

Application of Stabilization/Solidification (S/S) Method for Cadmium Pollution in Surface Sediments of the Dongjiaogou River in Kaifeng, China

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Abstract. Cd contamination of sediments poses a serious threat to the global environment human health. A detail and comprehensive investigation of cadmium (Cd) pollution in the surface sediments of Dongjiaogou River was carried out. Concentration analysis of Cd in various depth and locations was conducted based on 82 samples collected from the river surface sediments where the sediments is up to 353 mg/kg. Subsequently, stabilization/solidification (S/S) method, an effective method of improving the engineering properties of sediments and encapsulating contaminants, was applied in these sediments. According to the results, the Cd pollutant was treated effectively by S/S method, which verifies the feasibility to mitigate the hazards caused by Cd in those sediments from the river. Furthermore, the S/S sediments are favorable as filling material in the road for both recycling and construction.

1 Introduction

Cadmium (Cd) is a highly toxic environmental pollutant with slow rate of metabolism [1], which enters the sediment through human activities [2]. Cd pollution of waterbodies is an increasing issue due to the fast development of industry, agriculture and other human activities [3,4]. As time goes on, the Cd pollution in the water gradually precipitates into the sediments, which serve as a sink for Cd. Previous literature pointed out that Cd contamination of sediment is increasing dramatically, posing a serious threat to the global aquatic system [5]. Moreover, it also poses adverse impacts of kidneys and the skeleton on human health, even at low exposure level [6].

In China, heavy metal contamination of riverine sediments did not attract much attention from researchers or governments prior to the year 2000, i.e., relatively few studies were carried out before this time [7,8]. Industrial and mining activities always discharge heavy metals into the rivers, especially in the industrial area. Since the 1980s, plenty of industrial enterprises have moved to suburban areas from mega cities due to the nationwide adjustment of urban layout in China [9-11]. The soil contaminations, especially Cd contamination at these places, is of increasing concern because of the potential threat to the public health and detrimental effects on the ecosystems [12-14]. Dumping into seas or storing in other locations are the typical disposal strategies for these

sediments [15], which result in land occupation and serious ecological environmental degradation [16]. Therefore, stabilization/solidification (S/S) technique is widely used for treating sediments. Thereinto, cement is the most popular binder used in previous literature and engineering practice [9,17-20]. After improving the sediments, recycling as construction materials is now becoming increasingly preferable alternatives to control these wastes [21, 22].

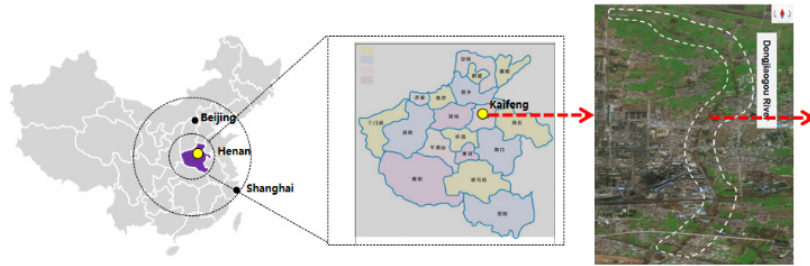
Since the 1980s, a few enterprises have been built around Dongjiaogou River. Including but not limited to Kaifeng Zinc Smelting Plant, Jinkai Chemical Fertilizer Plant, Kailiu Instrument plant, Kaifeng Qingshang chemical fertilizer Co., Ltd. A large amount of wastewater generated from those enterprises was directly discharged into this river. As a consequence, the suspended solids in the wastewater were slowly deposited in the river, which led to the sediment pollution. Since the waste residue generated from those enterprises was undisposed at all, there were high level of heavy metal pollutants in those sediments. This study takes Dongjiaogou River as the target area and investigate the sediments Cd pollutants via concentration analysis. Furthermore, the feasibility to eliminate the polluted sediments based on S/S method is evaluated and discussed.

