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Health Risk Assessment and Control Countermeasures of Heavy Metal Contaminated Soil in an Abandoned Concentrator in Guangxi

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Abstract: Taking an abandoned concentrator as an example, the characteristics of heavy metal pollution in the soil of this site was explored, and the carcinogenic risk and harm quotient of heavy metal pollution to human body was evaluated. The results showed that: 1) the carcinogenic risk and hazard quotient of three heavy metals (As, Sb, Cd) in the soil of the plot were unacceptable; 2) The risk of lead (Pb) pollutants in the soil of the plot to human body is unacceptable. Combined with the plot development and utilization planning, the actual needs of pollution prevention and control, and the economic and environmental benefits, a risk control scheme aimed at preventing the spread of pollution was proposed, and the benefits of risk control were analyzed.

1. Introduction

China is facing severe soil heavy metal pollution. In recent years, heavy soil metal pollution incidents have occurred frequently in China [1]. Heavy metals will cause long-term harm to the soil environment due to their difficulty in degradation. They migrate and enrich from soil to crops and finally to human body through the food chain, endangering human health [2]. There are numerous reasons causing heavy metal pollution. Mining areas, smelting areas and waste landfill areas are the prone areas of soil heavy metal pollution [3]. The pollution in these sites has been widely concerned. Although the abandoned mines are no longer mined, the abandoned mines and tailings piles can still cause pollution to the surrounding environment through surface runoff and dust [4-6].

Hechi City, is a famous "hometown of nonferrous metals" in China, which located in the Danchi metallogenic belt in the northwest of Guangxi. It has resources of more than 20 kinds of nonferrous metals such as Zn, Pb, Sn and Sb, with a total reserve of 11 million tons, and a long mining history [7]. Since 1980s, mining and dressing industry in this area has developed in disorder, and tailings sand has been piled up randomly, causing serious and extensive soil heavy metal pollution. In this study, a shut-down concentrator in Guangxi was taken as an example to assess the risk assessment and control countermeasure of the contaminated soil. The application of risk assessment and control countermeasure in soil pollution can provide the basis for the formulation of ecological security protection strategy.

2. Project Overview

The target plot is a typical washery in nonferrous metal mining and dressing industry of Guangxi. The washery was founded in 1998 and closed in 2012. In 2021, the factory buildings and equipment on the plot had been dismantled, and some living and office areas and mining platforms of the plot still remain. The washery was mainly used for flotation of lead antimony, zinc and pyrite. According to the hydrogeological survey results, the strata in the survey area from new to old are mainly artificial fill layer, Quaternary eluvial layer, mudstone of Upper Devonian Tongchejiang Formation. The revealed Quaternary eluvial layer is mainly clay. According to the stratum lithology, occurrence conditions and hydrodynamic characteristics of groundwater in the project area, there are two types of water-bearing rock groups: loose rock pore water and clastic rock bedrock fissure water. The groundwater in the project area mainly receives the lateral supply of atmospheric precipitation and clastic rock bedrock fissure water in the north-east mountain. Short-distance runoff is formed through structural fissures and interlayer fissures, and is discharged to the surface in the form of loose flow and spring at the terrain cutting low-lying areas. The groundwater is collected into gullies and streams, which are discharged to the low-lying areas.

3. Plot investigation

According to the preliminary investigation, the soil of the site was polluted by heavy metals. Excessive heavy metals may be related to the original industrial activities or foreign miscellaneous fill. Through the preliminary site investigation, the potential areas of concern of the site were identified. On this basis, according to the over-standard factors of the original preliminary investigation, the samples collected at this encrypted monitoring site were tested. A total of 137 soil samples from 25 sites were collected. Standard, replicate and blank samples were set during the test. The soil samples were sent to the third-party laboratory certified by CNAS or CMA for testing and analysis.

The excessive pollutants in the plot included lead (Pb), cadmium (Cd), arsenic (Ar) and antimony (Sb), which exceeded the standard at all sites. Detailed information can be seen in Table 1.

Table 1: Statistical Information of heavy metal pollution in soil at all sites (mg/kg)

Pollutant	Number of samples	Over-standard samples	Exceeding standard rate (%)	Average value (mg/kg)	Maximum value (mg/kg)	Excess multiple of maximum value	95% confidence upper limit (mg/kg)	Excess multiple of 95% confidence upper limit
Ar	137	121	88.30%	1687	19900	285.67	1889.6	30.49
Sb	137	92	67.20%	872	4450	23.72	1012.3	4.62
Pb	137	39	28.50%	1090	22200	21.25	1359.2	0.7
Cd	137	10	7.30%	17	232	2.57	21.9	/

4. Health Risk Assessment

This plot is planned to be used for villages and towns, but the specific planned use is not yet clear, and there is no development plan at present. The plot is close to Class II landfill site, so it does not meet the requirements of Class I land use and is considered as Class II land. The main receptor of pollution are the residents around the plot. The adults have a long exposure period and high exposure frequency. Generally, the carcinogenic risk and non-carcinogenic effect of pollutants are evaluated according to the exposure of adults.

