

DISTRIBUTION AND POTENTIAL ECOLOGICAL RISK ASSESSMENT OF HEAVY METALS IN THE YELLOW RIVER BEACH REGION, SHAANXI, CHINA

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Abstract. This study investigated the distribution of heavy metals in the soil layer from 0 to 30 cm in the Yellow River beaches of Hancheng, Heyang and Tongguan section, China. The results showed that: (1) In the soil of the study area, the average Zn content was highest, and the average contents of As and Cd were lowest. Except for Ni, the coefficient of variation of other heavy metals is relatively large. (2) Pb and Cd of Hancheng beach showed significant positive correlations between Cr and Cu ($p < 0.01$). The correlations among Cr-Cd, Pb-Ni, Zn-Cr, and Zn-Cu of Tongguan beach were significant ($p < 0.01$). (3) Single factor pollution index and Nemerow pollution index identified a certain degree of Zn pollution in the soil of Hancheng beach, and the overall heavy metal content of the soil of both Heyang and Tongguan beaches reached the level I safety level. (4) According to the Hakanson potential ecological hazard index, the average potential ecological risk index of the soil in the study area is $83.36 < 135$. The comprehensive potential risk of soil in different river sections follows: Hancheng > Heyang > Tongguan.

Keywords: heavy metal pollution, floodplain, pollution assessment, soil

Introduction

Over recent years, due to the rapid development of mining and transportation industries, compound pollution of inorganic and organic pollutants has gradually intensified (Chakraborty and Das, 2016). Especially in coastal areas, soil heavy metal pollution is gradually appearing. Due to the persistence and high toxicity of heavy metals in soil, the ecotoxicological risks induced by heavy metals have been gradually received increasing attention (Mi et al., 2015; Fan et al., 2019; Li et al., 2017). The problems of soil environmental quality and soil environmental safety related to agriculture have received particular attention (Crnkovic et al., 2006; Douay et al., 2007; Tume et al., 2008). All countries conducted research on the distribution laws of heavy metals in soil, their migration characteristics, enrichment characteristics, their forms, and phytoremediation. Starting from the idea of soil organic reconstruction,

Shaanxi Land Engineering Construction Group carry out soil heavy metal repair by the means of the soil materials and soil structure, and achieved notable results. At present, research on heavy metals in soils mainly explores their migration, transformation, enrichment, morphology, and bioremediation. The study area is dominated by farmland, urban land, and mining areas; however, river beaches and wetlands have not received sufficient attention (Islam et al., 2015; Fan et al., 2008; Li et al., 2015; Cheng et al., 2012).

The Yellow River Hancheng to Tongguan section is located at the junction between central Shaanxi and southern Shanxi, and is commonly known as the Xiaobei River, with a total length of 132.5 km. It forms an important section that integrates natural resources, humanities, agriculture, water resources, and tourism resources. This study focused on the distribution of heavy metals in the Yellow River beaches, beginning at the Hancheng-Tongguan section of the Yellow River. The sampling points include three regions, they are Xiayukou of Hancheng, Bailiang of Heyang and Qindong of Tongguan, Shannxi, China. The risk and harm for the ecological protection of the Yellow River beaches and the development and utilization of the Yellow River beaches were investigated. The results of this study have practical significance for the alleviation of heavy metal pollution in this region.

Materials and methods

Description of the research area

The section between Hancheng and Tongguan in the Yellow River is located at the junction between central Shaanxi and southern Shanxi. To the west of the Yellow River, Hancheng, Heyang, and Tongguan are located, and Hejin and Yongji in Shanxi Province form the main areas to the east of the Yellow River. The project covers a total length of 132.5 km from Yumenkou to the Tongguan Railway Bridge on the west bank of the Yellow River. It includes four cities and counties, such as Hancheng, Heyang, Dali, and Tongguan in Weinan City, as well as 12 towns and 54 administrative villages with a total population of 57,500. Sampling points of Hangcheng range between 110°5'50"-108°36'29" E and 34°36'59"-35°39'34" N; sampling points of Heyang range between 109°58'33"-110°27'00" E and 34°59'16"-35°26'07" N; sampling points of Tongguan range between 110°09'13"-110°25'26" E and 34°23'38"-34°40'17" N (Fig. 1).

