RESEARCH ARTICLE

Assessment of heavy metal contamination in the sediments from the Yellow River Wetland National Nature Reserve (the Sanmenxia section), China

Qingli Cheng · Ruiling Wang · Wenhai Huang · Wenlin Wang · Xudong Li

Abstract The Yellow River Wetland National Nature Reserve (the Sanmenxia section) is an important area of the Yellow River for two important hydrologic gauging stations: the Sanmenxia reservoir and the Xiaolangdi reservoir. Seven sites along the section were selected: Jiziling, Dinghuwan, Houdi, Canglonghu, Shangcun, Wangguan, and Nancun. After the microwave digestion with aqua regia, concentrations of Cu, Pb, Cd, Cr, Zn, and Mn in the sediments were analyzed by flame atomic absorption spectrometry with air-acetylene flame. The results showed that all the concentrations of Cr detected were from the lithogenic source, and 63 % Mn, 48 % Pb, 41 % Cu, 20 % Cd, and 12 % Zn were from the anthropogenic source. The values of the index of geo-accumulation pointed out that there was moderate contamination of Mn at the Dinghuwan (1.04) and Houdi (1.00) sites (class 2), while the modified degree of contamination denoted that the contamination at the Houdi site (2.02) was moderate, nil to very low at the Nancun and Shangcun sites and low at the other sites, consisting with the tendency of pollution load index. For metal toxicity, the sediment pollution index

indicated that the sediments of the Canglonghu site were low polluted, that of the Houdi site is nearly slightly contaminated, and those of others were natural and uncontaminated. It was vital to evaluate the degree of contamination with individual and overall elements and even with the metal toxicity. Cu, Pb, and Mn contaminations were aggravated in the Sanmenxia section, and there maybe was one of the main anthropogenic sources of these metals along the Yellow River. The findings were expected to update the current status of the heavy metal pollution in the Sanmenxia section as well as to create awareness concerning the sound condition of the whole reaches of the Yellow River.

Keywords The Sanmenxia section · Heavy metal · Assessment · Sediment · The Yellow River · The wetland

Abbreviation

JZL	Jiziling
DHW	Dinghuwan
HD	Houdi
CLH	Canglonghu
SC	Shangcun
WG	Wangguan
NC	Nancun
I_{geo}	The index of geo-accumulation
mC_d	Modified degree of contamination
PLI	Pollution load index
SPI	Sediment pollution index
Cf_i	Contamination factor

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Introduction

In aquatic environment, heavy metals tend to be incorporated into the bottom sediments. Sediment has also been recognized

as one of the important indicators of metal contamination for ecosystem quality assessment (Giusti 2001; Birch and Taylor 2002; Rate et al. 2000) and has drawn wide attention in recent years (Liu et al. 2009; Chen et al. 2009, 2000; He et al. 2009; Zhao et al. 2008). Those metals can be released by various processes under favorable conditions, and aquatic organisms might be exposed to a high level of heavy metals, which may cause potential health risks to the local inhabitants through food webs (Ghregat et al. 2011; Cui et al. 2011).

The Yellow River is the second longest river in China, with a length of 3395 miles (5464 km), and flows through seven provinces and two autonomous regions, empting into the Bohai Sea near the Dongying City in Shandong Province. It is famous for sediment laden, carrying a large number of sand from the Loess Plateau. The sediment carries many elements, such as metals, from the cities and industrial and mining enterprises in the basin. Heavy metal contamination in sediment is influenced by many factors, such as wastewater discharge (Feng et al. 2010; Wang et al. 2010), petroleum-hydrocarbon spillage (Nie et al. 2010), fossil fuel combustion (Cheng et al. 2012), flow-sediment regulation (Bai et al. 2012), etc.

