In the above formula: $i = 1, 2, \cdots, n; j = 1, 2, \cdots m$. $x_i(t_j)$ is a subset of n-dimensional ecological factor space E^n at time t_j, then $f\left(x_1(t_j), x_2(t_j), \cdots, x_n(t_j)\right)$ is called the niche of the ecosystem. Suppose the actual value of the ecological factor is $X_t = \left(x_1(t_j), x_2(t_j), \cdots, x_n(t_j)\right)$, the most suitable value is $X_\alpha = \left(x_1(\alpha), x_2(\alpha), \cdots, x_n(\alpha)\right)$, and the approach degree between the two is the niche suitability of ecological factors, expressed in NS_t. In that case, $NS_t = \tau(X_i, X_\alpha)$, the niche suitability model can be determined by using the

181 distance formula as follows:

182
$$NS_t = \sum_{i=1}^{n} \frac{W_i\left(\delta_{min} + \lambda\delta_{max}\right)}{\delta_{it} + \lambda\delta_{max}} = \sum_{i=1}^{n} \frac{W_i\left\{min\left[\left|x_i\left(t_j\right) - x_i\left(\alpha\right)\right|\right] + max\,\lambda\left[\left|x_i\left(t_j\right) - x_i\left(\alpha\right)\right|\right]\right\}}{\left|x_i\left(t_j\right) - x_i\left(\alpha\right)\right| + max\,\lambda\left\{\left|x_i\left(t_j\right) - x_i\left(\alpha\right)\right|\right\}} \tag{6}$$

183 In the formula: $\delta_{it} = \left|x_i(t_j) - x_i(\alpha)\right|$, $\delta_{max} = max\{\delta_{it}\} = max\{\left|x_i(t_j)\text{-}x_i(\alpha)\right]\}$, $\delta_{max} =$

184 $max\{\delta_{it}\} = min\{\left|x_i(t_j) - x_i(\alpha)\right\}|.i = 1,2,\cdots,m$; $t = 1,2,\cdots,$n; λ is the model parameter

185 ($0\leq\lambda\leq1$), in the average case $\lambda = 0.5$. In order to improve the effectiveness of niche suitability

186 model assessment, this paper reconstructs the niche model based on the traditional niche

187 suitability model and tries to build a comprehensive assessment model of spatial niche suitability.

188 Taking the heavy metal concentration value in Taihu Lake as the niche value, $X_i(t_j)$ represents

189 the concentration value of heavy metals at the *i*th detection point, the *j*th detection point. In order

190 to construct the comprehensive assessment model of niche suitability, the generalized correlation

191 degree in grey theory is introduced to calculate the niche of ecological factors (Ye et al., 2016).

192 Since the concentration of heavy metals in Taihu Lake sediment is obtained through a laboratory

193 test, this paper does not adopt the weakening buffer processing of the assessment indicators. In

194 order to facilitate the calculation of niche suitability, the assessment indicators need to be

195 normalized processing, the data after normalization processing has no dimension, and its value

196 range is between [0,1]. The specific calculation formula is as follows:

197
$$\begin{cases} X_i'\left(t_j\right) = X_i\left(t_j\right)\cdot\left[max\,X_i\left(t_j\right)\right]^{-1} & (\textit{forward pointer}) \\ X_i'\left(t_j\right) = 1\text{-}X_i\left(t_j\right)\cdot\left[max\,X_i\left(t_j\right)\right]^{-1} & (\textit{contrary indicator}) \end{cases} \tag{7}$$

198 If $X_i(\alpha)$ is the most appropriate value in the assessment indicators in line i, $X_{i\alpha}'$ is the most

199 appropriate value after normalization processing. The specific calculation formula is as follows:

200
$$\begin{cases} X_i'\left(\alpha\right) = X_i\left(\alpha\right)\cdot\left[max\,X_i\left(t_j\right)\right]^{-1} & (\textit{forward pointer}) \\ X_i'\left(\alpha\right) = 1\text{-}X_i\left(\alpha\right)\cdot\left[max\,X_i\left(t_j\right)\right]^{-1} & (\textit{contrary indicator}) \end{cases} \tag{8}$$

201 In order to build a comprehensive assessment model of spatial niche suitability, firstly, an absolute

202 niche suitability measurement model is constructed. According to the dimensionless processing

203 results, use the following formula to calculate the absolute null transformation:

