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Development of a green remediation tool in Japan

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HIGHLIGHTS

- Quantitative green remediation assessment tool was developed for contaminated sites.
- The tool can evaluate 130 inventory inputs/outputs in 9 impact categories.
- The tool can integrate the inventory inputs/outputs into a single index.
- Case study result indicates that CO_2 and SO_2 and oil were the main contributors.

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ABSTRACT

The green remediation assessment tool for Japan (GRATJ) presented in this study is a spreadsheet-based software package developed to facilitate comparisons of the environmental impacts associated with various countermeasures against contaminated soil in Japan. This tool uses a life-cycle assessment-based model to calculate inventory inputs/outputs throughout the activity life cycle during remediation. Processes of 14 remediation methods for heavy metal contamination and 12 for volatile organic compound contamination are built into the tool. This tool can evaluate 130 inventory inputs/outputs and easily integrate those inputs/outputs into 9 impact categories, 4 integrated endpoints, and 1 index. Comparative studies can be performed by entering basic data associated with a target site. The integrated results can be presented in a simpler and clearer manner than the results of an inventory analysis. As a case study, an arsenic-contaminated soil remediation site was examined using this tool. Results showed that the integrated environmental impacts were greater with onsite remediation methods than with offsite ones. Furthermore, the contributions of CO_2 to global warming, SO_2 to urban air pollution, and crude oil to resource consumption were greater than other inventory inputs/outputs. The GRATJ has the potential to improve green remediation and can serve as a valuable tool for decision makers and practitioners in selecting countermeasures in Japan.

1. Introduction

The environmental impacts of contaminated sites on both human health and ecosystems have attracted considerable attention because risks come not only from the sites but also from remediation activities associated with site cleanup. In the 2000s, the concept of "green and sustainable remediation" (GSR) was developed in the United States and Western Europe (SURF, 2009; U.S. EPA, 2008). GSR considers general environmental impacts (e.g., global warming and air pollution) and the socioeconomic aspects of dealing with contaminated sites, including effects on the people living in and around the sites.

A tiered approach is usually used in GSR appraisal. The advantage of this approach is that the number of tasks associated with such appraisals can be reduced. Qualitative approaches, such as ranking and discussions associated with the selection of countermeasure methods, are mainly used in simple situations. Semi-quantitative approaches, which include footprint analysis, or quantitative approaches, such as life-cycle assessments (LCA) and cost–benefit analysis, are mainly used in more complicated situations (SURF-UK, 2010). Users need to

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select the most suitable method from these qualitative and quantitative approaches according to the needs and purposes of the evaluation.

LCA is a widely accepted technique for assessing environmental impacts associated with product life cycles. In studies of several contaminated sites, LCAs were effective for identifying and quantifying environmental impacts of remediation activities for GSR. Diamond et al. (1999) developed a framework for applying LCA to the remediation of contaminated soil by qualitatively relating environmental impacts and remediation methods. Quantitative evaluations of several remediation methods for soil and groundwater contamination have also been reported (Bayer and Finkel, 2006; Cadotte et al., 2007; Godin et al., 2004), although only a limited number of inventory inputs/outputs, such as CO_2 and NOx, were evaluated in these studies.

Some studies have normalized environmental impacts associated with remediation activities using various impact assessment models. One of these models, EDIP97 (Hauschild and Wenzel, 1998), estimates the risk of human toxicity and ecotoxicity. This model has been used to assess environmental impacts in several research projects (Godin et al., 2004; Lemming et al., 2010a; Toffoletto et al., 2005). Other environmental impact assessment models include EDIP2003 (Lemming et al., 2010b) and the United States Environmental Protection Agency's TRACI model (Cadotte et al., 2007). Lemming et al. (2010b) stated that studies using these toxicity models ended midstream, and that the researchers did not extend their analyses to estimates of certain aspects of potential damage to humans or the environment, such as disability-adjusted life years (DALY) (Murray and Lopez, 1996) for humans or extinction of species in ecosystems (Matsuda et al., 2003). Furthermore, the abovementioned studies only considered toxicity to humans and ecosystems as secondary impacts.

