Research Article

Ranking of cadmium low amount measurement systems according to economic, environmental, and functional indicators using ELECTRE analytical method

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Abstract

Cadmium is one of the transition metals, known by the scientific name Cd. One of its main characteristics is the high toxicity, even in very little amounts. Cadmium is often released through industrial effluents, pesticides, chemical fertilizers, and the burning of fossil fuels. Since the presence of cadmium ions in the living organisms’ body, especially humans, can cause serious damage to the liver and pancreas, and also because its role in causing cancer has been proven, measuring very low amounts of this metal is of high importance. In the first step, this study has reviewed and analyzed common laboratory methods for measuring small amounts of cadmium. Then, according to economic, environmental, feasibility, speed, and accuracy factors, all available methods were evaluated using the ELECTRE technique. The results showed that the extraction methods using Dowex Optipore V-493 resin and extraction system in Triton X-114 surfactant, placed in the first and second positions.

Introduction

Today, environmental pollution is one of the most complex challenges of communities, environmental management, and control systems. Among these pollutants in water, soil, and air, the existence of different concentrations of heavy metals has to be mentioned. Meanwhile, among all heavy metals, cadmium is of special importance due to its acute and chronic epidemiological effects [1]. Low concentrations of cadmium are found at about 0.2 mg/kg of the lithosphere, 0.53 mg/kg of the soil surface, and 0.66 mg/kg of the dry weight of the edible plants [2]. Cadmium can leak into the environment through solid waste and wastewater of industries such as; Electroplating, plastics production, mining, alloy production, pigments, and batteries [3]. The International Agency for Research on Cancer (IARC) has identified cadmium as a major carcinogenic agent as well as renal failure [4]. On the other hand, due to the biomagnification and the cumulative effect of small amounts of cadmium in the upper species of the food chain, the importance of measuring small amounts of cadmium in real samples becomes more and more obvious [5]. Separation methods include precipitation, crystallization, freezing, evaporation, distillation, liquid-liquid extraction, solid-phase extraction, droplet extraction, and so on. Due to the measurement limitations for low amounts of cadmium and the lack of decomposition devices, pre-concentration methods are popular. Due to the small amounts of analyte in the samples, different extraction methods have been employed for pre-concentration, each of which has advantages and disadvantages. In some methods, like liquid-liquid extraction long extraction time, and in some others, such as re-extraction along with solvent and activated carbon, a large volume of organic solvent and sample could be the disadvantage [6]. Hence, in recent years, microextraction methods by low sample consumption have been welcomed [7]. The present study also intends to prioritize small cadmium detection systems using the ELECTRE¹ hierarchical analysis method and considering the economic, environmental, feasibility, speed, and accuracy of measurement systems.

¹ELimination Et Choice Translating REality
Materials and methods

Cadmium measurement methods

Researchers and industries have used various methods to measure small amounts of cadmium. In this study, measurement methods and systems will be compared and evaluated based on economic, environmental, feasibility, speed, and accuracy indicators. These methods and systems are described in Table 1.

Data analysis using ELECTRE method

ELECTRE (Elimination and Choice Expressing Reality) method is a multi-decision method first proposed by Benayoun and Roy in 1966. It is based on binary superiority comparisons between alternative decision points for each rating factor [22]. In this method concordance and discordance indexes are defined as measurements of satisfaction and dissatisfaction for decision maker in choosing one alternative over another. These indexes are then used to analyze the outranking relations among the alternatives [23] using following 8 steps [24].

1. Construct a decision matrix
2. Construct the normalized decision matrix
3. Calculate the weighted normalized decision matrix
4. Ascertainment of Concordance to Discordance set
5. Calculation of The Concordance and Discordance Matrices
6. Determine The Concordance and Discordance Dominance Matrix
7. Determine the aggregate dominance matrix
8. Eliminate the less favorable alternative and rank them

In this research, instead of ranking the options, we use a new concept called “non-ranking” [25,26]. For example, \( A_k \rightarrow A_i \) means that the DM and the risk analyst accept that option \( A_i \) is better than option \( A_k \). First, with the help of Equation (1), we convert the decision matrix into a scaleless one.

\[
N_{ij} = \frac{r_{ij}^2}{\sum_{j=1}^{n} r_{ij}^2}
\]

(1)

The matrix of the \( S_{ij} \) concordance set and the \( D_{ij} \) discordance set will be calculated following equation (2) then the criterion of concordance between \( A_i \) and \( A_i \) will be estimated based on equation (3) which the higher value of \( I \) indicates the more appropriateness of \( A_i \) rather than \( A_k \).

