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Selection of remedial alternatives for mine sites: A multicriteria decision analysis approach

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ABSTRACT

The selection of remedial alternatives for mine sites is a complex task because it involves multiple criteria and often with conflicting objectives. However, an existing framework used to select remedial alternatives lacks multicriteria decision analysis (MCDA) aids and does not consider uncertainty in the selection of alternatives. The objective of this paper is to improve the existing framework by introducing deterministic and probabilistic MCDA methods. The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) methods have been implemented in this study. The MCDA analysis involves processing inputs to the PROMETHEE methods that are identifying the alternatives, defining the criteria, defining the criteria weights using analytical hierarchical process (AHP), defining the probability distribution of criteria weights, and conducting Monte Carlo Simulation (MCS); running the PROMETHEE methods using these inputs; and conducting a sensitivity analysis. A case study was presented to demonstrate the improved framework at a mine site. The results showed that the improved framework provides a reliable way of selecting remedial alternatives as well as quantifying the impact of different criteria on selecting alternatives.

1. Introduction

Acid Rock Drainage (ARD) from mine wastes that contains elevated metals and metalloids poses human and environmental risks (Gray, 1996; Azapagic, 2004). ARD is produced when sulfide-bearing material is exposed to oxygen and water during mining activities (Morin and Hutt, 1997; Price, 2009). Examples of human health risks include increased chronic diseases and various types of cancer. On the other hand, examples of ecological risks range from the elimination of species to a significant reduction of ecological stability, and to the bioaccumulation of metals in the flora and fauna (Gray, 1996). In the eastern and western U.S., between 7000 and 16,000 km of streams are affected by acid generating waste rocks and between 8000 and 16,000 by ARD (USEPA, 1994). In Canada, an estimated 351 million tonnes of waste rock, 510 million tonnes of sulfide tailings, and more than 55 million tonnes of other mining sources have the potential to cause ARD (Minewatch, 2006). Liability costs of potentially acid-generating wastes at mining sites are estimated to be US$ 530 million in Australia, between US$ 1.2 and 20.6 billion in USA, and between US$ 1.3 and 3.3 billion in Canada (USEPA, 2006). Therefore, it is important to use remedial technologies to control the impacts of ARD caused by the considerable amounts mine waste rocks.

ARD remedial technologies are categorized into source control and water treatment technologies (USEPA, 2006). The source control technologies chemically stabilize reactive rocks, or physically isolate waste rocks from water or oxygen, while water treatment technologies reduce contaminants in mine waters. However, selecting the optimal technology for a mine site is quite complex (USEPA, 2006). This is because most environmental decision-making (i.e., the selection process) involves multiple and conflicting objectives (e.g., minimizing risk and cost, maximizing benefit, and maximizing stakeholder preferences) (Kiker et al., 2005; Sadiq and Tesfamariam, 2009). Moreover, input information for each objective is often obtained in different forms (i.e., quantitative and qualitative), which are non-commensurable and thus exacerbate the decision making process (Tesfamariam and Sadiq, 2008). It is worth noting that there is a move away from decision-making based on single objective (e.g., cost or technical feasibility) toward selecting a sustainable remediation technology by considering multiple objectives such as environmental, economical and social objectives.

A framework for selecting remedial alternatives at mine sites, which is recommended by USEPA (1988), is shown in Fig. 1. This

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framework consists of series of steps: scoping, site characterization, treatability investigations, development and screening of alternatives, detailed analysis of alternatives, and selection of optimum alternative. The scoping step consists of collecting existing data, identifying the boundary of a study area, identifying the remedial action objectives, assembling a "technical advisory committee," and preparing the project plan. The site characterization step involves conducting field investigation, defining the nature and extent of the contamination, identifying regulatory standards and requirements, and conducting a baseline risk assessment. If there is no adequate data to evaluate technologies, the treatability investigation step is followed, where the evaluation of bench or pilot-scale technologies is performed. In the next step, Development and Screening of Alternatives, potential technologies are identified and screened. These, technologies are then assembled into potential alternatives and screened. Next, in the Detailed Analysis of Alternatives, the developed alternatives are analyzed against established criteria, and then, using the results of this analysis, compared with each other. In the final step, Select Optimum Alternative, the optimum alternative is selected based on information obtained from the detailed analysis of alternatives. In this framework, experts conduct remedial selection analysis without multiple criteria decision analysis (MCDA) aids. However, the literature shows that humans are not capable of solving multiple objectives unaided. When they attempt to do so, opposing views are often discarded (McDaniels et al., 1999).