204
$$\begin{cases} X_{it}'\left(0\right) = \left(x_{1t}'\left(0\right),\ x_{2t}'\left(0\right),L\ ,\ x_{mt}'\left(0\right)\right) = x_i'\left(t_j\right) - x_1'\left(t_j\right) \\ X_{i\alpha}'\left(0\right) = \left(x_{1\alpha}'\left(0\right),\ x_{2\alpha}'\left(0\right),L\ ,\ x_{m\alpha}'\left(0\right)\right) = x_i'\left(t_j\right) - x_1'\left(0\right) \end{cases} \tag{9}$$

205 Then, the absolute niche suitability model is constructed according to the results of absolute zero

206 transformation and referring to the niche suitability basic model. The model is as follows:

207
$$ANS_{t\alpha} = \frac{1 + |S_\alpha| + |S_t|}{1 + |S_\alpha| + |S_t| + |S_\alpha - S_t|} \tag{10}$$

208
$$\begin{cases} S_t = \int_1^n \left(x_{it}'(0) - x_{i1}'(0) \right) dt \\ S_\alpha = \int_1^n \left(x_{i\alpha}'(0) - x_{i1}'(0) \right) dt \\ |S_t| = \left| \int_1^n \left(x_{it}'(0) - x_{i1}'(0) \right) dt \right| = \left| \sum_{k=2}^{n-1} x_{kt}'(0) + \frac{1}{2} x_{mt}'(0) \right| \\ |S_\alpha| = \left| \int_1^n \left(x_{i\alpha}'(0) - x_{i1}'(0) \right) dt \right| = \left| \sum_{k=2}^{n-1} x_{k\alpha}'(0) + \frac{1}{2} x_{mt}'(0) \right| \\ S_t - S_\alpha = \int_1^n \left(x_{it}'(0) - x_{i\alpha}'(0) \right) dt \\ |S_t - S_\alpha| = \left| \sum_{k=2}^{n-1} \left(x_{i\alpha}'(0) - x_{it}'(0) \right) + \frac{1}{2} \left(x_{m\alpha}'(0) - x_{kt}'(0) \right) \right| \end{cases}$$

209 On this basis, the relative niche suitability model is constructed by using the same method above.

210 First, the relative null transformation calculation is carried out, and the calculation formula is as

211 follows:

212
$$\begin{cases} X_{it}''(0) = \left(x_{1t}''(0), \ x_{2t}''(0), \text{L}, \ x_{nt}''(0) \right) = x_i''(t_j) \times \left[x_1''(t_j) \right]^{-1} \\ X_{i\alpha}''(0) = \left(x_{1\alpha}''(0), \ x_{2\alpha}''(0), \text{L}, \ x_{n\alpha}''(0) \right) = x_i''(\alpha) \times \left[x_1''(t_j) \right]^{-1} \end{cases} \tag{11}$$

213 Then, the relative niche suitability assessment model is constructed by using the above relative

214 null transformation calculation results. The specific assessment model of relative niche suitability

215 is as follows:

216
$$RNS_{t\alpha} = \frac{1 + |S_\alpha''| + |S_t''|}{1 + |S_\alpha''| + |S_t''| + |S_\alpha'' - S_t''|} \tag{12}$$

217
$$\begin{cases} S_t'' = \int_1^n \left(x_{it}''(0) - x_{i1}''(0) \right) dt \\ S_\alpha'' = \int_1^n \left(x_{i\alpha}''(0) - x_{i1}''(0) \right) dt \\ |S_t''| = \left| \int_1^n \left(x_{it}''(0) - x_{i1}''(0) \right) dt \right| = \left| \sum_{k=2}^{m-1} x_{kt}''(0) + \frac{1}{2} x_{mt}''(0) \right| \\ |S_\alpha''| = \left| \int_1^n \left(x_{i\alpha}''(0) - x_{i1}''(0) \right) dt \right| = \left| \sum_{k=2}^{m-1} x_{k\alpha}''(0) + \frac{1}{2} x_{m\alpha}''(0) \right| \\ S_t'' - S_\alpha'' = \int_1^n \left(x_{it}''(0) - x_{i\alpha}''(0) \right) dt \\ |S_t'' - S_\alpha''| = \left| \sum_{k=2}^{n-1} \left(x_{k\alpha}''(0) - x_{kt}''(0) \right) + \frac{1}{2} \left(x_{m\alpha}''(0) - x_{kt}''(0) \right) \right| \end{cases}$$