At the Lanzhou section situated on the upper reach of the Yellow River, spatial distributions of Cu, Pb, Zn, and Cd in the sediments show that heavy metal concentrations remain almost constant at this region (Liu et al. 2009) and the levels of these metals are proposed to influence the abundance and structure of nematode communities (Chen et al. 2009). In the middle stretch of the river, e.g., Inner Mongolia, heavy metals in the bed mud are evaluated to be in the non-to-mid-pollution condition and the ecological risk of Cd, Cu, Pb, and Cr is moderate in this area (Zhao et al. 2008). At the beginning of the lower reach, the Yellow River Wetland Nature Reserve of Zhengzhou, the contamination of Cr and Pb is more serious than that of Cu, Cd, and Mn, and Pb pollution is moderate at some sampling sites (Cheng et al. 2012). Cui et al. (2011) also report that the concentrations of Zn, Pb, Cd, Cr, and Cu are detected in sediments of the Yellow River delta.

The Yellow River Wetland National Nature Reserve in Henan Province includes the Yellow River reservoir area of Sanmenxia (the Sanmenxia section), Xiaolangdi Dam, and the region from the Xiaolangdi Dam Reservoir to the junction of Mengjin County and Gongyi County. The Sanmenxia section is an important area as wintering and stopover sites for many geese and ducks, such as whooper swan (Cygnus cygnus), and also as breeding habitats for a large number of species. In this reserve, there are two important hydrologic gauging stations: the Sanmenxia reservoir and the Xiaolangdi reservoir. The Xiaolangdi reservoir is just following the Sanmenxia section. These two reservoirs are effective in protecting the Lower Yellow River and offer an excellent example of the consequences of reservoir sedimentation, sediment management strategies, and potential solutions to critical sedimentation problems (Jiang et al. 2004; Wang et al. 2005; Zhou and Zhang 2012). Over the past 58 years, from 1950 to 2007, the sediment trapping by the Sanmenxia and Xiaolangdi reservoirs accounts for 30 % of the total amount of reduction in the upper, middle, and lower reaches of the Yellow River basin (Peng et al. 2010; Wang et al. 2007). The praxis of sustainable water dispatching has also resulted in significant economic and social benefits (He et al. 2013). It is important to protect and maintain the ecological security of the Sanmenxia section. However, the wastewaters discharged by various plants (gold, bauxite, pyrite mining companies, etc.) and sewage inputs from the cities along the river bank may have caused the contamination of metals in the section. It is vital to investigate the origin and the spatial distribution of the metals in the river sediments along the section and then to clarify the pollution degree and quantify potential ecological risk of these contaminations.

Materials and methods

Study sites

The study region is located between 110° 24′–111° 48′ E longitude and 34° 34′–35° 2′ N latitude. It belongs to warm temperate continental monsoon climate, the average annual temperature is 14.1 °C (57.38 °F), and the mean annual rainfall is 614 mm. The study region lies close to the Loess Plateau, and the soil type is loosely silt, thin-grained sand, and clay, overlying the Quaternary sediments. The section is dominated with different flora in wild land, e.g., *Populus simonii*, *Salix matsudana*, *Tamarix chinensis*, *Phragmites communis*, *Typha orientalis*, and *Xanthium sibiricum*, and some places are cultivated mainly for *Glycine max*, etc. Seven sites were selected: Jiziling (JZL), Dinghuwan (DHW), Houdi (HD), Canglonghu (CLH), Shangcun (SC), Wangguan (WG), and Nancun (NC) (Fig. 1). JZL is the westernmost site of the study region and also the beginning of the Sanmenxia section; DHW and HD are the entry and exit sites of the Sanmenxia reservoir; CLH and SC are the upper and lower sites of the Sanmenxia City; WG and NC are just up the Sanmenxia Dam and Xiaolangdi reservoir, respectively.

Sampling, preparation, and analysis

The sediment samples were collected with stainless steel containers and wrapped in the polyethylene plastic bags during May–July in 2011. All of the samples were extracted at top horizon (5–20 cm deep from the surface). Replicates were taken at each site to reduce the probability of random performance. After being air-dried at room temperature, removed off

