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Cost–benefit calculation of phytoremediation technology for heavy-metal-contaminated soil

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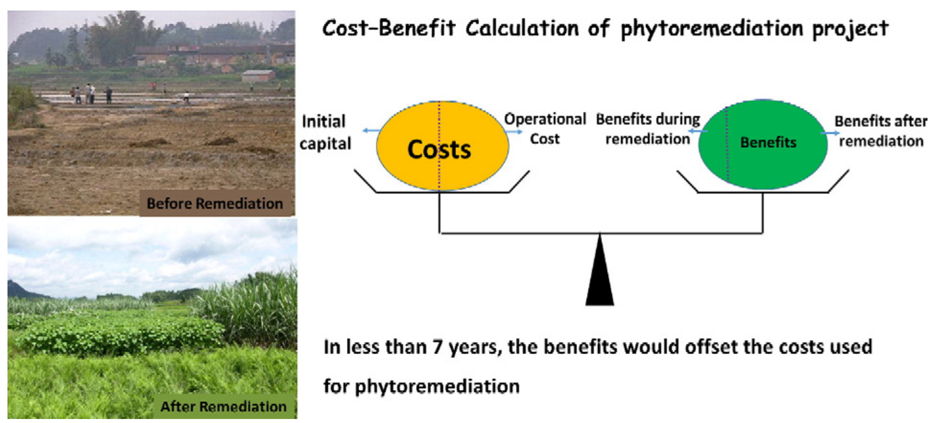
HIGHLIGHTS

- A two-year phytoremediation project was introduced.
- Costs and benefits of a phytoremediation project were calculated.
- Costs of phytoremediation project can be offset by benefits in 7 years.

GRAPHICAL ABSTRACT



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ABSTRACT

Heavy-metal pollution of soil is a serious issue worldwide, particularly in China. Soil remediation is one of the most difficult management issues for municipal and state agencies because of its high cost. A two-year phytoremediation project for soil contaminated with arsenic, cadmium, and lead was implemented to determine the essential parameters for soil remediation. Results showed highly efficient heavy metal removal. Costs and benefits of this project were calculated. The total cost of phytoremediation was US$75,375.2/hm^2 or US$37.7/m^3, with initial capital and operational costs accounting for 46.02% and 53.98%, respectively. The costs of infrastructures (i.e., roads, bridges, and culverts) and fertilizer were the highest, mainly because of slow economic development and serious contamination. The cost of phytoremediation was lower than the reported values of other remediation technologies. Improving the mechanization level of phytoremediation and accurately predicting or preventing unforeseen situations were suggested for further cost reduction. Considering the loss caused by environmental pollution, the benefits of phytoremediation will offset the project costs in less than seven years.

1. Introduction

Soil heavy-metal (HM) pollution is one of the main global environmental problems, particularly in China (Hernandez et al., 2003; Li et al., 2015; Toribio and Romanya, 2006). Soil HM pollution adversely affects not only the yield and quality of crops, and animal and human

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health, but also the environment (Chen et al., 1999). Soil HM pollution has been paid much attention given that the cleanup costs amount to billions of dollars (Manea et al., 2013; Wu et al., 2014). Cheap and effective technologies would significantly improve the prospects of cleaning-up metal-contaminated sites.

Phytoremediation is considered an economical and environmentally friendly method of exploiting plants to extract contaminants from soil (Padmavathiamma and Li, 2007; Prasad, 2003). This process is relatively cost-effective compared with other remediation techniques. However, a thorough economic analysis for this process is unavailable. Most phytoremediation studies are directed at the biological, biochemical, and agronomic processes (Ali et al., 2013). An economic outlook, instead of simple estimates of the cost advantages of phytoremediation over other techniques, has not been reported.

A method that can effectively allocate remediation funds is necessary because of the high cost of remediation and insufficiency of funds. Decision-making on the application of remediation alternatives is a crucial step after a comprehensive analysis and assessment of contaminants has been conducted (Scholz and Schnabel, 2006). Cost–benefit analysis, using environmental economics, becomes increasingly important (Karachaliou and Kaliampakos, 2011). Numerous methodological studies were conducted to establish models and techniques to calculate cost-effectiveness and aid economic decision analysis (Demougeot-Renard et al., 2004; Lemming et al., 2010; Scholz and Schnabel, 2006). However, available case studies are insufficient, resulting in incomplete essential parameters. Correct decision-making is achieved with enhanced experience and knowledge on the consequences of the decision. These experience and knowledge should be derived from real cases.