218 The comprehensive assessment model of spatial niche suitability is the weighted average value of

219 the absolute and relative niche suitability models. If ξ is a relative weight, there are:

220
$$SNS_{t\alpha} = \xi \cdot ANS_{t\alpha} + (1 - \xi)RNS_{t\alpha} \tag{13}$$

221   In the formula: ξ∈[0,1] is the weighting coefficient. Considering that the importance of absolute

222   and relative niche suitability is equal, the value of ξ is 0.5. When the value of ξ is less than 0.5

223   and tends to 0, the spatial niche suitability value tends to be the relative niche suitability value.

224   When the value of W is greater than 0.5 and tends to 1, the spatial niche suitability value tends to

225   be the absolute niche suitability value. In order to use the Spatial niche suitability model to assess

226   the effect of heavy metals pollution in the sediment of Taihu Lake, based on the most recent

227   Chinese and international research results (Wang et al., 2019; Ohore et al., 2019; Niu et al., 2020),

228   it is necessary to refer to *China's Urban Sewage Treatment Plant Sludge Quality* (GB T24188

229   -2009), *Urban Sewage Treatment Plant Sludge Treatment Technical Standard Consultation Draft*

230   (*Jianbiao-Gongzheng*[2017] No.149), *Urban Sewage Treatment Plant Pollutant Emission*

231   *Standard* (GB18918-2016), and other statutory documents to determine the assessment standards

232   for the potential effect levels of heavy metal pollution in the sediment of Taihu Lake, see Table 3.

233   **Table 3. Effect assessment standard for heavy metal pollution in the sediment of Taihu Lake**

Pollution degree	Level Ⅰ	Level Ⅱ	LevelⅢ	LevelⅣ	Level Ⅴ
Zn	0-25	25-150	150-350	350-500	>500
Mn	0-100	100-200	200-300	300-500	>500
Ni	0-30	30-50	50-100	100-200	>200
Cr	0-60	60-90	90-210	210-300	>400
Pb	0-25	25-150	150-350	350-500	>500
Cu	0-30	30-120	120-280	280-400	>400
As	0-10	10-15	15-30	30-40	>40
Cd	0-0.20	0.20-0.30	0.30-0.60	0.6-1.00	>1.00
Hg	0-0.15	0.15-0.30	0.30-0.50	0.50-1.00	>1.50

234   Since the value range of the assessment result is within the interval [0, 1], the assessment results

235   and the degree standards can be used to determine the potential effect level of heavy metals

236   pollution in the sediment of Taihu Lake, as follows：Level Ⅰ∈[0.90,1.00], excellent; Level

237   Ⅱ∈[0.80,0.90), good; Level Ⅲ∈[0.60,0.80), medium; Level Ⅳ∈[0.40,0.60), pass；Level

238   Ⅴ∈[0,0.40), fail. In order to effectively assess the assessment objects, the value of a quantity of the

239   assessment indicators must be standardized so that the value of the assessment indicators can be

240   converted into comparable standardized values (Zhang et al., 2017).

3. Results and discussion

242   *3.1 Main research results*

243   In order to use the spatial niche suitability model to assess the potential effect of heavy metal

pollution in the sediment of the Taihu Lake, first use formula (7-8) to conduct a dimensionless process for the basic data in Table 1, where the maximum value is 1.5 times the lower boundary of level V and the assessment value of the indicator greater than this value is determined to be zero. The specific dimensionless processing results are shown in Table 4.

Table 4. Normalized results of effect assessment indicators of heavy metal pollution treatment in Taihu Lake