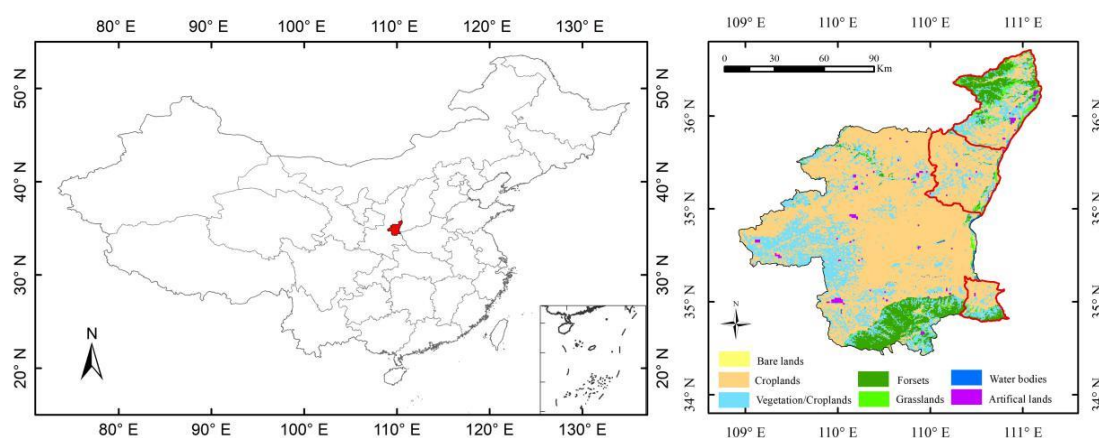


Figure 1. The sample distribution from Hancheng to Heyang

The study area has a warm temperate semi-humid and semi-arid monsoon climate, with four seasons. The frost-free period lasts 199-255 days, and the area has a changing spring climate, with hot and rainy summers, cool autumns, and dry and sunny winters. The average annual temperature is 12-14 °C, the annual rainfall is 600 mm, and the sun shines for 2200-2500 h annually. Climatic conditions are conducive to the development of agriculture; however, droughts, autumn floods, and dry and hot summer winds are more harmful for crops. *Figure 2* shows the average temperature and precipitation for each month. The economy of this region is mainly based on agricultural production and transportation hubs.

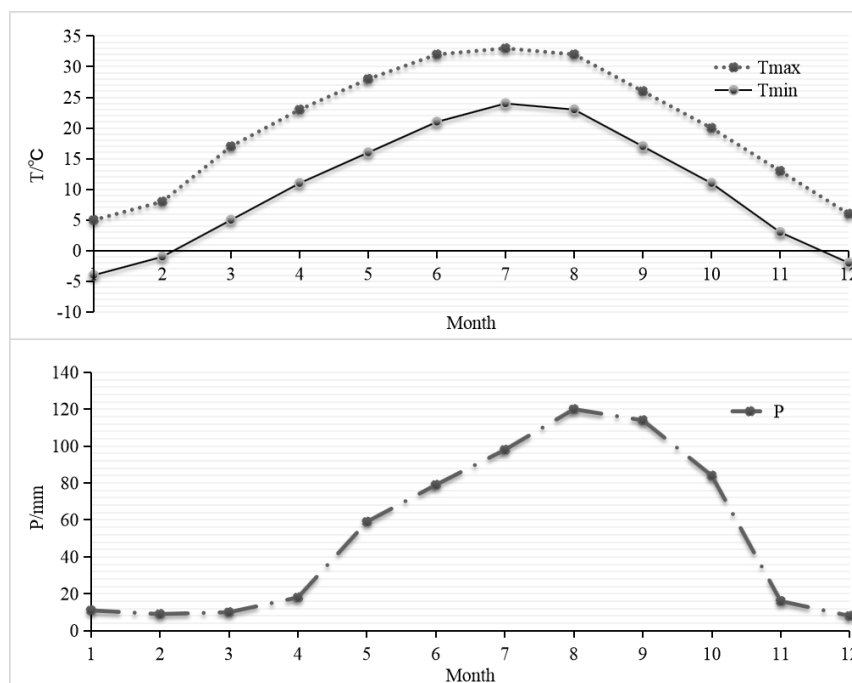


Figure 2. An average temperature and rainfall in the study area from January to December of the year 2016 (Tmax, Tmin and P are represent the an average maximum temperature, anaverage minimum temperature and precipitation of every month)

Sample collection

Soil samples were collected in May 2016. Sampling spots were distributed throughout Hancheng, Heyang, and Tongguan Yellow River floodplains and were collected from the Yellow River beach 0-30 cm surface soil layer. 300 samples were collected, 120 of which were collected from the Xiayukou in Hancheng section of the Yellow River. 80 samples were collected from Bailiang Town in Heyang. 100 samples were collected from Tongguan; the sampling point distribution is shown in *Figure 1*.