The screening standard of soil samples was implemented according to the Class II land in the *Soil environmental quality—Risk control standard for soil contamination of development land* (GB36600—2018) [8]. The pollutants exceeding the screening value were listed as potential pollutants for risk assessment [9]. The exposure pathways of soil pollutants include oral intake, skin contact, particulate matter inhalation, etc. The risk assessment was conducted on basis of the method of *Technical guidelines for risk assessment of soil contamination of land for construction* (HJ 25.3—2019) [10]

For the convenience of this risk assessment, two situations were set. In the case of temporary non-exploitation, the heavy metal pollutants in this plot only involved the surface exposure pathways, and only the surface (0—0.5m) risk was calculated. In the case of possible development and utilization in the later period, the exposure pathways of the lower heavy metal pollutants were involved in the consideration of the possibility of exposure of the lower soil after land excavation(0.5—23 m). In this assessment, the surface layer of 0m-0.5m was divided as surface layer for assessment, and the lower layer of 0.5m-23m soil was divided as deep layer for assessment.

For arsenic, cadmium, antimony pollution, the Risk Assessment System for Contaminated Sites (CRISK) was adopted. For lead pollution, as Class II land, the ALM model was used to assess the risk of adult lead exposure. This model characterizes the human health risk of lead-contaminated soil by assessing the fetal blood lead content of pregnant women exposed to lead-contaminated soil of Class II land. The acceptable risk level in this risk assessment is defined as: the acceptable level of carcinogenic risk of a single pollutant is 10^{-6}, and the acceptable level of non-carcinogenic risk of a single pollutant is 1[11].

According to the calculation results of CRISK software (seen in Table 2), for the Class II land, the carcinogenic risk of arsenic (As) and cadmium (Cd) in 0m-0.5m polluted soil on the surface of the plot is unacceptable, and the hazard quotient of arsenic (As), antimony (Sb) and cadmium (Cd) in 0m-0.5m polluted soil is unacceptable; the carcinogenic risk of arsenic (As) and cadmium (Cd) in the 0.5m-23m lower polluted soil is unacceptable, and the hazard quotient of arsenic (As), antimony (Sb) and cadmium (Cd) is unacceptable.

Table 2: Risk to human health of the Class II land calculated according to CRISK

Soil depth (m)	Pollutant	Maximum value (mg/kg)	Oral intake		Skin contact		Inhaled particulate matter		Carcinogenic risk	Hazard quotient
			Carcinogenic risk	Hazard quotient	Carcinogenic risk	Hazard quotient	Carcinogenic risk	Hazard quotient		
Surface layer (0m-0.5m)	Ar	17200	9.41E-03	1.27E+02	1.71E-03	2.30E+01	1.08E-03	1.02E+02	1.22E-02	2.52E+02
	Sb	4340	-	2.41E+01	-	-	-	1.28E+00	-	2.53E+01
	Cd	116	-	2.57E-01	-	6.22E-02	3.04E-06	1.03E+00	3.04E-06	1.35E+00
Deep layer (0.5m-23m)	Ar	19900	1.09E-02	2.67E+01	1.97E-03	1.47E+02	1.25E-03	1.18E+02	1.41E-02	2.91E+02
	Sb	4450	-	-	-	2.47E+01	-	1.31E+00	-	2.60E+01
	Cd	232	-	1.24E-01	-	5.14E-01	6.09E-06	2.06E+00	6.09E-06	2.70E+00

According to ALM model (Calculation of Adult Blood Lead Concentration) for the Class II land, the risk target should be the 95% probability target value of fetal blood lead content is lower than the critical value of 10 ug/dL. The calculation results in this study are shown in Table 3. Based on the results, the 95% probability target value of fetal blood lead content of the surface layer and the lower layer of the plot is greater than the critical value of 10 μg/dL, and the risk is unacceptable. Therefore, the risk of lead (Pb) pollutants in both layers of soil in this plot to human body is unacceptable for the Class II land.

Table 3: 95% probability target value of fetal blood lead content (ug/dL)

Soil depth	Maximum lead (mg/kg)	95% probability target of fetal blood lead content (ug/dL)	Critical value (ug/dL)
Surface layer (0-0.5m)	22200	66.88	10
deep layer (0.5-23m)	17800	55.16	

5. Risk Control Countermeasures

Considering that there is no development and utilization plan for the project area, and the pollution has a large depth, it is planned to take risk control with the purpose of preventing pollution diffusion and blocking the migration and diffusion of pollutants in soil media.