Sample	Zn	Mn	Ni	Cr	Pb	Cu	As	Cd	Hg
S_1	0.8290	0.3035	0.6971	0.9129	0.9290	0.8929	0.6960	0.7248	0.5450
S_2	0.8542	0.4716	0.7424	0.8356	0.8783	0.9312	0.6793	0.2908	0.7806
S_3	0.9080	0.6328	0.8721	0.9312	0.9036	0.9479	0.8286	0.0555	0.7972
S_4	0.7818	0.2422	0.6587	0.8339	0.9063	0.8810	0.1423	0.7582	0.5188
S_5	0.8002	0.4635	0.6691	0.8595	0.9116	0.8860	0.1688	0.8241	0.6901
S_6	0.8715	0.6220	0.7458	0.9145	0.9170	0.9329	0.7119	0.6521	0.8388
S_7	0.8810	0.3383	0.6444	0.8297	0.8796	0.9360	0.6605	0.1715	0.8654
S_8	0.9063	0.7356	0.8588	0.9464	0.9124	0.9445	0.8355	0.8374	0.6611
S_9	0.8290	0.5943	0.7921	0.9294	0.9049	0.8877	0.7621	0.6248	0.4922
S_{10}	0.8556	0.5063	0.7325	0.9467	0.8809	0.8960	0.3289	0.7818	0.5721
S_{11}	0.8836	0.7263	0.7991	0.9445	0.9178	0.9510	0.7459	0.8407	0.6792
S_{12}	0.9170	0.5570	0.8259	0.9245	0.9356	0.9462	0.6270	0.7175	0.8383
S_{13}	0.9196	0.5863	0.8388	0.9195	0.9023	0.9429	0.7286	0.3451	0.8476
S_{14}	0.9116	0.4650	0.7257	0.8462	0.8850	0.9402	0.1619	0.2042	0.8286
S_{15}	0.9180	0.7050	0.8591	0.9362	0.9460	0.9368	0.6276	0.8321	0.8605
S_{16}	0.9210	0.7130	0.8928	0.9429	0.9360	0.9479	0.8170	0.8435	0.8699
S_{17}	0.8330	0.4383	0.7191	0.8445	0.9475	0.8850	0.5603	0.4915	0.8828
S_{18}	0.9202	0.5250	0.7986	0.9127	0.9182	0.9342	0.7621	0.5841	0.8463
S_{19}	0.9090	0.4318	0.8291	0.8511	0.9343	0.9329	0.2401	0.4775	0.8405
S_{20}	0.9171	0.4697	0.9066	0.9145	0.9614	0.9576	0.8438	0.8335	0.9184
S_{21}	0.9347	0.5823	0.8658	0.9080	0.9565	0.9427	0.7003	0.8428	0.9049
S_{22}	0.9168	0.5437	0.8721	0.9112	0.9168	0.9412	0.5436	0.8599	0.8828
S_{23}	0.9197	0.4382	0.7091	0.8677	0.8690	0.9351	0.1453	0.7915	0.8334
S_{24}	0.8810	0.3890	0.8558	0.8612	0.8535	0.9445	0.6620	0.7582	0.8556
S_{25}	0.9183	0.5970	0.8725	0.9387	0.9489	0.9394	0.8119	0.8545	0.8694
S_{26}	0.9170	0.7597	0.8958	0.9462	0.9235	0.9379	0.8527	0.8563	0.8610
S_{27}	0.9332	0.5383	0.9118	0.9295	0.9223	0.9327	0.7453	0.8508	0.9521
S_{28}	0.9308	0.5623	0.9067	0.9496	0.9342	0.9566	0.8640	0.8575	0.9145

The absolute null transformation calculation is carried out based on the dimensionless treatment of the assessment indicators. First, absolute null transformation processing refers to the use of different methods to determine the zero base of the first row, that is, the data of each row of all assessment indicators minus the base data of the first row, so that the difference of the first row is zero. Then calculate the relative null transformation, which refers to the use of the ratio method to

254 determine the zero base of the first row, that is, the ratio of the data in each row of all assessment

255 indicators to the first row is used, and the ratio minus one is used as the calculation result; the data

256 in the first row is zero. The author has utilized formulas (9) and (11) to calculate absolute and

257 relative null transformation results for the assessment indicators. In the following, the author will

258 use formulas (10), (12), and (13) to calculate the assessment results of the absolute niche

259 suitability, the relative niche suitability, and the spatial niche suitability of the effect of heavy

260 metal pollution treatment in Taihu Lake sediment, respectively. The composition, difference and

261 trend of the assessment results obtained from the three assessment models are shown in Table 5.