Each sample is a mixture of five points and consists of mixed samples. At each sampling spot, approximately 1 kg of soil was taken, stored in a sample bag, and returned to the laboratory to determine heavy metals in the soil.

Sample processing and determination

The soil samples (50 g) were air-dried, debris was removed, and samples were ground through a 0.149 mm nylon mesh (Hu et al., 2014; Xu et al., 2014). The soil total

Pb-Zn was determined according to GB/T 17141-1997, “Determination of Pb and Cd in Soil Quality: Graphite Furnace Atomic Absorption Spectrometry” (GB/T-22105.1-2008), “Determination of Cr: Flame atomic absorption spectrophotometry” (HJ 491-2009), “Determination of soil quality Ni: Flame atomic absorption spectrophotometry” (GB/T 17139-1997), “Determination of soil quality of Cu, Zn: Flame atomic absorption spectrophotometry” (GB/T 17138-1997), “Determination of total mercury in soil quality, total As, total Pb by atomic fluorescence spectrometry Part 1: Determination of total mercury in soil” (GB/T 22105.1-2008), and “Determination of total mercury, total As and total Pb in soil quality: atomic fluorescence spectrometry Part 2: Determination of total As in soil” (GB/T 22105.2-2008). The pH was determined potentiometrically and the heavy metal contents in soils were determined by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

Hakanson potential ecological risk index

This study used the Hakanson potential ecological risk index method (Hakanson, 1980) to evaluate the degree of heavy metal risk in the soils of Yellow River beaches. The equations are as follows:

$$C_f^i = \frac{C^i}{C_n^i} \quad (\text{Eq.1})$$

$$E_r^i = T_r^i \times C_f^i \quad (\text{Eq.2})$$

$$RI = \sum_{i=1}^m E_r^i \quad (\text{Eq.3})$$

where C_f^i represents the individual pollution coefficient, C^i represents the actual content of pollutant i in the soil sample, and C_n^i represents the reference value of pollutant i . E_r^i represents the single potential ecological risk index of pollutant i , in which T_r^i represents the toxicity coefficient of pollutant i , and RI represents the potential ecological risk index. E_r^i and RI can be used to evaluate the degree of the potential ecological risk of single pollutants and multiple pollutants, respectively. *Tables 1, 2, and 3* are the toxicity coefficients of pollutants, the potential ecological risk classification criteria according to Hankanson, and the grading standards, respectively.

Results

Descriptive statistics of the data

According to the national soil environmental quality standard (GB 15618-2018), the soil environmental quality was divided into three grades (Yuan et al., 2008) (*Table 4*). As an important section of the middle and lower reaches of the Yellow River, the Hancheng-Tongguan section forms an important demarcation line between Shaanxi Province and Shanxi Province. A wide range of agricultural cultivation areas are distributed throughout both sides of the Yellow River. The environmental quality of the

Yellow River soil is directly related to the broad masses. In addition, the Yellow River beach area also forms a very important wetland system in this region. Therefore, this study used the soil background value of Grade I standard of the national soil environmental quality standard to evaluate the soil of the Yellow River beach land. The main evaluation index includes As, Ni, Pb, Cd, Cr, Cu, and Zn.

Table 1. *Toxic coefficients of heavy metals and reference values*

Elements	As	Pb	Cd	Cr	Cu	Zn	Ni
Toxic coefficient	10	5	30	2	5	1	5
Reference value	9.7	21.9	0.1	66.6	26	65.2	30.2

Table 2. *Grading standards of Hakanson potential ecological risk*

Ecological damage	Slight	Medium	Strong
E_r^i	< 30	30~60	> 60
RI	< 135	135~265	> 265

Table 3. *Grading standards for evaluation factors of C_f^i*

Pollution degree	Slight	Medium	Strong	Very strong
C_f^i	< 1	1~3	3~6	> 6

Table 4. *National Soil Environmental Quality Standard (GB 15618-2018)*

Level	1 st	2 nd			3 rd
pH	Background	< 6.5	6.5~7.5	> 7.5	> 6.5
As	15	40	30	25	40
Ni	40	40	50	60	200
Pb	35	250	300	350	500
Cd	0.20	0.30	0.30	0.60	1.0
Cr	90	150	200	250	300
Cu	35	50	100	100	400
Zn	100	200	250	300	500
Hg	0.15	0.30	0.50	1.0	1.5