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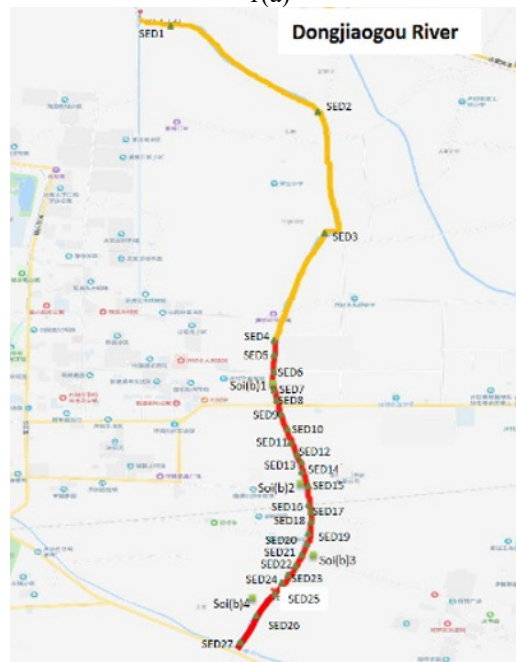
2 Area Description

Dongjiaogou River is about 9.5km in length, located in the eastside of Kaifeng, China (as shown in Figure 1a). The surrounding buildings are relatively evacuated and farmland, industrial factories as well as some sewage

outlets are spread around. The pollution sources in the river mainly came from rainwater, domestic sewage and factory wastewater along the river. The water quality of the river was poor and had a negative impact on the living environment.



1(a)



1(b)

Figure 1(a) Dongjiaogou River Location;
1(b) 27 Sample Sections along Dongjiaogou River. The maps are collected from Baidu maps

3 Samples and Method

The 82 sediments samples used in this study were dredged by different depth from 27 sample sections (see from Figure. 1b) along Dongjiaogou River. After dehydration and grinding to powder, the Cd content experiment was carried out by oil quality-determination of lead cadmium-graphite furnace atomic absorption spectrophotometry method [23].

According to previous literature [24,25], S/S is considered as an effective method (using cement and other binders) for both improving the engineering properties of sediments as well as encapsulating contaminants. Cement treatment is combined with the development of physical-chemical processes [26]. In detail, hydration reactions produce calcium hydroxide (Ca(OH)₂), calcium silicate hydrates(CSH), calcium aluminate hydrates (CAH) and ettringite (Aft), which fill

the soil pores and cement soil particles [27]. Cation exchange causes the flocculation and agglomeration of soil particles with the consumption of Ca²⁺, which fills the pores and further strengthens the aggregate structure [28]. As these hydrates crystallize and harden over time, the engineering behaviors of stabilized soil will be improved (e.g., strength, permeability and swelling) and contaminants will be immobilized [29-32].

4 Results

Table 1 lists the results of the Cd for all the samples selected. From location Sed 1 to location Sed 4, the Cd contamination is undetected. However, starting from location Sed 5, the Cd contamination exists in different depths, which varies from 0.3 mg/kg to 353 mg/kg. According to Soil Environmental Quality - Risk Control Standard for Soil Contamination of Development Land [33], the results indicates that majority dredged sediment

Cd content exceed the prescribed limits of the soil contamination of Cd (illustrated in Figure 2).

Figure 3 presents the statistic of Cd content grouped by different depth, where one sees the Cd contamination on the shallow depth is heavier than the deeper cases. After the S/S method applying to treat the river sediments, another 40 samples were chosen along the river for every

100 ~300 meters. The experiments was conducted by Solid Waste-Extraction procedure for leaching toxicity-acetic acid buffer solution method (described in Ref. [34]). According to the experiments, Cd leaching content results less than 0.01mg/L, which demonstrates that the S/S method work effectively for Cd pollution.