Another problem of existing impact assessment models is that different countries need different evaluation models, because each country has different basic inventory inputs/outputs units. For example, the CO_2 emission unit of 0.08–0.55 kg CO_2 per kWh varies greatly between countries (IEA, 2009). In addition, previous models address only limited types of countermeasures. Countermeasures for soil contaminated with heavy metals are particularly limited. For example, only soil washing (Diamond et al., 1999), excavation and disposal (Page et al., 1999), and in-situ stabilization/solidification (Harbottle et al., 2007) have been separately evaluated. For practical purposes, GSR tools should be able to evaluate more countermeasures than this.

In Japan, a model that calculates and compares CO_2 emissions generated by remediation methods was developed several years ago (GEO-ENVIRONMENTAL PROTECTION CENTER, 2010; Yasutaka et al., 2009). Because of a lack of inventory data at the time, however, the model was restricted to CO_2 emissions.

In the present study, we constructed a green remediation assessment tool for Japan (GRATJ) to evaluate 19 countermeasures and estimate 130 types of emissions or resource consumption associated with remediation activities. The tool can further analyze associated environmental impacts by incorporating a life-cycle impact assessment method based on endpoint modeling (LIME2) developed in Japan (Itsubo and Inaba, 2010). We also performed a case study to investigate five methods typically used for remediating sites contaminated with heavy metals in Japan, and evaluated the most important inventory inputs/outputs in terms of environmental impact.

2. Model description

2.1. Targeted countermeasures

Table 1 shows the countermeasures targeted. Our model can evaluate 19 countermeasures, 14 for heavy metals and 12 for volatile organic compounds (VOCs), as well as 7 for both.

Our tool considers not only offsite remediation methods (such as excavation and landfills) but also onsite remediation and risk management methods (such as containment). These countermeasures were mainly selected from the Japanese Soil Contamination Countermeasures Act.

2.2. Targeted inventory, impact categories, and an integrated index

Emissions, such as PM_{10} and CO_2 from remediation activities, and resource consumption, such as oil consumed by these activities, were defined as the "inventory inputs/outputs". The inventory data of our tool uses 130 inventory inputs/outputs available from the Inventory Database for Environmental Analysis (IDEA) of MiLCA (Japan Environmental Management Association for Industry, 2012), one of the newest databases in Japan (Nakano et al., 2009; Tahara et al., 2008). This inventory database includes 3825 process data (example shown Table 2), both statistical and process-based data, and is one of the largest databases in the world. Many researchers and private companies have used this database for both scientific and environmental reports.

Environmental impacts are assessed and integrated using LIME2 (Itsubo and Inaba, 2010). LIME2 is the second version of LIME, which was developed by the National Institute of Advanced Industrial Science and Technology. It was adopted in this study because of its

Table 1
Countermeasure methods assessed by GRATJ.

Name		Target		Contaminants		
		Soil	Groundwater	VOCs	Heavy metals	Both
Excavation	and cement (EOC)	●			●	
	and landfill (EOL)	●		●	●	●
	and soil washing (EOW)	●			●	
	and mixing with $CaCO_3$	●		●		
Insolubilization (ISI)		●			●	
Containment with	steel sheet pile + concrete (ISC)	●	●	●	●	●
	steel sheet pile + asphalt	●	●	●	●	●
	pillar line wall + concrete	●	●	●	●	●
	pillar line wall + asphalt	●	●	●	●	●
	seepage control + concrete	●	●	●	●	●
	seepage control + asphalt	●	●	●	●	●
Mixing iron powder with contaminated soil		●	●	●		
Bioremediation			●	●		
Fenton			●	●		
Groundwater pumping			●	●		
Paving the site with	concrete	●			●	
	asphalt	●			●	
Filling excavated pit with clean soil		●			●	
Soil exchange (within the site)		●			●	

Note: Black dots indicate the targets and contaminants considered by each method.