Fig. 1 Map showing the research area and the geographical location of the sampling sites. **a** A zoomed view of the Yellow River. **b** Detailed sample sites
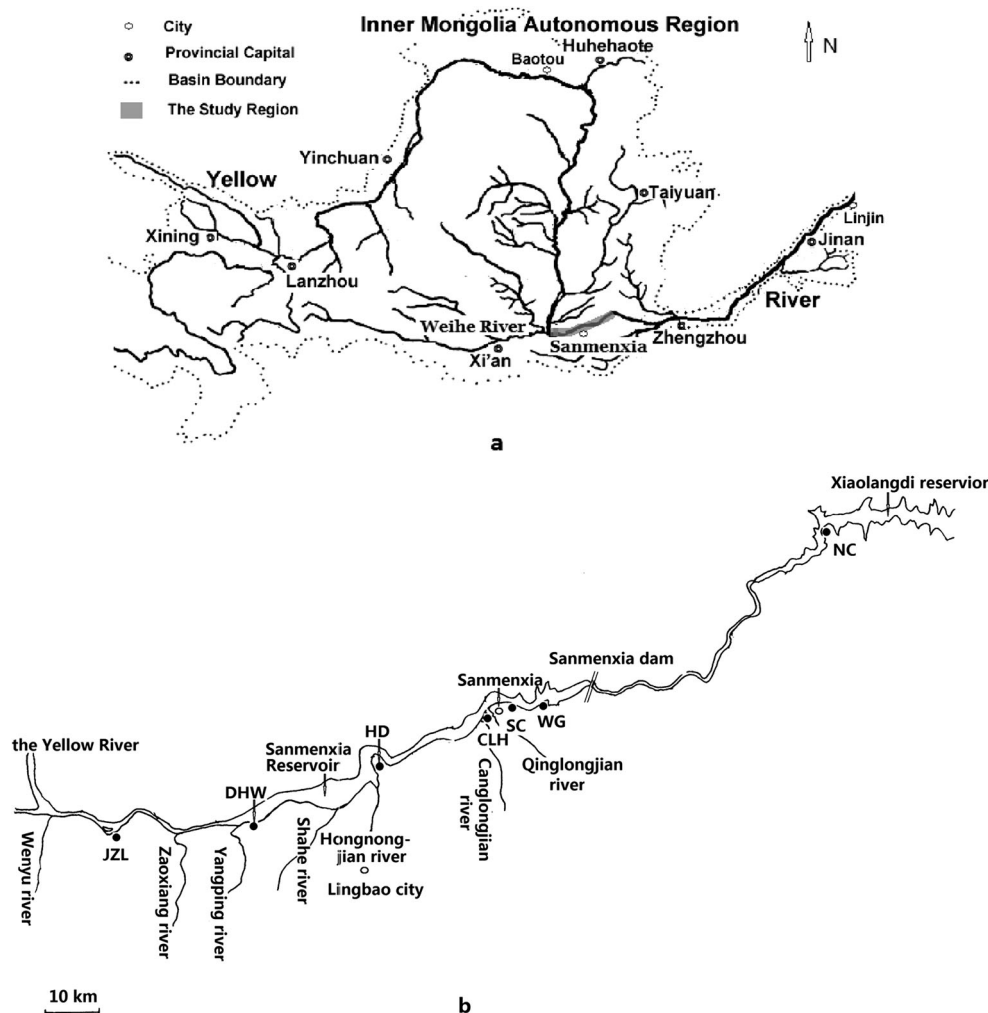
the coarse debris, ground using a mortar and pestle, and passed through a 100-mesh nylon sieve, 0.5 g of each sample was digested in capped Teflon tubes with 5 ml aqua regia (HNO$_3$:HCl=1:3), followed by the addition of a small amount of nitric acid or hydrogen peroxide until the supernatant became clear. Digested solution was diluted with 1 % HNO$_3$ (v/v) to 50 ml for the following analysis. Heavy metal concentrations of Cu, Pb, Cd, Cr, Zn, and Mn were analyzed by flame atomic absorption spectrometry with air-acetylene flame. All glassware used was previously soaked in 15 % HNO$_3$ (v/v) and rinsed with deionized water. All samples were treated in triplicate. Concentrations of metals shown below were given relative to dry mass (DM) and were the average values of the triplicates.