For the risk control scope, the surface pollution situation is mainly considered. Since the risk of surface soil pollution at all sties of the plot exceeds the acceptable level of human body, it is concluded that the risk control scope of the factory in the plot is full-site control, and the factory boundary is the control boundary.

The mainly environmental problems of soil risk control in the project area are listed as follows:

(1) The main pollutants in the soil of the project area are Ar, Sb, Cd and Pb, and the potential receptors of the pollution are mainly people living in the plot and around the plant area. To protect human health, it is necessary to block the exposure pathways.

(2) In the hardened area composed of the left-over structures and cement pavements, some pavements are damaged and cracked due to cart rolling and disrepair, etc. In the process of rainfall or sprinkling water to reduce dust, rainwater and dust water may seep into groundwater through damage and cracks, resulting in pollution risk.

(3) No rain and sewage collection and treatment system has been built in the factory area, and pollutants may migrate with the precipitation and cause harm to human body and surrounding environment.

Therefore, in combination with the actual situation of the plot, the management and control strategy of "engineering management and control first and system management and control second" was finally adopted for this project. The technical scheme of risk management and control is as follows: adopting horizontal barrier "30cm clay + two cloths and one film +30cm planting soil + ecological restoration + retaining wall" in the polluted area; using arch skeleton for slope protection in the steep slope area; blocking the hardened area horizontally (concrete repair), and repairing the original retaining wall with 2cm mortar plaster; cutting off the exposure pathway of pollutants in the soil and reducing the rainfall infiltration recharge. The flood intercepting trench and drainage ditch are designed to prevent the surface water from the mountainous area on the north side of the factory area from entering the factory area through the gully and reduce the infiltration and recharge of groundwater from the surface water in the factory area and the existing drainage ditch. The control system includes setting up signboards, land parcel data management and dynamic monitoring. The implementation process is shown in Figure 1.