\[
D_{ij} = \{ l_{ij} \} \quad S_{ij} = \{ l_{ij} \}
\]

(2)

\[
I_{ij} = \sum_{j=1}^{n} w_{ij} \quad ; \quad \sum_{j=1}^{n} w_{ij} = 1
\]

(3)

The discordance matrix is formed using Equation (4) and the effective concordance matrix based on the minimum threshold of two binary array Boolean matrices named F and
G, based on Equation (5).

\[
N_{ikl} = \frac{\max_{j \in D_{ikl}} V_{kj} - V_{lj}}{\max_{j \in D_{ikl}} V_{kj} - V_{lj}}
\]

\[
T = \sum_{m=1}^{m} \sum_{k=1}^{k} \frac{I_{kj}}{m(m-1)} \quad \bar{N}_I = \sum_{m=1}^{m} \sum_{k=1}^{k} \frac{N_{ik} - I}{m(m-1)}
\]

\[
\begin{align*}
&\text{if } I_{kj} \geq T \rightarrow f_{kj} = 1 \\
&\text{if } N_{ik} < \bar{N}_I \rightarrow g_{kj} = 1 \\
&\text{if } N_{ik} < \bar{N}_I \rightarrow g_{kj} = 0
\end{align*}
\]

Finally, the overall \( h \) matrix, representing the order of relative preferences of the options, will be calculated using Equation (6).

\[
h_{k,l} = f_{k,l} \cdot g_{k,l}
\]

Finally, it should be noted that all of the above mathematical relationships have been implemented in the MATLAB 2012b programming environment.

**Results and discussion**

The analysis begins with scoring each parameter and studied options based on the five indicators of economic, environmental, feasibility, measurement speed, and accuracy. These scores have been obtained by asking from 9 experts in this field. The results are shown in Figure 1.

The ELECTRE calculations were performed on the above values. The results of the prioritization of the mentioned methods are summarized in Table 2.

As shown in the table 2 Options A7 (Dowex Optipore V-493) and A5 (Triton X-114 surfactant) are the first and second positions in the low cadmium metering methods ranking. In this prioritization, economic, environmental, feasibility, measurement speed, and accuracy indices have weights of 0.25, 0.2, 0.1, 0.15, and 0.3, respectively. On the other hand, options A7 and A5 have differences from other options in terms of these indicators. The distribution of the score difference between the A7 option and the other options in the economic indicators (A7-ECH) and measurement accuracy (A7-MEA) is shown in Figure 2.

Considering Figure 2; The A7 and A5 options are significantly different from the other options in terms of economic and measurement accuracy. The difference between the A7 and A5 options is the measurement speed, which creates better conditions for the A7 rather than the A5. Therefore, option A7 was ranked first and option A5 placed next. Malek, et al. (A7) used the solid phase extraction method to measure lead and cadmium ions. In this method, after the reaction between cadmium and lead ions and dibenzyl dithiocarbamate ligand, Dowex Optipore V-493 resin was used to extract the desired complex. After extracting the complex on the resin surface, a solution of nitric acid in acetone was used to wash the resin. Finally, the eluent was injected into an atomic flame absorption device to measure cadmium and lead ions. In this method, after the reaction between cadmium and lead ions and dibenzyl dithiocarbamate ligand, Dowex Optipore V-493 resin was used to extract the desired complex. After extracting the complex on the resin surface, a solution of nitric acid in acetone was used to wash the resin. Finally, the eluent was injected into an atomic flame absorption device to measure cadmium and lead ions. In this method, after the reaction between cadmium and lead ions and dibenzyl dithiocarbamate ligand, Dowex Optipore V-493 resin was used to extract the desired complex. After extracting the complex on the resin surface, a solution of nitric acid in acetone was used to wash the resin. Finally, the eluent was injected into an atomic flame absorption device to measure cadmium and lead ions.
Conclusion

Cadmium is one of the toxic and allergenic metals that is found in the effluent of many industries, including machinery, plating, etc. Small amounts of this metal also have the possibility of biological accumulation and magnification in the body of living organisms and make them face various biological problems. Thus, the measurement of small amounts of cadmium, which is out of the accuracy range of measuring devices, becomes obvious. This study first conducted a library study of different methods for measuring small amounts of cadmium and prioritized these measurement methods using the ELECTRE analytical technique. The results of comparisons and analyzes showed that using Dowex Optipore V-493 resin and the extraction system in Triton X-114 surfactant is more reliable than all other methods of measuring small amounts of cadmium.

References