Evaluation of contamination degree of heavy metals

The index of geo-accumulation (I_{geo}) and the modified degree of contamination (mC$_d$) are simple measures to quantify metal accumulation in contaminated sediments in terrestrial, aquatic, and marine environments and have been widely applied for evaluating individual metal pollution and overall enrichment impact of groups in sediments. Pollution load index (PLI) also provides a simple and comparative mean for assessing the level of heavy metal pollution of the entire sampling area. The empirical index has been determined as the nth root of the product of the nth contamination factor (Cf) (Varol 2011). Sediment pollution index (SPI) is defined as a linear sum of the metal enrichment factors along with the account of metal toxicity weights and is also adopted to assess the sediment quality (Singh et al. 2002).

I_{geo} (Müller 1969), mC$_d$ (Hakanson 1980), PLI (Varol 2011), and developed SPI (Singh et al. 2002; Lin et al. 2008) in this study were expressed as follows:

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n}$$

where C_n is the measured concentration of the heavy metal in the sediment, constant 1.5 is the background matrix correction factor due to lithogenic effects (Abrahim and Parker 2008; Çevik et al. 2009; Qian et al. 2005), B_n is the geochemical local background levels (LBLs) of Henan

Table 1 Mean, standard deviation, and minimum and maximum value of heavy metal concentrations in sediments at seven sampling sties from the Sanmenxia section (mg kg^{-1} dry weight)

Sampling site	Cu	Cr	Cd	Pb	Mn	Zn
JZL	34.8	61.5	0.13	45.4	1536.0	73.4
DHW	42.7	64.4	0.05	40.5	1787.8	59.9
HD	51.3	59.3	0.15	44.0	1740.7	80.5
CLH	34.3	53.8	0.15	56.0	1535.2	75.2
SC	20.5	34.5	0.12	27.8	1179.6	62.8
WG	35.5	42.3	0.10	36.6	1686.8	85.1
NC	30.6	37.8	0.07	27.2	1525.9	52.2
Mean	39.3	53.6	0.11	41.1	1633.5	72.4
SD	13.4	17.2	0.05	17.1	201.7	15.1
Min	20.5	9.2	0.03	15.4	1179.6	39.5
Max	71.7	82.6	0.22	77.4	1935.6	98.0
Median	37.1	56.6	0.11	40.5	1624.0	73.5
LBL[a]	19.7	63.8	0.07	19.6	579	–

– not listed in the LBL

[a] In Henan Province (EMC 1990)

Province (EMC 1990) (Table 1), and n is the number of analyzed elements.

$$Cf_i = \frac{C_n}{B_n}$$

where Cf_i is the contamination factor and i is the number of pollutants.

$$mC_d = \frac{\sum_{i=1}^{i=n} Cf_i}{n}$$

$$PLI = (Cf_1 \cdot Cf_2 \cdot Cf_3 \cdot \dots Cf_n)^{1/n}$$

$$SPI = \frac{\sum (Cf_i \times W_i)}{\sum W_i}$$

where W_i is the toxicity weight of metal i. Toxicity weight 1 was assigned for Cr, Zn, and Mn; 2 was assigned for Cu, 5 for Pb, and 300 for Cd (Singh et al. 2002).

The contamination levels may be classified descriptively for increasing I_{geo} (Forstner et al. 1993) and mC_d (Abrahim and Parker 2008) values, and the sediment classification is given for the SPI values (Singh et al. 2002) listed in Table 2. When PLI index is more than 1, it means that metal pollution exists; otherwise, there is no pollution (Varol 2011).

Results and discussion

Metal concentration and their relationships

Analysis results of heavy metals in the sediments from JZL, DHW, HD, CLH, SC, WG, and NC are presented in Table 1. These heavy metals in the sediments displayed a wide range of concentrations (in mg kg^{-1}). Cu shows concentration of 39.3 ± 13.4 mg kg^{-1}, Cr of 53.6 ± 17.2, Cd of 0.11 ± 0.05, Pb of 41.1 ± 17.1, Mn of 1633.5 ± 201.7, and Zn of 72.4 ± 15.1. The peak data are related with Mn at the DHW (1787.8 mg kg^{-1}) and HD (1740.7 mg kg^{-1}) sites, which are over triple of the corresponding LBL values (579 mg kg^{-1}). After that are the values of Pb (56.0 mg kg^{-1}) at the CLH site and Mn (1683.6 mg kg^{-1}) at the WG site, which are nearly three times of the LBL standards accordingly. Following are the data of Cu at the HD site (51.3 mg kg^{-1}) and Mn at the JZL site (1536.0 mg kg^{-1}), NC site (1525.9 mg kg^{-1}), and CLH site (1535.2 mg kg^{-1}), more than 2.5 times of the LBL standards. Only the mean values of Cu at the SC site (20.5 mg kg^{-1}), Cd at the DHW site (0.05 mg kg^{-1}) and NC site (0.07 mg kg^{-1}), Zn at the NC site (52.2 mg kg^{-1}) and DHW site (62.8 mg kg^{-1}), and all the concentrations of Cr detected at seven sampling sites are approximately equal to the LBLs.