MCDA methods deal with a problem whose alternatives are predefined and decision-makers rank available alternatives based on the evaluation of multiple criteria (Tesfamariam and Sadiq, 2006; Sadiq and Tesfamariam, 2009). There are many MCDA methods, most of which consist of four steps – (i) structuring the decision problem, (ii) articulating and modeling preferences, (iii) aggregating the alternative evaluations (preferences); and (iv) making recommendations (Guitouni and Martel, 1998). The main differences between these methods lie in the type of algorithm used to aggregate alternative evaluations, the types of input data required, and their final results (i.e., a single alternative vs. rank of alternatives). The literature classifies the MCDA methods into elementary, utility theory, and outranking (Belton and Stewart, 2002; Figueria et al., 2005). The elementary methods identify a non-

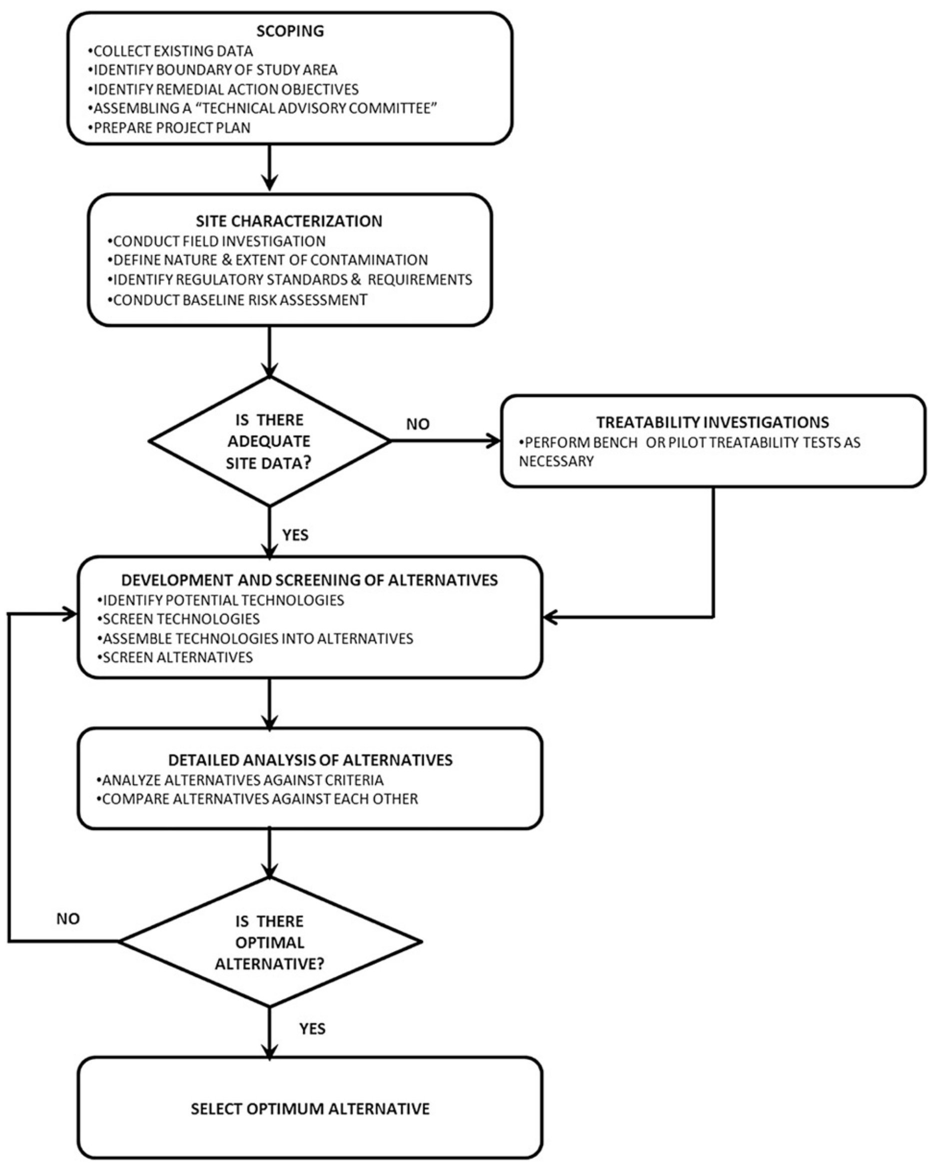

Fig. 1. The USEPA (1988) framework for selecting remedial alternatives at mine sites.