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Offering the Best Remediation Method for Cadmium Contaminated Sediment Using Hybrid FAHP and FVIKOR Models

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Abstract

These days, contamination of sediment and water resources to heavy metals, especially cadmium, cause severe human health and other organism's disorders due to its high toxicity. Remediation of cadmium-contaminated sediments is of particular importance and several studies have been carried out on various remedial techniques. Considering that the remedial actions of sediment are diverse and each of them has its own pros and cons, Choosing the suitable and proper method based on geographical, economical, and social conditions is not only challenging but also plays a key role in implementing a successful remediation action. In this study, multi-criteria decision making model and fuzzy hierarchical analysis were used to find the best approach for restoring polluted sediment. In this regard, important methods and indicators have been determined consisting literature review and experts' opinions. Based on the Weights determination by FAHP, the cost with 46% of weight, the availability of technology (39%), the potential of Pollutant recovery (9%), and time (6%) were determined as the main indicators of decision-making process. Moreover, by using VIKOR as a multi-criteria decision-making model, the best options for cadmium-contaminated sediment were identified. Ranking the options shows that the absorption method by using biological adsorbents (Q=0.002, S=0.274, R=0.205) and electrokinetic (Q=0.005, S=0.271, R=0.214) has been selected as the best possible approaches.

Keywords: Cadmium, FAHP, FVIKOR, Sediment, Water Pollution

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Extended abstract

Introduction

The estuary is one of the richest and most complex aquatic ecosystems, which contains many forms of marine life and provides a suitable environment for the breeding and growth of newly born aquatic animals. In today's world, some marine ecosystems and their species are threatened by human activities such as industrial wastewater production, consumption of fossil fuels, and the extraction of metals. The entry of contaminations to the estuaries can cause various consequences; for example, the presence of small amounts of pollutants can lead to the loss of sensitive species and plants in the media and the growth of resistant species (Bełdowski et al., 2018; Dhamodharan et al., 2019). Among all pollutants, heavy metals are considered the most harmful and threatening sources of pollution in water bodies. Heavy metals usually exist in nature and small amounts are necessary for organisms; however, in large amounts, they can affect living organisms. Cadmium is one of the heavy metals that is very toxic and has caused major problems due to its high stability and non-degradability. In this regard, cadmium is considered one of the most important sources of pollution (Zhao et al., 2018; Losada Ros et al., 2020). Cadmium a heavy metal with high mobility can be easily transferred in water and soil and one of the most common ways of human contamination with cadmium is through the food chain of contaminated products. Therefore, restoration and remediation of polluted sites are highly demanded (Xue et al., 2018).

Materials and Methods

- **Identify Criteria and Alternatives**

In this research hybrid multi-criteria decision-making techniques considering fuzzy AHP and fuzzy VIKOR approach based on triangular fuzzy sets were investigated to identify the best remediation method for cadmium-contaminated sediment. The analytic hierarchy process (AHP) is proposed based on multi-criteria decision-making problems including criteria, alternatives, and goals; (Putra et al., 2018; Wang et al., 2019; Gul, 2020; Salimi et al., 2020). In this process, an approach was used to select the most important criteria and alternatives for contaminated sediment: 1. identifying main criteria and sub-criteria based on literature review and questionnaires 2. extracting preferred remedial actions (alternatives) from analyzing questionnaires 3. Calculating the importance of each criterion by fuzzy AHP and using pairwise comparison matrix, and 4. ranking remediation techniques by fuzzy VIKOR.

- **Calculating the weights of criteria by Fuzzy-AHP**

In the first step, the comparison matrix is formed by using Saaty's nine-point ratio scale. Cost, time, technology availability, and pollution recovery potential are considered as criteria in this process; After scoring each pair of criteria (e.g. criteria i to criteria j) based on averaged preferences, the fuzzy comparison matrix is structured as shown below (Pourjavad and Mayorga, 2016). After the completion of the pairwise matrix, the consistency ratio will be checked by equations (2) and (3)

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12}^{\alpha} & \cdots & \cdots & \tilde{a}_{1n}^{\alpha} \\ \tilde{a}_{12}^{\alpha} & 1 & \cdots & \cdots & \tilde{a}_{2n}^{\alpha} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{n2}^{\alpha} & \tilde{a}_{n2}^{\alpha} & \cdots & \cdots & 1 \end{bmatrix} \quad (1)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

After checking the compatibility of pairwise comparisons, the fuzzy weight of each of the selected indicators is obtained, defuzzied, and normalized.

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$$NW_i = \frac{DF_i}{\sum_{i=1}^{n} DF_i} \quad (4)$$

- **Ranking remediation methods by FVIKOR**

In this research, to determine the best method of cleaning sediments contaminated with cadmium, 6 indicators have been used to prioritize 4 methods of remediation. After weighting the selected indicators, the fuzzy VIKOR method has been used to rank the remediation techniques; based on negative and positive ideal solution and normalized matrix the S, R, and Q were calculated as shown below;

$$\tilde{S}_i = \sum_{j=1}^{J} (\tilde{w}_j \otimes \tilde{d}_{ij}) \quad (5)$$

$$\tilde{R}_i = max_i (\tilde{w}_j \otimes \tilde{d}_{ij}) \quad (6)$$

$$\tilde{Q}_i = v \frac{(\tilde{S}_i \ominus \tilde{S}^*)}{S^{\circ r} - S^{*l}} \oplus (1 - v) \frac{(\tilde{R}_i \ominus \tilde{R}^*)}{R^{\circ r} - R^{*l}} \quad (7)$$

- **Ranking remediation options**

In this step, decisions are made considering R, S, and Q values for the alternatives sorted in descending order. The one with the lowest values in R, S, and Q will be the best option. On the other hand, the best option will be the one with the lowest Q and simultaneously conditions shown below should be considered;

$$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{(m-1)} \quad (8)$$

m value is the number of alternatives

$A^{(1)}$ is the alternative with the first position in the ranking list by Q

$A^{(2)}$ is the alternative with the second position in the ranking list by Q

If the first condition is not met, the second condition will be checked;

$$Q(A^{(M)}) - Q(A^{(1)}) < \frac{1}{(m-1)} \text{ for maximum M} \quad (9)$$

Discussion of Results

Based on the above-mentioned approach, S, R, and Q values were obtained. and are shown in Table **1**.

Table 1 S, R, and Q values

	Q	rank	S	rank	R	rank
Bioremediation	0.19	5	0.594	5	0.315	4
Electrokinetic	0.005	2	0.271	1	0.214	3
Washing Sediment	0.028	3	0.331	3	0.207	2
Adsorption	0.002	1	0.274	2	0.205	1
Solidification/Stabilization	0.143	4	0.487	4	0.315	4

Conclusions

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Pollution of estuaries and bays are rich ecosystems with great biodiversity are considered one of the most serious environmental issues. However, due to the limitations and challenges in developing countries such as Iran, choosing a method in which technology is available, does not involve high costs, needs a relatively short period, and returns some of the implementation costs by pollution recovery, is complicated. In the present study some indicators and sub-indices have been proposed, and the most important ones including Cost, time, and technology availability and pollution recovery potential were selected. The importance of each index was determined using a fuzzy analytic hierarchy process, and some practical remediation methods were selected in Iran. Finally, by using "Fuzzy VIKOR" indicators were ranked. The obtained results show that considering indicators including implementation costs, the time required for the implementation of treatment, the availability of the desired method's technology as well as the potential of pollutant recovery after cleaning, the absorption technique (especially by using bio-sorbents) and electro-kinetic can be the more practical approaches in developing countries.

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