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The application of a hybrid model for identifying and ranking indicators for assessing the sustainability of wastewater treatment systems

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A B S T R A C T

This paper proposes a combination of the Fuzzy Delphi and Fuzzy Analytic Hierarchy Process (FAHP) as an efficient tool for dealing with complex decision-making problems and to prove that integrating the Fuzzy Delphi and FAHP modeling is an objective and practical process. The application of these methods allows a large amount of information to be aggregated in a rigorous manner. The suggested fuzzy set theory helps to represent the uncertainty and vagueness of human's subjective thinking process in dealing with decision problems. This hybrid approach enables decision-makers to evaluate priorities more efficiently and objectively and make the decision process more reliable. Therefore, the main goal of the present research is to develop this decision support approach to identify the key evaluation criteria and indicators in the process of selecting industrial wastewater treatment technology (WTT) from a sustainability perspective based on expert opinion and questionnaires. Since a realistic evaluation needs to be conducted in an actual condition, Iran's steel industry was selected as the case study. In this research, based on the findings of the literature review and Fuzzy Delphi method screening, several evaluation criteria and indicators are identified. Then, the FAHP is employed to examine their relationships under a hierarchy structure and to determine their weights and priorities. The findings of this paper can be applied as a reference for the steel industry in decision-making for the selection of the optimal wastewater treatment technology. In addition, other industries can apply this feasible and practical approach in their decision-making process with respect to their differences in capacities, limitations, wastewater characteristics and local conditions.

Keywords: Sustainability assessment; Criteria and indicators; Wastewater treatment technology; Fuzzy Delphi; FAHP

1. Introduction

In sustainable water management, the control of water pollution and protection of its quality are considered crucial points. In countries experiencing high environmental pressure and water resources scarcity, employing an effective Q3 pollution control system is vital. An example of such a country is Iran, which is located in an arid and semi-arid area. In Iran, the average annual rainfall, about 250 mm, is about one third of the average world precipitation. Consequently, Iran presently faces water scarcity, and, by 2035, is predicted to face water stress. Furthermore, rapid population growth and industrial and agricultural development are producing a huge amount

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of municipal, industrial and agricultural effluents that are threatening the quality of the water resources.

Among the different industries, the steel industry, as a strategic and national industry, has a significant role. The steel industry is the second biggest industry in the world after oil and gas with an estimated global turnover of 900 billion USD. Steel is used in every important industry: energy, construction, automotive and transportation, infrastructure, packaging and machinery. By 2050, steel use is projected to increase by 1.5 times more than the present levels in order to meet the needs of a growing population (World Steel Association, 2015). Now, Iran is ranked 14th among the major steel producing countries in the world and is the top steel producer in the Middle East. On the other hand, steel plants use a tremendous amount of water for waste transfer, cooling and dust control. Wastewater is generated in huge quantities in this industry and contains many dissolved, and undisclosed substances and chemicals. Accordingly, the treatment of steel industrial wastewater requires a variety of strategies to remove the different types of contaminants. Such treatments include: the removal of solids, oil and grease, and biodegradable organics, as well as the treatment of toxic materials, acids and alkalis, and other organics (Sinha et al., 2014).

In general, the selection of the appropriate technology is the first step toward achieving sustainability (Kalbar et al., 2012a). Sustainable technology is a system that does not threaten the quantity and quality (including diversity) of the resources. It is very similar to what used to be defined as appropriate technology, namely technology that is compatible with or readily adaptable to the natural, economic, technical, and social environment, and that offers a possibility for further development (Balkema et al., 2002). Therefore affordability, acceptability and manageability are the three main perspectives in determining the appropriate technology. Since, the sustainable solutions are based on the sustainability criteria and indicators, their determination is an important step and, since the 1990s, they have emerged as a common device for measuring progress toward sustainable development. Governments, international agencies, nongovernmental organizations, and researchers have all contributed to the development of indicators that can aid stakeholders in making sound decisions (Murray et al., 2009).