Table 2 The contamination condition of sediment classified descriptively for I_{geo}, mC_d, and SPI

Class	Contamination levels	I_{geo}[a]	Pollution degrees	mC_d[b]	Sediment condition	SPI[c]
0	Uncontaminated	≤0	Nil to very low	<1.5	Natural	<2
1	Uncontaminated to moderately	<1	Low	<2	Lowly polluted	<5
2	Moderately contaminated	<2	Moderate	<4	Moderately polluted	<10
3	Moderately to strongly	<3	High	<8	Highly polluted	<20
4	Strongly contaminated	<4	Very high	<16	Dangerous	>20
5	Strongly to extremely	<5	Extremely high	<32		
6	Extremely contaminated	>5	Ultra high	>32		

[a] Forstner et al. (1993)

[b] Abrahim and Parker (2008)

[c] Singh et al. (2002)

To investigate and determine possible sources of heavy metals in the sediments, statistical analysis of Spearman correlation with two-tailed test was performed using the software package SPSS 19.0. Table 3 shows that the relationships between Cu and Cr ($r=0.654$), between Cu and Mn ($r=0.762$), between Cr and Pb ($r=0.605$), and between Cd and Zn ($r=0.596$) are significant ($P<0.01$), and the clear-cut correlation ($P<0.05$) also exists between Cu and Pb ($r=0.520$) and between Mn and Zn ($r=0.448$). This kind of significant relationship suggests that these elements in sediments have common sources, or mutual dependence and/or similar behavior during transport, or is subject to certain factors control (Cheng et al. 2012).

Sediment quality assessment

In aquatic ecosystem, various assessment approaches of the sediment quality can be proposed. It is a daunting task to select the most appropriate approach to assess the sediment quality of the Sanmenxia section, because there are no sediment quality guidelines that have been developed for the Yellow River, a worldly famous sediment-laden river. In the present study, several assessment approaches were adopted including I_{geo}, mC_d, PLI, and SPI.

Table 4 is listed for the details of the I_{geo} values for the individual element at different sites in the section. For the background variability factor (1.5) in the I_{geo} equation, some I_{geo} values in the table are negative with the relatively low levels of contamination for some metals in some sites. There is no or only very light pollution (class 0 or 1) for Cu, Cr, Pb, Mn, Zn, and Cd in the study region with the exception of moderate pollution of Mn at the DHW (1.04) and HD (1.00) sites (class 2). Furthermore, the I_{geo} values of Pb at the CLH site and Mn at the WG site are more than 0.9, which point out that these metal contaminations at these two sites should be of concern.

For evaluating the overall pollution degree of the different sampling sites, mC_d data are shown in Table 5. The results from the table indicates that the degrees of contamination are

Table 4 Index of geo-accumulation (I_{geo}) and contamination level for mean metal concentrations in the sediments from the Sanmenxia section

