



Full length article

Sustainability assessment of groundwater remediation technologies based on multi-criteria decision making method

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ABSTRACT

Sustainability assessment of the technologies for groundwater remediation is of vital importance for helping the decision-makers to select the most sustainable technology among multiple alternatives. This paper aims at developing an innovative methodology for sustainability assessment of the technologies for groundwater remediation. A total of eight criteria have been used for sustainability assessment of the technologies for groundwater remediation in this study, and they are capital cost, detection and analysis costs, and operation and maintenance costs in economic aspects, effect of secondary pollution environmental aspect, effectiveness for water quality improvement and time for remediation in technological aspect, the effect on public health in social aspect, and policy support belonging to political aspect. The relative priorities of the alternative technologies with respect to each criterion were scored by Analytic Hierarchy Process (AHP), and it was also employed to calculate the weights of the criteria. After determining the decision-making matrix, ELECTRE was employed to rank the alternatives according to their sustainability performances. An illustrative case has been studied by the proposed method, monitored natural attenuation (MNA) has been recognized as the most sustainable technology for groundwater remediation, followed by pump-treat (P&T) technology, permeable reactive barriers (PRB) and air sparging (AS). Finally, Sensitivity analysis was also carried out to test the robustness of the results.

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1. Introduction

With the booming of China's economy and the development of China's process industry for modernization, especially the heavy industry including chemical industry, energy industry, steel industry, and cement industry, more and more wastewater that contains toxic and harmful substances was generated. Similarly to the developed countries, some soil and groundwater in the industry area was polluted due to the discharge of the wastewater. For instance,

it was estimated that around 10%–30% of the underground storage tanks in US leaked, and more than 30% of the gas stations, almost all the chemical factories and oil refineries had serious leakage phenomenon (Flathman et al., 1994; Zhao, 2012). China also faces severe groundwater and soil pollution problems due to the industrialization. Recently, some organic substances, heavy metal and radioactive wastes entered the groundwater system in some regions of China due to the inappropriate treatment of the industrial wastes, discharge in contamination accidents, and the leakage of underground oil storage facilities (Zhang et al., 2006). Yang et al. (2012) pointed out that the contaminated groundwater caused by the spill and leakage of petroleum hydrocarbons would cause great threats to the local environment and people's health. Groundwater contamination becomes more and more serious recently. In order to address this problem, many different technologies for groundwater remediation have been developed (Barcelona, 2005).

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As mentioned above, there are usually various different technologies for groundwater remediation. However, different technologies for groundwater remediation have different economic performances, cause different levels of secondary pollutions, and also lead to different social impacts. Therefore, it is usually difficult for the decision-makers/stakeholders to select the most suitable technology from among multiple alternative technologies (He et al., 2006; Khelifi et al., 2006; Lu et al., 2015; Ren and Sovacool, 2014) as it is a multi-criteria decision-making problem and the decision-makers/stakeholders usually have to consider multiple criteria. Recently, the concept of sustainability has been widely incorporated in selecting the most suitable technology among many available technologies to achieve the targets of the decision-maker/stakeholders (Manzardo et al., 2012). Sustainability assessment can provide insights and implications to the users for promoting sustainable development by helping them to choose the most sustainable scenario to achieve their objective among multiple alternatives. Similarly, sustainability assessment of the technologies for groundwater remediation can investigate the sustainability performances of different alternative technologies and identify the most sustainable one. The World Commission on Environment and Development Sustainable development defined sustainable development as “development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). Sustainability is usually recognized to have the main three pillars including economic, environmental, and social aspects (Othman et al., 2010), the most famous is the so-called “Triple Bottom Line (TBL)” (Norman and MacDonald, 2004), which can measure the sustainability by analyzing economic, environmental and social performances simultaneously. However the technological and political aspects are also incorporated in sustainability assessment, because the criteria in these two aspects usually exert the criteria in the main three pillars of sustainability economic, environmental and social aspects (Ren et al., 2016, 2015a,b,c). Therefore, developing appropriate criteria system for sustainability assessment of the technologies for groundwater remediation is of vital importance for selecting the most sustainable technology for groundwater remediation.