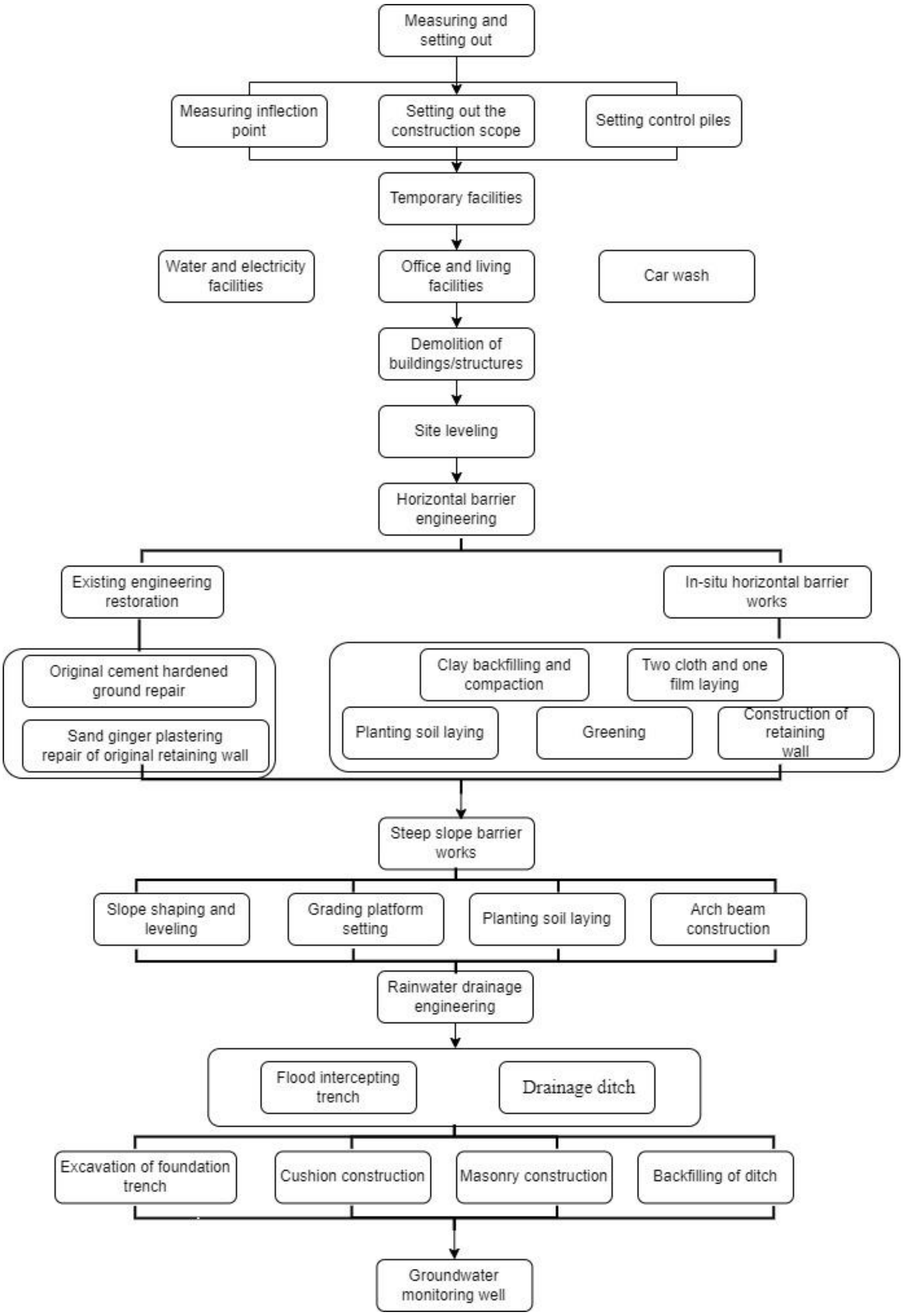

Figure 1: Technical flow chart of project implementation

This technological process mainly includes eight links, namely, surveying and setting out, temporary facilities construction, building demolition, site leveling, horizontal barrier engineering, steep slope barrier engineering, rainwater drainage engineering, groundwater monitoring well engineering, etc. The details are as follows:

① Carrying out surveying and setting-out to determine the scope of project implementation;

② Setting up temporary facilities, including water and electricity facilities, office and living facilities, car wash, etc.

③ Demolition of the buildings left in the plot;

④Carrying out site leveling to establish working face for the subsequent technical implementation;

⑤ Implementing horizontal barrier engineering, including existing engineering restoration and original site horizontal barrier engineering. Among it, the existing engineering restoration is subdivided into original cement hardened ground restoration and original retaining wall mortar plastering restoration. The original site horizontal barrier construction is subdivided into clay backfilling and compaction, two cloth and one film laying, planting soil laying, greening restoration and retaining wall barrier construction;

⑥ Implementing steep slope barrier project, adopting arch skeleton to protect slope, specifically including slope shaping and leveling, setting grading platform, horizontal barrier covering soil and arch beam construction;

⑦ Implementing rainwater drainage works, including flood intercepting ditch and drainage ditch works;

⑧ Implementing groundwater monitoring well project, and establishing engineering foundation for subsequent long-term monitoring by adopting system control measures to prevent and control land risk.

6. Benefit Analysis of Risk Control

6.1 Analysis of Economic Benefits

The implementation of the project can help solve the employment of some local people within a certain period of time and increase farmers' income; the implementation and development of the project can not only effectively improve the indexes of heavy metals in regional soil and water, significantly enhance regional environmental security, further eliminate or reduce the harm of pollution to residents' health, and improve the living quality of the masses, but also timely resolve social contradictions and disputes caused by environmental problems, and safeguard and protect the rights and interests of the masses. The one-time investment of risk control project is much lower than that of restoration project, which can alleviate the current financial pressure borne by the government in terms of environmental governance.

6.2 Analysis of Ecological Benefits

After the implementation of this project, the pollution sources are effectively controlled. The pollution risk is prevented from spilling over, and the pollutants are prevented from migrating along with the rain in the environmentally sensitive areas such as surface water, farmland and residential areas outside the plot, which can effectively promote a virtuous circle of ecological environment in the construction area. This project plays an important role in the ecological environment protection of local agriculture, water sources and surface water, comprehensively improves the ecological civilization construction of Luocheng County, and brings huge ecological maintenance and ecological construction benefits.

6.3 Analysis of Social Benefits

The management and control of the project area, it is conducive to ecological sustainable development. Environmental protection and ecological civilization construction have become a focus of China, and various social problems caused by waste pollution have been widely concerned.

This project is an environmental treatment project, benefiting the people of the whole county. In the long run, the whole society and future generations will benefit a lot. The government has undertaken the heavy task of pollution control, but at the same time, it is also a beneficiary. The project benefits the people and is a historical monument. After the project is completed, it can effectively enhance the prestige and image of the government, and ensure regional social stability and sustainable economic development. It is of positive significance for maintaining environmental and social stability and promoting economic development and national unity, especially for enhancing the credibility of the government and the cohesion of the people. Moreover, through extensive publicity of heavy metal pollution prevention and control, people's awareness of ecological environment has been continuously improved.

7. Conclusions

The heavy metal contaminated site of a typical concentrator in Guangxi adopted the risk management and control system of heavy metal contaminated site, which is composed of "site trimming + horizontal barrier + steep slope barrier + hardening restoration + ecological restoration + water interception and drainage treatment + monitoring system". The system has realized site risk management and control, blocked pollutant exposure pathways, and reduced and eliminated the risk of pollutants on human health and environment. The idea of risk management and control of this project takes both economic and social development and ecological environment protection into consideration, which can provide reference for risk assessment and control of heavy metal pollution in typical sites in China.

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