Sampling site	Cu	Cr	Cd	Pb	Mn	Zn
JZL	0.23	−0.64	0.19	0.63	0.82	−0.30
DHW	0.53	−0.57	−1.25	0.46	1.04	−0.59
HD	0.80	−0.69	0.40	0.58	1.00	−0.16
CLH	0.21	−0.83	0.43	0.93	0.82	−0.26
SC	−0.53	−1.47	0.11	−0.08	0.44	−0.52
WG	0.27	−1.18	−0.20	0.31	0.96	−0.08
NC	0.05	−1.34	−0.67	−0.11	0.81	−0.79

nil to very low at the SC (1.28) and NC (1.33) sites; low at the JZL (1.77), DHW (1.66), WG (1.66), and CLH (1.89) sites; and moderate at the HD (2.02) site. The mC_d data suggest a light anthropogenic impact at the JZL, DHW, WG, CLH, and HD sites. The main factors affecting the mC_d value of the HD site are the Cf_i values of Mn (3.01), Pb (2.25), and Cu (2.61). The decreasing tendency of PLI values for the sediments is from 1.87 (the HD site), 1.74 (the CLH site), 1.67 (the JZL site), 1.51 (the WG site), and 1.44 (the DHW site) to 1.18 (both the NC and SC sites), similar with the variation of mC_d. Both the values of mC_d and PLI suggest an anthropogenic impact on the metal levels in the sediments (Hakanson 1980; Varol 2011; Abrahim and Parker 2008). This result could be used as a reference in establishing appropriate conservation planning of the Sanmenxia section.

Though I_{geo}, mC_d, and PLI can evaluate the contamination degree with individual element and overall average, all of them do not consider relative metal toxicity. SPI is adopted to fill this gap. Table 6 indicates that only the SPI of the CLH site (2.03) is classified into class 1 and the sediments there are lowly polluted and that of the HD site is 1.98 and the sediments there are nearly slightly contaminated, while others are less than 2 and the sediments are natural and uncontaminated.

Table 3 Spearman correlation coefficient with two-tailed test between different heavy metals in the sediments from the Sanmenxia section

	Cu	Cr	Cd	Pb	Mn
Cr	0.654[a]				
Cd	0.404	0.197			
Pb	0.520[b]	0.605[a]	0.278		
Mn	0.762[a]	0.313	0.170	0.218	
Zn	0.314	0.063	0.596[a]	0.226	0.448[b]

[a] Significant probabilities at 0.99 level

[b] Significant probabilities at 0.95 level

Table 5 Contamination factors (Cf), modified degree of contamination (mC_d), and pollution load index (PLI) for mean metal concentrations in the sediments from the Sanmenxia section

Sampling site	Cu	Cr	Cd	Pb	Mn	Zn	$\sum Cf$	mC_d	PLI
JZL	1.76	0.96	1.71	2.32	2.65	1.22	10.63	1.77	1.67
DHW	2.17	1.01	0.63	2.07	3.09	1.00	9.96	1.66	1.44
HD	2.61	0.93	1.97	2.25	3.01	1.34	12.10	2.02	1.87
CLH	1.74	0.84	2.03	2.85	2.65	1.25	11.36	1.89	1.74
SC	1.04	0.54	1.62	1.42	2.04	1.04	7.70	1.28	1.18
WG	1.80	0.66	1.31	1.87	2.91	1.42	9.97	1.66	1.51
NC	1.55	0.59	0.95	1.39	2.64	0.87	7.98	1.33	1.18

Table 6 Sediment pollution index (SPI) for mean metal concentrations in the sediments from the Sanmenxia section

Sampling site	Cu	Cr	Cd	Pb	Mn	Zn	$\sum(Cf*W_i)$	SPI
JZL	3.53	0.96	513.51	11.59	2.65	1.22	533.47	1.72
DHW	4.34	1.01	189.19	10.33	3.09	1.00	208.95	0.67
HD	5.21	0.93	591.89	11.23	3.01	1.34	613.61	1.98
CLH	3.48	0.84	608.11	14.27	2.65	1.25	630.60	2.03
SC	2.08	0.54	486.49	7.09	2.04	1.04	499.28	1.61
WG	3.61	0.66	391.89	9.33	2.91	1.42	409.82	1.32
NC	3.10	0.59	283.78	6.94	2.64	0.87	297.92	0.96