Descriptive statistical analysis of the heavy metals As, Hg, Pb, Cr, Cd, Cu, and Zn in soils from the Hancheng to Tongguan section of the Yellow River (Table 5) showed that the mean value of Zn was highest in the Yellow River beach soil, which was followed by Cr, and the average value of Cd was lowest. The average level of Cr was highest in Heyang and Tongguan, where the average Cd was lowest. Coefficients of variation of heavy metals of Hancheng exceeded 10%. Coefficients of variation for heavy metals such as Cr, Cu, Zn, and Ni were highest in Heyang and Tongguan. The sources of soil heavy metal pollution are very complex and other sources may add

pollution based on the siltation of the Yellow River beach soil. The status of heavy metal pollution in this soil is similar in that of the section of Heyang and Tongguan. As, Pb, Cd, and other heavy metals have a small variation coefficient, which may be mainly related to the formation and deposition of soils on the Yellow River beaches. Heavy metal elements such as Cr, Cu, Zn, and Ni may be affected by other sources of pollution. Among these, the coefficient of variation of Cu was highest in all reaches. The coefficient of variation of Cu was 40.1% in the lower reaches of Hancheng, the coefficient of variation of Cu in Heyang was 49.4%, and the coefficient of variation of Cu in Tongguan was 56.9%. Although the average content of Cu met the national standard, the Cu content of several samples reached the national standard. This shows that Cu in the Yellow River beach soil is particularly affected by external disturbances. The main origin may lie in the heavy use of pesticides and the emission of smelting gases around the Yellow River. The study area is located at the junction between Shaanxi, Shanxi, and Henan provinces, where the main modes of transportation include cars and trains, especially large trucks, according to the data on the official website of 12306 (the official website of China Railway), there are more than 40 trains through this area, which introduce a significant volume of tail gases and heavy metal pollution. The main pesticides used include *butacarb*, *bensultap*, *bismerthiazol*, *bromacil*, and *2,4,5-TB*. Farmers use these pesticides about two to three times every year to reduce pests and weeds. Furthermore, this area features a large number of coal and gold mines, which also introduce severe heavy metal pollution, such as Pb, Cd, and Hg.

Table 5. Descriptive statistics of soil heavy metal contents in the Yellow River region between Hancheng to Tongguan

Sites	Sample types	As	Pb	Cd	Cr	Cu	Zn	Ni
Hancheng	Maximum	9.8	23.3	0.5	79.3	76.2	307.8	52.6
	Minimum	3.4	7.0	0.2	36.4	19.4	205.5	21.3
	Average value	5.8	12.4	0.3	55.8	43.7	265.8	41.2
	Standard deviation	1.8	4.0	0.1	12.5	17.5	31.0	9.2
	Coefficient of variation	31.8	32.2	30.6	22.4	40.1	11.7	22.3
Heyang	Maximum	12.8	27.6	0.2	89.7	45.7	62.9	40.1
	Minimum	7.9	19.9	0.1	33.6	11.2	32.7	17.3
	Average value	11.1	23.5	0.1	57.7	21.9	50.4	25.7
	Standard deviation	1.4	2.5	0.0	16.9	10.8	9.3	6.0
	Coefficient of variation	12.5	10.6	11.5	29.4	49.4	18.5	23.5
Tongguan	Maximum	12.3	27.6	0.132	120	54.3	95.4	40.1
	Minimum	8.6	19.9	0.11	23.9	10.1	42	22.5
	Average value	10.8	23.0	0.1	62.5	23.0	59.6	30.3
	Standard deviation	1.0	2.5	0.0	23.4	13.1	15.6	4.1
	Coefficient of variation	9.2	10.7	5.0	37.4	56.9	26.2	13.6
Overall characteristics	Maximum	12.8	27.6	0.5	120.0	76.2	307.8	52.6
	Minimum	3.4	7.0	0.1	23.9	10.1	32.7	17.3
	Average value	9.0	18.8	0.2	58.4	30.3	137.3	33.2
	Standard deviation	3.0	6.3	0.1	17.6	17.7	106.4	9.8
	Coefficient of variation	33.7	33.3	45.3	30.2	58.5	77.5	29.6

Table 5 and Figure 3 show that the As content in the soils of the Yellow River Hancheng to Tongguan section ranged within 3.4-12.8 mg·kg⁻¹, with an average content of 9.0 mg·kg⁻¹. The As content in the soil of the floodplain in various regions follows a distribution of Heyang > Tongguan > Hancheng. The As content of the river beaches of Heyang was highest, with an average of 11.1 mg·kg⁻¹, and lowest in Hancheng. As content in the soil of the floodplain of Tongguan is more than Hancheng significantly ($p < 0.05$). The soil As content in the estuary was 5.8 mg·kg⁻¹. These results showed that the average As content in the floodplain of the Yellow River Hancheng to Tongguan section remained below the national soil environmental quality standard.