Table 1. Experiment results of sediment samples

Location				Location				Location			
Section Name	Sample Name	Sample Depth(m)	Results Cd mg/kg	Section Name	Sample Name	Sample Depth(m)	Results Cd mg/kg	Section Name	Sample Name	Sample Depth(m)	Results Cd mg/kg
SED1	SED1-1	0.2	<0.01	SED12	SED12-1	0.2	160	SED21	SED21-1	1.0	66.4
	SED1-1 Parallelism	0.2	<0.01		SED12-2	0.5	82.8		SED21-2	2.0	29.6
	SED1-2	0.5	<0.01		SED22	SED12-3	1.0	54.9	SED22-1	1.0	88.6
	SED1-3	1.0	<0.01	SED13-1		0.5	87.3	SED22-2	2.0	50.5	
SED2	SED2-1	0.5	<0.01	SED13	SED13-2	1.0	63.6	SED23	SED23-1	0.5	50.6
SED3	SED3-1	0.5	<0.01		SED13-3	1.5	52.9		SED23-2	1.5	12.0
SED4	SED4-1	0.5	<0.01	SED14	SED14-1	0.5	89.2	SED23-3	2.0	12.5	
SED5	SED5-1	0.5	<0.01		SED14-2	1.0	55.8	SED24-1	0.5	86.1	
	SED5-2	1.0	56.5		SED15	SED15-1	0.5	353	SED24-2	1.0	15.4
	SED5-3	1.5	12.6	SED15-2		1.0	82.2	SED24-3	1.5	12.4	
SED6	SED5-3 Parallelism	1.5	12.8	SED15-3	1.5	4.52	SED25	SED25-1	0.5	13.0	
	SED6-1	0.5	90.9	SED16-1	0.5	92.0		SED25-2	1.0	13.3	
SED7	SED6-2	1.0	56.7	SED16	SED16-2	1.0	66.0	SED25-3	1.5	9.92	
	SED7-1	0.5	163		SED16-3	1.5	10.0	SED26	SED26-1	0.5	73.9
	SED7-2	1.0	57.8		SED16-3 Parallelism	1.5	10.1		SED26-2	1.0	55.7
SED8	SED7-3	1.5	58.9	SED17-1	0.5	124	SED27	SED27-1	0.5	1.30	
	SED8-1	0.5	92.3	SED17-2	1.0	74.5		SED27-1 Parallelism	0.5	1.28	
SED9	SED8-2	1.0	56.1	SED17-3	1.5	22.5	SED27-2	1.0	1.28		
	SED9-1	0.2	255	SED18-1	0.5	94.1	SED27-3	1.5	0.30		
SED10	SED9-2	0.5	161	SED18	SED18-2	1.0	49.8	CG1	Soil(b)1	0.2	1.26
	SED9-3	1.0	63		SED18-3	1.5	33.6		Soil(b)1 Parallelism	0.2	1.33
SED11	SED10-1	0.5	92.7	SED19	SED19-1	0.5	49.9	CG2	Soil(b)2	0.2	0.93
	SED10-2	1.0	60.3		SED19-2	1.0	10.3		Soil(b)3	0.2	1.22
	SED10-3	1.5	44.1	SED19-2 Parallelism	1.0	10.5	CG3	Soil(b)3 Parallelism	0.2	1.13	
SED12	SED11-1	0.2	91	SED19-3	1.5	12.6		CG4	Soil(b)4	0.2	1.35
	SED11-2	0.5	50.7	SED20-1	0.5	86.4					
	SED11-3	1.5	45.7	SED20-2	1.5	63.6					
	SED11-4	2.0	35.7	SED20-3	2.0	29.3					

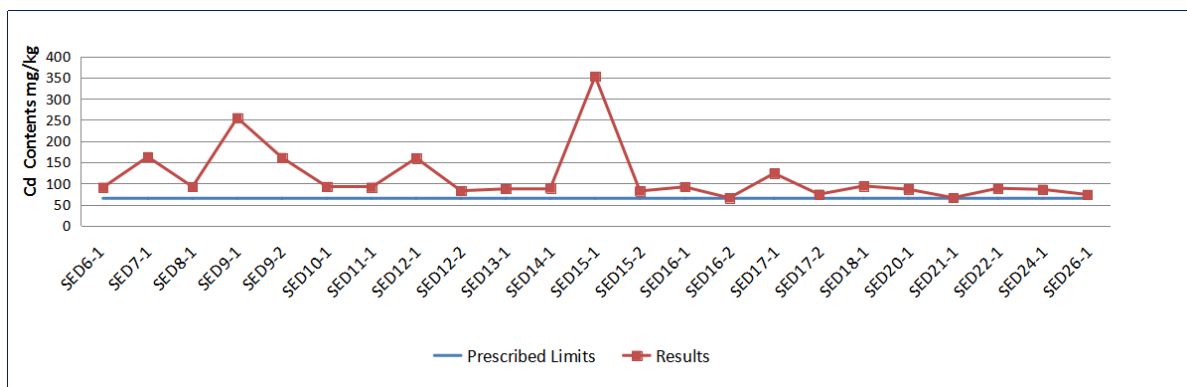


Figure 2. Cd content compared with prescribed limits given by Ref. [33]