Anthropogenic sources

Considering the local geochemical background levels of Henan Province as lithogenic fraction, the source of anthropogenic fraction in total heavy metal concentrations in the sediments from the Sanmenxia section is estimated. The percentages of anthropogenic and lithogenic sources for each sampling sites are listed in Table 7. All the concentrations of Cr are lower than the standards, meaning that this metal in the sediments is mainly from the lithogenic source, while 63 % Mn, 48 % Pb, 41 % Cu, 20 % Cd, and 12 % Zn are from the anthropogenic source. More than half of Mn (in all the sampling sites), Pb (in the JZL, DHW, HD, and CLH sites), Cu (in the DHW and HD sites), and Cd (in the CLH sites) contaminations are derived from anthropogenic source (Fig. 2). The JZL, DHW, HD, and CLH sites belong to or near the Lingbao City, which is also called "the land of gold" and "kingdom of pyrite." There are many gold mining company headquarters in the Lingbao City or near the Sanmenxia City. These part percentages of anthropogenic fraction are mainly from the tributaries of the Yellow River, such as the Hongnongjian River (YRCC 2011). Certainly, some agricultural activities also contribute to these kinds of contamination (Cheng et al. 2012). These heavy metals are easily available to biotic components

of the river's ecosystem of the Sanmenxia section and possibly enter into the food chain under suitable physicochemical conditions (Varol 2011; Ghregat et al. 2011; Cui et al. 2011). In addition, this kind of contamination could be flowed to the downstream with the flow-sediment regulation (Bai et al. 2012) which has happened every year since 2007.

Feng et al. (2010) already reported the concentrations (mg kg^{-1}) of Cd (0.07–1.41), Cr (30.89–102.72), Cu (10.95–34.87), Pb (17.42–55.13), and Zn (51.06–133.77) in the surface sediments mainly in the Luoyang and Zhengzhou sections, just downstream of the Sanmenxia section along the Yellow River. These heavy metals in the sediments mainly from the wastewater discharged into the Yellow River directly or indirectly without remediation. Especially in Luoyang District and its tributary, the Yiluohe River, a variety of industries have been fast developed during recent scores of years, such as mine plants, smelter plants, electronics plants, battery plants, and tannery plants. In addition, the agricultural activities around the river may also have contributed to the high levels of Pb and Cu, because of the use of pesticides, compost, and manure. For some sites far from industrial areas and with no wastewater discharge, the metal contaminations in the sediments showed a lower level.

Spatial distributions of metals in sediments along the whole reaches of the Yellow River

Variations of the concentrations of heavy metals in sediments along the course of the Yellow River are shown in Table 8. The measured data are characterized by highly spatial change. Along the whole region of the river, all of the Cd concentrations are above the standards (EMC 1990) and show a decreasing trend from Lanzhou reach to the Huanghe delta, which is similar with the variation of Zn. Cu and Pb are also detected in the ecological system in the Lanzhou section, the upper stream of the Yellow River, which acts as the main effluence channel of wastewater and receives a great amount of contaminants every year (Wang et al. 2010). Sediment

Table 7 Percentage composition of lithogenic (Lit.) and anthropogenic (Ant.) fractions (%) of heavy metals in the sediments from the Sanmenxia section

	Cu		Cr		Cd		Pb		Mn		Zn	
	Ant.	Lit.	Ant.	Lit.	Ant.	Lit.	Ant.	Lit.	Ant.	Lit.	Ant.	Lit.
JZL	43	57	−4	104	42	58	57	43	62	38	18	82
DHW	54	46	1	99	−59	159	52	48	68	32	0	100
HD	62	38	−8	108	49	51	55	45	67	33	25	75
CLH	42	58	−19	119	51	49	65	35	62	38	20	80
SC	4	96	−85	185	38	62	29	71	51	49	4	96
WG	45	55	−51	151	23	77	46	54	66	34	29	71
NC	36	64	−69	169	−6	106	28	72	62	38	−15	115
mean	41	59	−33	133	20	80	48	52	63	37	12	88