There are many studies focusing on multi-criteria decision making on selecting the technology for groundwater remediation. For instance, Khelifi et al. (2006) employed PROMETHEE II method to rank the alternative technologies for groundwater remediation based on technical, economical, environmental and social criteria. Zhang et al. (2009a,b) used data envelopment analysis based approach to design the petroleum-contaminated groundwater remediation systems. Vranes et al. (2000) developed a Decision Aid for Remediation Technology Selection (DARST) for decision-makers to assess the available technologies and select the best remedial options. An et al. (2016) developed a novel MCDM method by combining the logarithmic fuzzy preference programming based fuzzy analytic hierarchy process and the improved ELECTRE method for ranking the alternative technologies for groundwater remediation. Banar et al. (2015) employed Analytic Network Process (ANP) and ELECTRE III to assess different site remediation technologies. All MCDM methods presented in these studies can help the decision-makers to select the appropriate technology among multiple alternatives for groundwater remediation. However, there are still some two issues to be improved, one is about the determination of the complete criteria system for sustainability, and another is about scoring the alternatives with respect to the soft criteria.

Developing a novel framework for sustainability assessment of groundwater remediation technologies which is usually a multi-criteria decision making problem with many soft criteria and conflicting criteria (Afgan et al., 2000; Ren et al., 2015a; Kahraman et al., 2009) can help the decision-makers/stakeholders to select

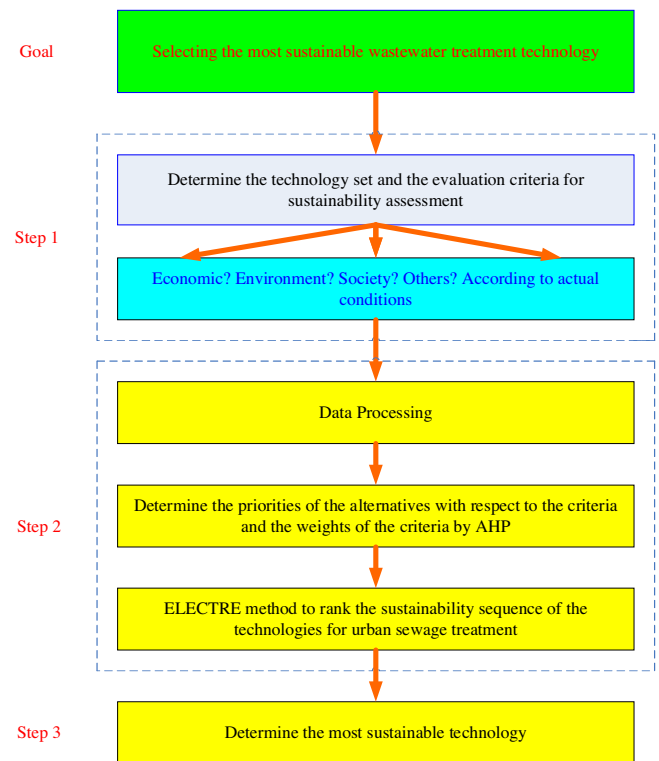


Fig. 1. Framework of the proposed method for selecting the most sustainable technology for groundwater remediation.

the most sustainable technology for groundwater remediation among multiple alternatives for promoting sustainable development. In addition, searching for the most sustainable technology for groundwater remediation among different alternatives requires a set of decision criteria that may include environmental, economic, resource and social aspects. This study is to develop a sustainability decision support framework for prioritizing the alternative technologies for groundwater remediation by developing the evaluation criteria system, and employing the combined multi-criteria decision making method for ranking the alternatives.

Four technologies for groundwater remediation including pump-treat (P&T), monitored natural attenuation (MNA), permeable reactive barriers (PRB), and air sparging (AS), have been studied by the proposed method.

2. Methods

This study presenting a decision supporting framework for selecting the most sustainable groundwater remediation technology has been presented in Fig. 1. The goal is to select the most sustainable groundwater remediation technology. It consists of three steps: the first step is to select the suitable criteria for sustainability assessment; the second step is to use the proposed MCDA method to rank the alternatives; and the third step is to determine the most sustainable groundwater remediation technology.

2.1. Criteria selection for sustainability assessment of groundwater remediation technology

Sustainable development depends on many variables (Onat and Bayar, 2010). Accordingly, sustainability assessment is a complex multi-criteria problem, the first difficult question which the decision-makers/stakeholders has to face is: how to select the criteria for sustainability assessment? Now there is not a solid answer. There are various criteria for measuring the sustainability per-

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