262

Table 5. Assessment results of different niche suitability models

Evaluation Method	Zn	Mn	Ni	Cr	Pb	Cu	As	Cd	Hg
$ANS_{t\alpha}$	0.9148	0.8123	0.7987	0.9457	0.9296	0.9562	0.4975	0.6064	0.7028
Level	I	II	III	I	I	I	IV	III	III
$RNS_{t\alpha}$	0.8748	0.7580	0.7130	0.9234	0.9016	0.9253	0.3246	0.3253	0.4891
Level	II	III	III	I	I	I	V	V	IV
ξ	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
$SNS_{t\alpha}$	0.9008	0.7933	0.7687	0.9379	0.9198	0.9454	0.4370	0.5080	0.6280
Level	I	III	III	I	I	I	IV	IV	III

263 According to the above assessment results, the assessment results using the absolute niche

264 suitability model are: *Cu, Cr, Pb,* and *Zn* are Level I, its assessment result is excellent; *Mn* is Level

265 II, its assessment result is good; *Ni, Hg,* and *Cd* are Level III, its assessment result is medium; *As*

266 is Level IV, its assessment result is pass. The assessment results using the relative niche suitability

267 model are: *Cu, Cr,* and *Pb* are Level I; *Zn* is Level II; *Mn* and *Ni* are Level III; *Hg* is Level IV;

268 *Cd* and *As* are Level V. The assessment results using the spatial niche suitability model are: *Cu,*

269 *Cr, Pb,* and *Zn* are Level I; *Mn, Ni,* and *Hg* are Level III; *Cd* and *As* are Level IV.

270 *3.2 Discussion on the assessment results and influencing factors*

271 The above three niche suitability models are used to assess the effect of heavy metal pollution

272 treatment in the sediment of Taihu Lake, and the assessment results are relatively different. In

273 order to reflect the differences between the assessment results obtained by different assessment

274 methods, the assessment results of the three niche suitability models are drawn with a cone

275 diagram in the rectangular coordinate system, and the differences between them can be seen. See

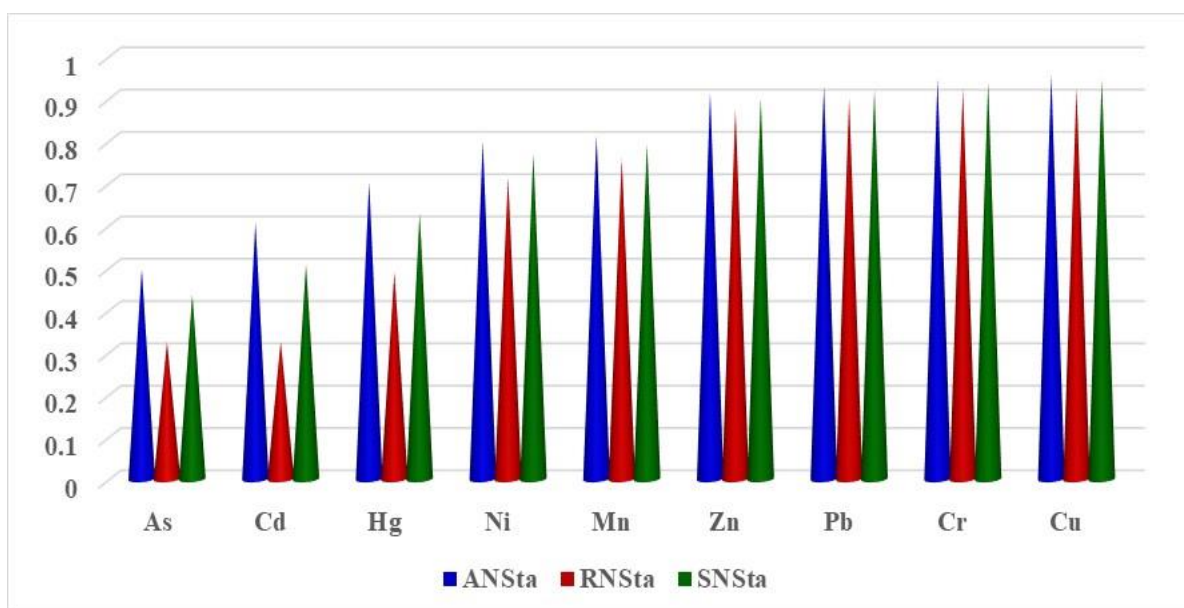276 Figure 3 for the specific differences.