The Pb level in the soil of the Yellow River Hancheng to Tongguan section was 7.0-27.6 mg·kg⁻¹, at an average content of 18.8 mg·kg⁻¹. The average Pb content in the soil of the Yellow River beach in Hancheng was significantly lower compared with the whole area ($p < 0.05$). Here, the average content was 12.4 mg·kg⁻¹, and the average Pb content of the soil in the Yellow River beaches of Heyang County and Tongguan County were 23.5 mg·kg⁻¹ and 23 mg·kg⁻¹, respectively. However, the value was lower than that of the first-level standard for soil environmental quality. These levels remain below the national first-level standard for soil environmental quality.

The Cd content in the soil of the Yellow River Hancheng to Tongguan section was 0.1-0.5 mg·kg⁻¹, with an average of 0.2 mg·kg⁻¹. The Cd content in the floodplains of each region can be ordered according to: Hancheng > Heyang and Tongguan. Cd content in the soil of the floodplain of Hancheng is more than Heyang and Tongguan significantly ($p < 0.05$). The average Cd content in the Yellow River beach in Hancheng was 0.3 mg·kg⁻¹, which basically met the national secondary standard for soil environmental quality.

The Cr content in the soil of the Yellow River Hancheng to Tongguan section was 23.9-120.0 mg·kg⁻¹, with an average of 58.4 mg·kg⁻¹. The average content of Cr in the Yellow River beach of Hancheng was lowest at 55.8 mg·kg⁻¹ and the Cr content in the Yellow River beach of Tongguan County was highest, with an average value of 62.5 mg·kg⁻¹. Both levels remain far below the national first-level standard for soil environmental quality.

The Cu content in the soil of the Yellow River Hancheng to Tongguan section was 10.1-76.2 mg·kg⁻¹, with an average of 30.3 mg·kg⁻¹. The Cu content in the soil of Hancheng was about twice as high as that of Heyang and Tongguan ($p < 0.05$), with an average value of 43.7 mg·kg⁻¹. This exceeds the national first-level standard for soil environmental quality.

The Zn content in the soil of the Yellow River Hancheng to Tongguan section was 32.7-307.8 mg·kg⁻¹, with an average of 137.3 mg·kg⁻¹. The Zn content in the soil of the Yellow River beach in Hancheng was highest, reaching 265.8 mg·kg⁻¹, which slightly exceeded the national secondary standards for soil environmental quality.

The Ni content in the soil of the Yellow River Hancheng to Tongguan section was 17.3-52.6 mg·kg⁻¹, with an average content of 33.2 mg·kg⁻¹. The Ni content in the soil of each region followed: Hancheng > Tongguan > Heyang. Ni content in the soil of the floodplain of Hancheng is more than Tongguan significantly ($p < 0.05$), while Ni content of Tongguan and Heyang is not significantly ($p > 0.05$). The average Ni content in the soil of the Yellow River beach in Hancheng was 41.2 mg·kg⁻¹, which exceeds the national first-level standard for soil environmental quality.