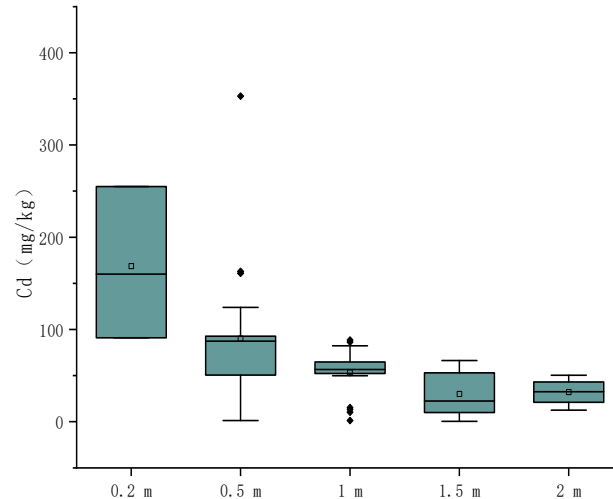


Figure 3. The statistic boxplot for content of Cd grouped by sampling depth.

5 Discussion

Sediments contain many pollutants besides Cd, e.g., nitrogen, phosphorus pollutants, and organic pollutants [35-37]. As a matter of fact, S/S applied here not only promotes the strength and stiffness of sediments, but also reduces the contaminant of Cd. The S/S method exhibits the characteristics of low permeability, high strength, high stiffness and low cost. Furthermore, the S/S sediments

could be widely utilized as materials on the project, e.g., road layers, river embankments, and foundation treatment (depicted in Figure 4) [35,36,38-42]. To recycle the S/S sediments, a viable path is proposed to reuse them as the road foundation next to the Dongjiaogou River. By this means, it saves the costs of the project itself while also ensure the safety of the treatments.

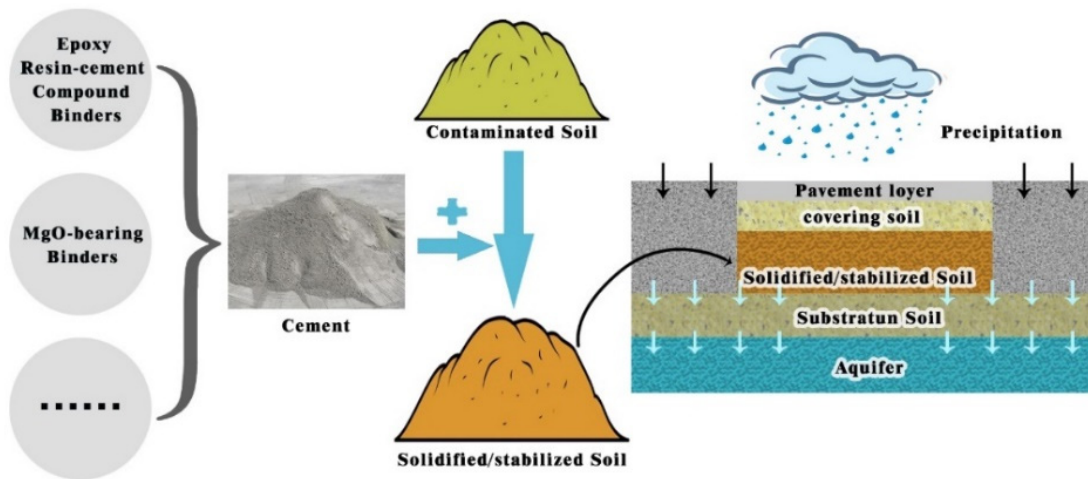


Figure 4. Recycling soil as road foundation

Although the S/S is a widely used method for sediment treatment, the accurate proportion of the binder selection should be addressed. The solidification agents for S/S sediments were cement initially. Subsequently, based on the physical and chemical properties of the sediments, other binders are added. For example, lime [43-45], epoxy resin-cement compound binders [46], MgO-bearing binders [47], cement-based mixture, use of alkali activators, expansive components and surfactants [48] are optional choice.

6 Conclusion

In summary, Dongjiaogou River was seriously polluted by Cd from location Sed 5 to Sed 27 according to concentration analysis. Besides, the surface level of sediment was polluted heavier than the inner level. Based on S/S method treatment, the Cd contamination in the sediment of this river was controlled effectively, where all the Cd leaching content shows less than 0.01 mg/L. Moreover, the S/S sediments were composed of sediment

aggregates, i.e., they can serve as the construction material. These results verify the feasible path to improve the Cd pollution in the river by means of S/S.

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