Multicriteria Algorithms with Applications

Journal Homepage: sciencesforce.com/mawa

Multicriteria Algo. Appl. Vol. 1 (2023) 19–30.

Paper Type: Original Article

A Multi-Criteria Decision Making Methodology for Assessment Performance of Electrocoagulation System

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Received: 30 Mar 2023 **Revised:** 31 May 2023 **Accepted:** 25 Jun 2023 **Published:** 15 Jul 2023

Abstract

The assessment of the performance of an electrocoagulation system is crucial for evaluating its effectiveness in treating wastewater or water. This study summarizes critical points related to the criteria for assessing the performance of an electrocoagulation system. These criteria include treatment efficiency, removal efficiency, energy consumption, electrode performance, reaction time, sludge production and handling, scalability and flexibility, system reliability and maintenance, cost-effectiveness, compliance with regulations, water recovery and reuse, system monitoring and control, chemical usage, system stability and robustness, and operational expertise and training. Considering these criteria enables organizations to evaluate the system's ability to remove contaminants effectively, optimize energy consumption, ensure electrode performance and durability, meet treatment objectives, handle sludge efficiently, comply with regulations, and demonstrate cost-effectiveness. The assessment process helps select an electrocoagulation system that aligns with specific requirements, improves water quality, and contributes to environmental sustainability. We used some multi-criteria decision-making (MCDM) methodology to deal with these criteria. The MABAC method is an MCDM method used to rank the alternatives. The 15 criteria and 10 alternatives are used in this paper. We conducted a sensitivity analysis to check the stability of the results. The main results show the results are stable.

Keywords: Electrocoagulation; Decision-Making; Multi-Criteria Decision-Making; Assessment.

1 | Introduction

Water pollution is a pressing global issue that demands effective and sustainable solutions for treating contaminated water sources. Electrocoagulation is an emerging technology that holds promise for addressing this challenge. This introduction provides an overview of electrocoagulation systems, highlighting their principles, applications, and advantages in water treatment. Electrocoagulation is a process that utilizes electrochemical reactions to remove contaminants from wastewater or water sources. It involves the application of an electric current to an electrolytic cell containing electrodes immersed in the water to be treated [1, 2]. The electrodes, typically made of aluminium or iron, generate coagulant species through the

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https://doi.org/10.61356/j.mawa.2023.16061

dissolution and oxidation of metal ions. These coagulants destabilize suspended solids, emulsions, and dissolved pollutants, facilitating their accumulation and subsequent removal. The electrocoagulation system offers a wide range of applications in water treatment. It removes contaminants, including suspended solids, heavy metals, organic compounds, oils, grease, bacteria, and viruses. This versatility makes electrocoagulation suitable for diverse industries such as municipal water treatment, industrial wastewater treatment, oil and gas, agriculture, food and beverage, etc [3-5].

One of the critical advantages of electrocoagulation systems is their potential for chemical-free treatment. Unlike conventional coagulation methods that rely on adding chemicals, electrocoagulation utilizes the inherent properties of the electrodes to generate coagulants, thereby reducing the need for external chemical additives. This feature minimizes the use of hazardous chemicals, simplifies the treatment process, and reduces the associated chemical handling and storage requirements. Another advantage of electrocoagulation is its adaptability to varying water qualities and flow rates. The system can be fine-tuned to accommodate different water sources, adjusting parameters such as current density, reaction time, and electrode configuration to optimize treatment efficiency [6, 7]. This flexibility enables the system to handle fluctuations in influent water quality and flow, making it suitable for small-scale and large-scale applications. Furthermore, electrocoagulation systems offer potential benefits in terms of energy efficiency. By optimizing the process parameters, such as current density and electrode spacing, energy consumption can be minimized while maintaining effective treatment performance. This energy efficiency contributes to operational cost savings and reduces the environmental footprint of water treatment processes[8-10].

In addition to their treatment capabilities, electrocoagulation systems also exhibit advantages in terms of sludge management. The coagulated contaminants form flocs that can be easily separated from the treated water, resulting in a concentrated sludge. This sludge can be further processed for dewatering or subjected to appropriate disposal methods, such as solidification or stabilization, minimizing the volume of waste generated. Overall, electrocoagulation systems offer a promising solution for water treatment, combining effective contaminant removal, adaptability to various water qualities, energy efficiency, and the potential for chemical-free operation. The technology's versatility and advantages make it a valuable option for organizations seeking sustainable and efficient water treatment solutions [11-13]. Electrocoagulation systems provide a robust and innovative approach to addressing water pollution challenges. Their ability to remove a wide range of contaminants, adaptability to varying water qualities, potential for chemical-free treatment, energy efficiency, and efficient sludge management make them a promising option in water treatment. As the demand for clean water continues to rise, electrocoagulation systems offer a sustainable and effective solution for ensuring the availability of safe and potable water resources [14, 15].

The evaluation of the performance of electrocoagulation systems is a critical task. We used an MCDM methodology to deal with various criteria and rank these criteria under different alternatives to electrocoagulation [16, 17]. This study used the MABAC method as an MCDM method to deal with multiple criteria and rank alternatives [18, 19].