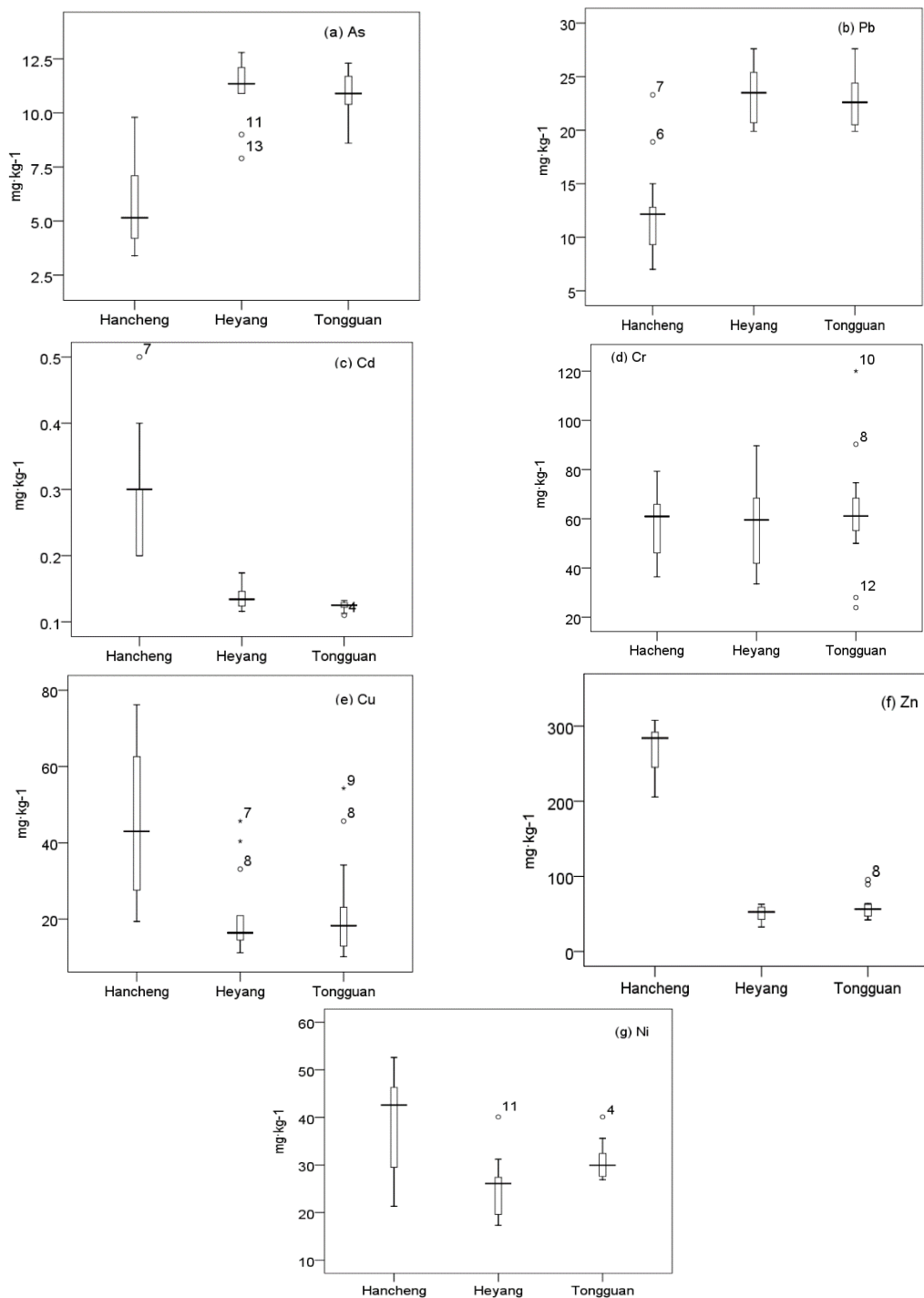


Figure 3. Boxplots of heavy metals concentration in the Yellow River region between Hancheng to Tongguan

Discussion

Correlation analysis of soil heavy metals

Correlation analysis of the soil heavy metal contents in the floodplain from Hancheng to Tongguan section of the Yellow River identified Pb, Cd, Cr, and Cu in

soils of the Yellow River beach at the Lower Xiayukou section of Hancheng (Table 6). A significant positive correlation was found between heavy metals ($p < 0.01$), indicating that these heavy metals have similar sources, which may mainly originate from the region's automobile exhaust and large-scale pesticide use. The correlation between Cr, Cd, Pb-Ni, Zn-Cr, Zn-Cu, and other heavy metals was significant ($p < 0.01$) in the Yellow River beach of Tongguan. This is likely due to the large-scale gold development in Tongguan.

Table 6. Correlation coefficient for heavy metals in the Yellow River region between Hancheng to Tongguan

Sites	Elements	As	Pb	Cd	Cr	Cu	Zn	Ni
Hancheng	As	1	.599**	.691**	.592**	.654**	0.311	0.214
	Pb		1	.660**	.777**	0.352	0.218	-0.075
	Cd			1	0.347	.573*	0.36	0.217
	Cr				1	.499*	0.139	-0.026
	Cu					1	0.373	-0.128
	Zn						1	-0.084
	Ni							1
Heyang	As	1	-0.259	0.253	0.287	0.177	-0.003	-0.361
	Pb		1	-0.126	-0.145	0.034	-0.055	0.013
	Cd			1	-0.377	0.007	-0.243	0.223
	Cr				1	0.151	.643*	-0.206
	Cu					1	0.116	-0.254
	Zn						1	-0.088
	Ni							1
Tongguan	As	1	-0.499	0.067	0.216	0.1	-0.022	0.181
	Pb		1	-0.083	0.371	0.184	0.493	-.643**
	Cd			1	-.589*	-0.269	-0.401	-0.221
	Cr				1	0.494	.755**	-0.24
	Cu					1	.756**	0.031
	Zn						1	-0.142
	Ni							1