Figure 3. Difference of assessment results of different niche suitability models

It is evident from the above figure that the assessment result of the absolute niche suitability model is relatively high, the assessment result of the relative niche suitability model is relatively low, and the assessment result of the spatial niche suitability model is between the two. In addition to the impact of the assessment model on the assessment results, the basic data used in the assessment will also affect the assessment results to a certain extent. The main reason for the potential effect of Taihu Lake is the heavy metal content in the sediment. In order to reflect the distribution of the heavy metal content at 28 measuring points and its impact, the membership degree of heavy metal content indicators of all the samples in the sediment of Taihu Lake is plotted in a rectangular coordinate system. The specific content level, composition, and change rule of heavy metals are shown in Figure 4.
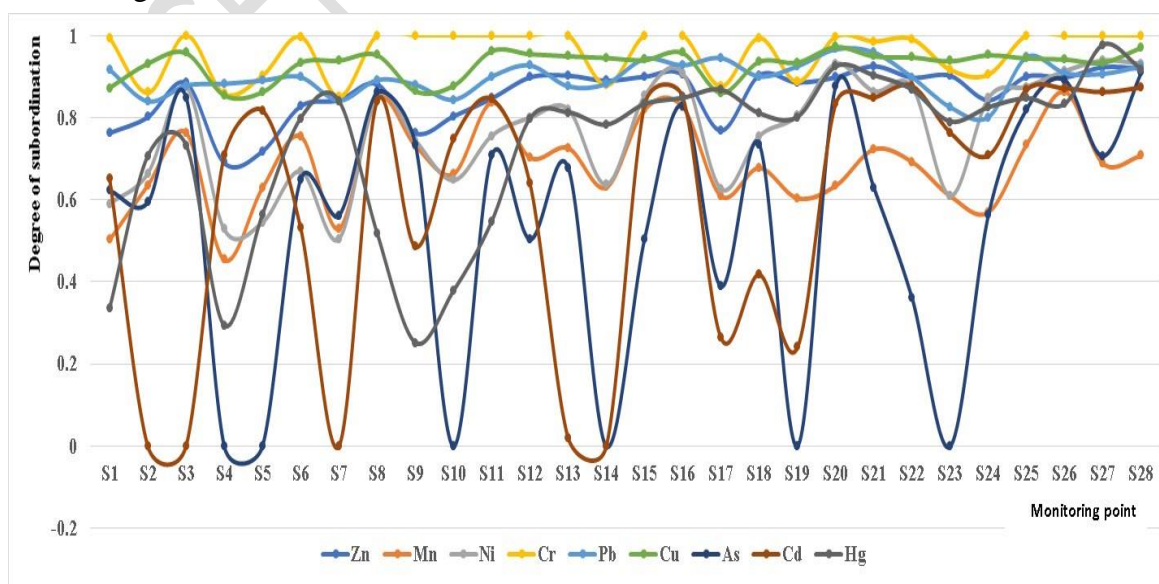
Figure 4. Variation diagram of main influencing factors of treatment effect of heavy metal pollution

291 It can be seen from the above figure that the membership degree of heavy metals in Taihu Lake

292 sediment is not the only factor determining the effect. The subordinate degree of certain heavy

293 metals in the figure is extremely high, although it has little impact on potential effects, such as

294 manganese. The subordinate degree of other heavy metals is not high, but it has a significant

295 impact on potential effects, such as heavy metals Cd, Hg, and etc. In addition to the content of

296 heavy metals, the factors affecting the potential effect of Taihu Lake also include the toxicity

297 coefficients and assessment standards of heavy metals (Chen et al., 2011).

298 *3.3 Analysis of effect trend of heavy metal pollution treatment*

299 According to the results of this study, the distribution of heavy metal pollution in Taihu Lake's

300 sediment is relatively concentrated (Fang et al., 2018). According to the spatial distribution of

301 heavy metal pollution in the sediment of Taihu Lake, the effect in the east of Taihu Lake is the

302 lowest, and the content of nine heavy metals in the sediment is relatively low, showing a good

303 treatment effect. The main reason is that Suzhou is east of Taihu Lake, and Suzhou is the city with

304 the best economic development in Jiangsu Province. The per capita GDP has reached 30000 US

305 dollars, the investment in environmental pollution treatment is high, and the ecological

306 environment is in good condition so that the ecological environment is the best. The western part

307 of Taihu Lake is relatively serious in heavy metals pollution such as Mn, Pb, Cr, and As. The

308 western part of Taihu Lake is Changxing County, where heavy metal emissions are concentrated