In order to provide a systematic approach for conducting a comprehensive evaluation of criteria and the indicators related to the selection of sustainable WTT in the steel industry, this paper is organized as follows. Firstly Section 2 reviews the literature, Section 3 describes the adopted methodology and then Section 4 contains the results and findings of the case study to which the method has been applied. Finally the last section presents the derived conclusions and suggests directions for further research.

2. Literature review

As human activity is closely associated with sustainability, in terms of water and wastewater managements, wastewater treatment plants play a key role, and are typically evaluated by end-of-pipe approaches (Garrido-Baserba et al., 2014). For assessing the optimal wastewater treatment technology and translating its appropriateness, the first step is to review the most commonly used criteria and indicators that have been proposed by various researchers (Balkema et al., 2002; Muga and Mihelcic, 2008; Singhirunnusorn and Stenstrom, 2009; Kalbar et al., 2012a). The sustainability criteria and indicators attempt to account for the local, regional priorities, and institutional aspects. They also quantify whether the technology is suitable for a given decision-making situation (Kalbar et al., 2012a). While the economic, environmental, and social–cultural indicators give insight into the efficiency of the solution, the functional indicators determine the effectiveness of the solution (Balkema et al., 2002).

Like all sustainability indicators, the selection of the criteria and indicators for determining an appropriate wastewater treatment technology that enables sustainable development, presents a challenge to the policy makers (Kalbar et al., 2012b). Decision-making in environmental projects requires consideration of the trade-offs between the socio-political, environmental, and economic impacts and is often complicated by the conflicting views of the various stakeholders (Huang et al., 2011). It is essential for the assessment of sustainability that the different dimensions are not judged separately, as such judgment should balance the different dimensions of sustainability, thus making the selection of sustainable wastewater treatment systems a multi-objective optimization problem (Balkema et al., 2002). In addition, the integration of the heterogeneous and uncertain information demands a systematic and understandable framework for its organization (Huang et al., 2011). Thus, a decision problem can be defined as a complex system with several elements that have to be considered in the evaluation.

In developing countries, and in light of the growing economy and increasing pressures on existing environmental resources, applying a decision support tool in environmental decisions based on the participation of various stakeholders is essential. This support could be granted by Multiple-Criteria Decision Analysis (MCDA) (Bottero et al., 2011) or which is a sub-discipline and full-grown branch of operations research that concerns the mathematical and computational design tools to support the subjective evaluations (Behzadian et al., 2012). Over the last decade, there has been a significant growth in the environmental applications of MCDA across all environmental application areas (Huang et al., 2011). MCDA methods allow several criteria to be taken into account simultaneously in a complex situation and are designed to help decision-makers (DMs) integrate the different options, which reflect the opinions of the actors involved (Figueira et al., 2005). The participation of the DMs in the process is a central part of the approach (Bottero et al., 2011).

An extensive literature review demonstrates the increasing application of MCDA, especially AHP, in water and wastewater context. Kalbar et al. (2012a,b, 2013) employed AHP and TOPSIS in their separate treatment assessments, Freitas and Magrini (2013) used AHP for sustainable water management in a mining complex, Molinos-Senante et al. (2014) compared the sustainability of seven WTT for secondary treatment by applying AHP for determining the weights of related indicators, Ghaitidak and Yadav (2015) used AHP for proposing the optimal coagulation condition in greywater treatment, Ehrampoush et al. (2016) applied AHP for choosing the best dye removal method in textile wastewater treatment, Hadipour et al. (2016) proposed the best alternative for wastewater reuse based on AHP implementation, and Aydiner et al. (2016) conducted AHP for analyzing the preferability of four innovative dual membrane combinations and a traditional system for dairy wastewater treatment. The literature review clearly supports the claim that the AHP can manage effectively: the decision complexity, the need for integrating viewpoints from different decision-makers and the

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