Soil ecological risk assessment of heavy metals

The results of Equations 1–3 were calculated for each heavy metal, and the values are listed in Table 7. With regard to the average single pollution coefficient of heavy metals, the soil of Hancheng had strong Zn pollution. Cd, Cu, and Ni caused moderate pollution, and other elements caused slight pollution. The pollution degree of the heavy metals followed $Zn > Cd > Cu > Ni > Cr > As > Pb$. As shown in Table 8, the percentage of samples with strong Zn pollution in soil reached 100%, the percentage of samples with strongly contaminated soil Cd was 11.11%, and 88.89% of samples were moderately contaminated. With regard to the single potential ecological risk index of heavy metals, the potential ecological risk of Cd in the soil of Hancheng in the Yellow River reached a strong level (=80), while the ecological potential risks of other heavy metal elements were slight. The contribution of Cd to the potential ecological risk of heavy metals reached as high as 50%, which therefore is the heavy metal with the most

important ecological risk. This is consistent with the study of Yuan et al. (2008), Ye et al. (2010) and Davidson et al. (1994). The order of the ecological hazards of heavy metals followed $Cd > Cu > Ni > As > Zn > Pb > Cr$.

Table 7. Assessment of potential ecological risks of soil heavy metals in the Yellow River region between Hancheng to Tongguan

Sites	Statistics items	C_f^i							E_r^i							RI
		As	Pb	Cd	Cr	Cu	Zn	Ni	As	Pb	Cd	Cr	Cu	Zn	Ni	
Hancheng	Max	1.01	1.06	5.00	1.19	2.93	4.72	1.74	10.10	5.32	150.00	2.38	14.65	4.72	8.71	195.89
	Min	0.35	0.32	2.00	0.55	0.75	3.15	0.71	3.51	1.60	60.00	1.09	3.73	3.15	3.53	76.61
	Ave	0.58	0.55	2.67	0.84	1.66	4.09	1.38	5.84	2.75	80.00	1.67	8.31	4.09	6.89	109.56
Heyang	Max	1.32	1.26	1.74	1.35	1.76	0.96	1.33	13.20	6.30	52.20	2.69	8.79	0.96	6.64	90.78
	Min	0.81	0.91	1.16	0.50	0.43	0.50	0.57	8.14	4.54	34.80	1.01	2.15	0.50	2.86	54.02
	Ave	1.16	1.07	1.37	0.86	0.81	0.78	0.84	11.52	5.34	41.08	1.72	4.03	0.78	4.19	68.66
Tongguan	Max	1.27	1.26	1.32	1.80	2.09	1.46	1.33	12.68	6.30	39.60	3.60	10.44	1.46	6.64	80.73
	Min	0.89	0.91	1.10	0.36	0.39	0.64	0.75	8.87	4.54	33.00	0.72	1.94	0.64	3.73	53.44
	Ave	1.12	1.05	1.24	0.92	0.84	0.90	1.00	11.20	5.24	37.22	1.84	4.18	0.90	5.00	65.58
Overall characteristics	Max	1.32	1.26	5.00	1.80	2.93	4.72	1.74	13.20	6.30	150.00	3.60	14.65	4.72	8.71	201.18
	Min	0.35	0.32	1.10	0.36	0.39	0.50	0.57	3.51	1.60	33.00	0.72	1.94	0.50	2.86	44.13
	Ave	0.93	0.86	1.83	0.87	1.14	2.08	1.10	9.27	4.32	54.75	1.74	5.72	2.08	5.48	83.36

Table 7 shows the average individual pollution coefficients of heavy metals. Cd, As, and Pb in Heyang cause moderate pollution, and soil was slightly polluted with other heavy metals. Their degree of pollution followed $Cd > As > Pb > Cr > Ni > Cu > Zn$. As shown in Table 8, 100% of Cd reached a moderate level of pollution, and the percentages of samples with moderate pollution of As and Pb were 85.71% and 64.29%, respectively. With regard to the average single potential ecological risk index of heavy metals in soils (Tables 7 and 8), all heavy metals in the soils of riverside beaches in Heyang, except for medium pollution (=41.08), reached a contribution rate of Cd to soil potential ecological risk in the floodplain of Heyang of 100%.