309 due to the concentrated industry, the main reason is the lack of investment in environmental

310 pollution treatment, and the potential effect is relatively large (Bian et al., 2017). The northern part

311 of Taihu Lake is the most heavily polluted area by heavy metals. The northern part of Taihu Lake

312 is Wuxi that is one of the largest cities in Jiangsu Province and one of the cities with the fastest

313 economic development, mainly due to the construction of Wuxi New District around Taihu Lake,

314 where a large number of industrial clusters are concentrated around Taihu Lake and heavy metals

315 pollution is inevitable. Wujiang City and Huzhou City are located south of Taihu Lake. The

316 condition of economic development in these two cities is average. Around Taihu Lake, there are

317 relatively few industrial firms, and heavy metal pollution levels are relatively low. The pollution

318 of heavy metals such as $A_S, C_d, H_g \ and \ N_i$, are relatively serious, caused by insufficient

319 investment in environmental pollution treatment.

320 The excessive heavy metal content in the sediment of Taihu Lake is the main reason for the

321 potential effect that is affected by many factors. Strengthening environmental pollution treatment

322 is a critical way to reduce the potential effect of Taihu Lake (Sun et al., 2020). According to the

323 results of this study, heavy metals in the sediment of Taihu Lake are mainly related to the

324 economic development of surrounding cities and the investment in environmental pollution

325 treatment. Economic development is positively correlated with heavy metals' content, while

326 investment in environmental pollution treatment is negatively correlated with the content of heavy

327 metals. Maintaining the balance of the two relationships is the key to preventing effects in Taihu

328 Lake. According to the detection results of heavy metals in the sediment of Taihu Lake and the

329 niche suitability methods' assessment results, the pollution status of heavy metals in the sediment

330 of Taihu Lake and the high potential effects are not formed in a short period. Therefore, the

331 content of heavy metals in the sediment of Taihu Lake is rising, and the potential effect is also

332 increasing. According to the evaluation results of the spatial ecological model, the effect of heavy

333 metals A_s and C_d have reached level IV, and the effect of heavy metals H_g, N_i and M_n have

334 reached level III. Dealing with the heavy metal pollution in Taihu Lake and promoting the

335 continuous improvement of the governance effect have become an essential task for the

336 surrounding units and the government, starting from two main aspects of pollutant emission

337 reduction and environmental pollution treatment investment

4. Conclusion

339 The potential effect assessment of heavy metal pollution in the sediment of Taihu Lake is a critical

340 research topic. To explore the effective assessment method of heavy metal pollution and its

341 potential effect on the sediment of Taihu Lake, based on the literature review and research status

342 analysis, nine heavy metals that have potential effects impacting Taihu Lake were selected

343 according to the detection results. Moreover, after the technical processing of the assessment data,

344 three niche suitability models, including the absolute niche suitability model, the relative niche

345 suitability model, and the spatial niche suitability model, were constructed to assess the treatment

346 effect of heavy metal pollution in Taihu Lake. The results showed that the heavy metal pollution

347 in the sediment of Taihu Lake had reached a high level, the order of pollution degree are: *As> Cd >*

348 *Hg >Ni >Mn>Zn >Pb >Cr >Cu.* The assessment results of the four heavy metal elements with

349 serious pollution (*As >Cd >Hg >Ni*) are: level IV, level IV, level III and level III according to the

350 spatial niche assessment model, among them, *As* and *Cd* are highly carcinogenic heavy metals.

351 The study also found that the selection of assessment indicators and the construction of the

assessment model are essential for assessing the treatment effect of heavy metal pollution in Taihu Lake. According to the research results of this paper, the government should make full use of the assessment results of the heavy metal pollution treatment, strengthen the treatment of *As*, *Cd*, and *Hg*, which are severely polluted, especially the treatment of the carcinogenic heavy metals *As* and *Cd*, promote the improvement of heavy metal pollution in Taihu Lake sediments, and continuously enhance the control effect. The treatment effect assessment of heavy metal pollution in the sediment of Taihu Lake is an important subject that needs long-term study. The purpose of this study is to promote the in-depth study of this subject in the academic community and to promote the continuous reduction of the degree of heavy metal pollution in Taihu Lake and the continuous improvement of the treatment effect of environmental pollution.

Abbreviation：HMP-heavy metal pollution; SNSM- spatial niche suitability model.

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