A two-year phytoremediation project was performed in the present study. Detailed costs were recorded and analyzed to provide a basic estimate of the real cost of phytoremediation project. The percentage of each item based on the total cost was calculated to determine the unreasonable high costs, facilitating further studies that will reduce phytoremediation costs. In addition, the benefits of remediating farmland soil were tentatively calculated. A few studies have reported the benefit of farmland soil remediation and projected the calculation of the benefits of soil remediation to evaluate the loss caused by environmental pollution (Hao et al., 2004; Vatn et al., 2006; Wu et al., 2004; Zhou et al., 2015). Results of the present study can help determine the most expensive procedure for phytoremediation, favoring subsequent work on reducing costs. In addition, the results can provide the parameters for future cost–benefit analysis in decision-making for the selection of a remediation technology for contaminated soil.

2. Materials and methods

2.1. Description of the case

Subject area was located in Huanjiang Maonan autonomous county (107°51′–108°43′ E, 24°44′–25°33′ N), northwest of Guangxi Zhuang Autonomous Region in southwest China (Fig. 1). Huanjiang County is rich in nonferrous mineral resources, and Pb–Zn mines are widely distributed in the area. The tailing dam of the Beishan Pb–Zn mine located upstream of Huanjiang river collapsed in the summer of 2001 because of a catastrophic flood, leading to the spread of mining waste spills on the farmlands along the river (Fu et al., 2015). The cause and status of pollution in the area were quite similar to those of the Guadiamar river valley affected by toxic flood (Cabrera et al.).

Approximately 700 ha of soil was seriously contaminated by HM-enriched flooding water. Some regions could no longer sustain agricultural products because of serious pollution, whereas some regions could produce agricultural products but with substandard quality. Local residents manifested some pathological symptoms, such as decreased phosphor in plasma and increased Cd in urine, after digesting crops produced by contaminated soils. HM contamination in this area has become one of the most impressing environmental issues in China.

Soil environmental quality and quality of agricultural products were evaluated before and after remediation. HMs in soils were determined through HNO_3–H_2O_2 digestion in accordance with the 3050B method of USEPA (1996). Plant samples were dried, ground, and digested with a mixture of HNO_3–$HClO_4$ (Chen et al., 2002b). We performed quality control by simultaneously digesting the samples of certified standard reference materials for soils (GSS-1) and plants (GSV-2) from the China National Standard Materials Center using the experimental samples. The As concentrations were determined using an atomic fluorescence spectrometer (Haiguang AFS-2202, Beijing Kechuang Haiguang Instrumental Co., Ltd., Beijing, China). The concentrations of other HMs were determined using an inductively coupled plasma mass spectrometer (ICP-MS ELAN DRC-e, PerkinElmer, USA).

Over-standard rates were calculated to evaluate the contamination status of the soil in the mining sites. An over-standard rate indicated the percentage of samples with HM concentrations higher than that recommended by China's Environmental Quality Standard for Soils

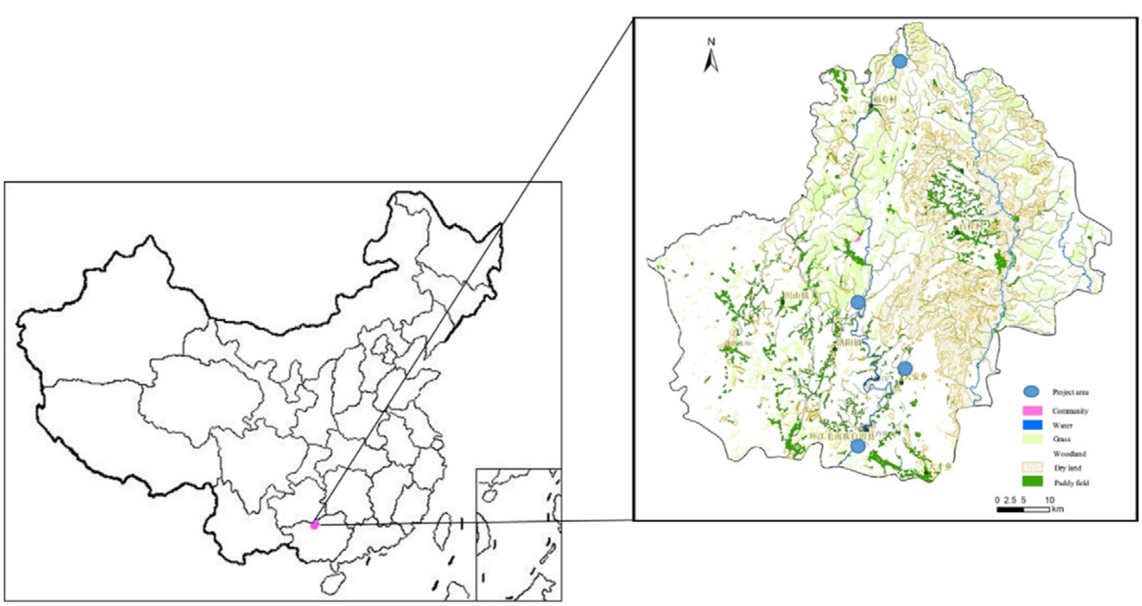

Fig. 1. Location of Huanjiang County.