Fig. 2 Percentage of anthropogenic and lithogenic sources (%) of heavy metals in the sediments from the Sanmenxia section. Average shale concentration given in the local geochemical background levels of Henan Province was considered as lithogenic source
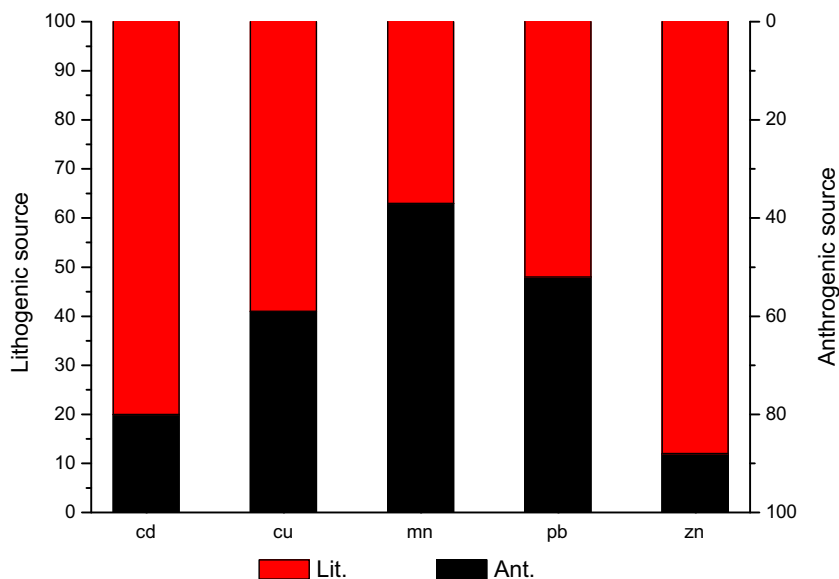
pollution of Cu, Pb, and Mn is aggravated at the Sanmenxia region and then decreased along the reaches until the Huanghe delta. The Sanmenxia section crosses Lingbao City and Sanmenxia City, which are famous for abound mineral resources. Only Cr contamination reaches the worst at the Zhengzhou region. The origin of Cr is mainly from the weathering degree, controlled by a complex combination of geochemical support phases (Jain et al. 2005).

Conclusions

In conclusion, heavy metal concentrations in the sediments from the Sanmenxia section display a wide variety. All the mean values of Pb and Mn, six values of Cu, and five of Cd are higher than the LBL values, respectively, except that of Cr detected at all sampling sites. That is to say, Cr in the sediments of the reservoirs was mainly from the lithogenic source, and 63 % Mn, 48 % Pb, 41 % Cu, 20 % Cd, and 12 % Zn are derived from the anthropogenic source. For individual element assessment in the sediments, I_{geo} values show that there

is no or only very light pollution (class 0 or 1) for Cu, Cr, Pb, Mn, Zn, and Cd in the study region with the exception of moderate pollution of Mn at the DHW and HD sites (class 2); considering the overall degrees of contamination at the sampling sites, mC_d data point out that it is nil to low at the SC, NC, JZL, DHW, WG, and CLH sites and moderate at the HD site, and all PLI values are more than the standard level 1. With a view to the toxicity of the elements, SPI values indicate that only the sediments of the CLH site is lowly polluted, that of the HD site is nearly slightly contaminated, and those of other sites were natural and uncontaminated. It is necessary to evaluate the contamination degree with individual and overall elements and the toxicity of these metals, and the conversation should be focused on ecosystem health and organisms in freshwater ecosystem. Along the reaches of the Yellow River, the levels of metal contaminations are different. The contaminations of Cd and Zn are serious in the Lanzhou reach, and the same situation of Cu, Pb, and Mn exists in the Sanmenxia section and that of Cr in the Zhengzhou area. The results of this study could be used as a reference in establishing appropriate conservation planning of the Sanmenxia section and keeping a sound condition for the Yellow River.

Table 8 Heavy metal concentrations (mg kg^{-1}) in sediments along the Yellow River

River reach	Sampling site	Cu	Cr	Cd	Pb	Mn	Zn	Reference
Upstream	Lanzhou	18.49	–	0.59	16.1	–	78.5	Wang et al. (2010)
	Baotou	23.53	–	0.24	14.9	–	62.4	Fan et al. (2007)
Middle stream	Sanmenxia	39.3	53.6	0.11	41.1	1633.5	72.4	This study
Downstream	Zhengzhou	15.47	98.5	0.10	31.5	843. 6	–	Cheng et al. (2012)
	Huanghe delta	15.86	59.3	0.09	9.3	382.0	52.6	Cui et al. (2011)

– not listed in the reference

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