With regard to the average individual pollution coefficient of heavy metals, the contents of Cd, As, Pb, Ni, and other elements in the soil of Yellow River beach in Tongguan caused moderate pollution. The contents of heavy metals in other soils caused slight pollution. The levels follow $Cd, As, Pb > Cr > Ni > Cr > Zn > Cu$. This is similar to the heavy metal pollution in the soil of the Yellow River beach in Heyang. The average single potential ecological risk index of heavy metals in Tonglian and Heyang followed a similar trend. Except for the moderate pollution (37.22), all other heavy metal elements caused slight pollution. Among these, the contribution of Cd to soil potential ecological risk of the Yellow River beach in Tongguan was 100%, which agreed with the results of Heyang.

In general, Cd was identified as the main pollutant in the Yellow River beaches of the Hancheng-Tongguan section of the Yellow River. The contribution rate of Cd to soil potential ecological risk was 82.98%, while that to the soil potential strong ecological risk was 17.02%. This study showed that the overall potential ecological risk index of soils in Hancheng-Tongguan section of Yellow River was $83.36 < 135$; therefore, the

potential risk of soils in the Yellow River beach is slight. The comprehensive potential risks of soil in different reaches of the river follow: Hancheng > Heyang > Tongguan. The comprehensive potential ecological risk index of soils in Hancheng was $109.5 < 135$, indicating slight risks.

Table 8. Percentage of the samples in different C_f^i and E_r^i grades for different metals in the Yellow River region between Hancheng to Tongguan/%

Sites	Elements	C_f^i				E_r^i		
		Slight pollution	Moderately polluted	Strongly contaminated	Strong pollution	Slight risk	Medium risk	Strong risk
Hancheng	As	94.44	5.56	11.11		100	50	50
	Pb	94.44	5.56			100		
	Cd		88.89					
	Cr	88.89	11.11	100		100		
	Cu	22.22	77.78			100		
	Zn					100		
	Ni	22.22	77.78			100		
Heyang	As	14.29	85.71			100	100	
	Pb	35.71	64.29			100		
	Cd		100					
	Cr	71.43	28.57			100		
	Cu	78.57	21.43			100		
	Zn	100				100		
	Ni	14.29	85.71			100		
Tongguan	As	6.67	93.33			100	100	
	Pb	46.67	53.33			100		
	Cd		100					
	Cr	73.33	26.67			100		
	Cu	80.00	20.00			100		
	Zn	86.67	13.33			100		
	Ni	60.00	40.00			100		
Overall characteristics	As	42.55	57.45	4.26		100	82.98	17.02
	Pb	89.36	10.64			100		
	Cd		95.74					
	Cr	95.74	4.26	89.36		100		
	Cu	17.02	82.98			100		
	Zn	10.64				100		
	Ni	17.02	82.98			100		

Conclusions

(1) The contents of As, Ni, Pb, Cd, Cr, Cu, Zn in the soil samples of the Hancheng to Tongguan section of the Yellow River were assessed. The average Zn content was highest, arrived $137.3 \text{ mg} \cdot \text{kg}^{-1}$. The average As and Cd contents were smallest, and with the exception of Ni, the coefficients of variation of all other tested heavy metals were large, indicating a notable difference between these heavy metals.

(2) A significant positive correlation ($p < 0.01$) was found between heavy metals such as Pb, Cd, Cr, and Cu in the Yellow River floodplain of Hancheng ($p < 0.01$). This

indicates that these heavy metals have similar origins and are most likely the result of car exhaust emissions and large-scale pesticide use. The correlation between Cr, Cd, Pb-Ni, Zn-Cr, Zn-Cu, and other heavy metals was significant ($p < 0.01$) in the Yellow River beach of Tongguan, which is likely due to the large-scale gold development in Tongguan.

(3) According to the Hakanson potential ecological risk index, the overall potential ecological risk index of soil in the Yellow River from Hancheng to Tongguan section is $83.36 < 135$; therefore, the potential risk of soils in the Yellow River beach is slight. The results follow: Hancheng > Heyang > Tongguan. The comprehensive potential ecological risk index of the soil of the Yellow River beach in Hancheng is $109.5 < 135$, which also indicates slight risk.

(4) The impact of human activities on heavy metal pollution in the Yellow River beaches is relatively minor; however, to avoid intensification of the potential ecological hazards in the soil, attention should be directed to the treatment of heavy metal pollution in the Yellow River beach at their source.

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