2 | Problem Definition

When assessing the performance of an electrocoagulation system, several criteria can be considered to evaluate its effectiveness and efficiency [20]–[22]. Here are some critical criteria for determining the performance of an electrocoagulation system:

- Treatment Efficiency: Evaluate the system's ability to remove contaminants from the wastewater or water being treated effectively. This can be measured by monitoring parameters such as chemical oxygen demand (COD), total suspended solids (TSS), turbidity, heavy metals, organic compounds, or specific contaminants of concern.

- Removal Efficiency: Determine the system's removal efficiency for target contaminants. This involves measuring the percentage of contaminant reduction achieved by the electrocoagulation process and comparing it to regulatory or desired standards.

- Energy Consumption: Assess the energy consumption of the electrocoagulation system. Energy efficiency is an important criterion, as it directly affects the system's operational costs and environmental impact. Evaluate the power consumption of the volume of water treated or the contaminant removal achieved.
- Electrode Performance: Evaluate the performance and durability of the electrode materials used in the electrocoagulation system. Factors such as electrode lifespan, maintenance requirements, and electrode fouling or degradation should be considered. Electrode material selection and design can impact the system's long-term performance and cost-effectiveness.
- Reaction Time: Consider the time required for electrocoagulation to achieve the desired treatment objectives. Assess the system's reaction kinetics and determine if the treatment process meets the expected treatment timeframes or can be optimized for faster reaction rates.
- Sludge Production and Handling: Assess the quantity and characteristics of the sludge generated during the electrocoagulation process. Evaluate the ease of sludge handling, dewatering, and disposal. Minimizing sludge production and managing it efficiently can reduce operational costs and environmental impacts.
- Scalability and Flexibility: Consider the system's scalability and ability to handle varying flow rates and contaminant loadings. Evaluate whether the electrocoagulation system can be easily adapted or expanded to accommodate changing treatment requirements or increased volumes of wastewater.
- System Reliability and Maintenance: Assess the system's reliability, uptime, and maintenance requirements. Consider factors such as system robustness, sensor calibration, routine maintenance tasks, and the availability of spare parts. A reliable and well-maintained system is essential for consistent performance.
- Cost-Effectiveness: Evaluate the overall cost-effectiveness of the electrocoagulation system, considering factors such as capital investment, operational costs (energy consumption, chemical usage, maintenance), and the system's lifespan. Compare the costs with alternative treatment technologies to determine the system's economic viability.
- Compliance with Regulations: Ensure the electrocoagulation system meets regulatory requirements and standards for the treated contaminants. Evaluate the system's ability to consistently meet effluent quality standards and comply with local, regional, and national regulations.
- Water Recovery and Reuse: Consider the potential for water recovery and reuse within the electrocoagulation system. Evaluate the system's ability to treat and recover water for various applications, such as irrigation, process water, or other non-potable uses. Water reuse can contribute to sustainability efforts and reduce water consumption.
- System Monitoring and Control: Assess the electrocoagulation system's automation, monitoring, and control capabilities. Look for features such as real-time monitoring of critical parameters, remote access for system monitoring and troubleshooting, and automated control algorithms to optimize treatment performance.
- Chemical Usage: Evaluate the need for chemical additives in the electrocoagulation process. Some systems may require the addition of coagulants or flocculants to enhance treatment efficiency. Assess the quantity and cost of chemicals used and consider the potential for chemical-free or reduced-chemical electrocoagulation systems.
- System Stability and Robustness: Assess the system's stability and ability to maintain consistent performance over time. Factors such as influent water quality variations, flow rate changes, or power

supply fluctuations should be considered. A stable and robust system can deliver reliable treatment performance under varying operating conditions.

- Operational Expertise and Training: Evaluate the need for specialized knowledge or expertise to operate and maintain the electrocoagulation system. Consider the availability of training programs, technical support, and resources the system manufacturer or supplier provides to ensure proper system operation and troubleshooting.

3 | Methodology

In this part, the steps of the MABAC method is introduced to evaluate the performance of electrocoagulation [23-26].

Step 1. Build an evaluation matrix

The evaluation matrix is built based on opinions of experts by the crisp value between one and nine.

Step 2. Normalize the evaluation matrix

The evaluation matrix is built based on benefit and cost criteria as:

$$z_{ij} = \frac{a_{ij} - \min_{1<k<m} a_{kj}}{\max_{1<k<m} a_{kj} - \min_{1<k<m} a_{kj}} \tag{1}$$

$$z_{ij} = \frac{a_{ij} - \min_{1<k<m} a_{kj}}{\min_{1<k<m} a_{kj} - \max_{1<k<m} a_{kj}} \tag{2}$$

Where $\max_{1<k<m} a_{kj}$ is the maximum value in factor j between alternatives.

Step 3. Compute the weighted normalized matrix.

The weighted normalized evaluation matrix is computed by the weights of criteria.

$$e_{ij} = w_j(z_{ij} + 1) \tag{3}$$

Where $i = 1,2, \dots m; j = 1,2, \dots n$

Step 4. Calculate the borer approximation area (BAA).

$$B_j = \left(\prod_{i=1}^{m} e_{ij}\right)^{\frac{1}{m}} \tag{4}$$

Step 5. Compute the distance matrix.

$$T = (t_{ij})_{m\times n} = (e_{ij})_{m\times n} - (B_j)_{1\times n} \tag{5}$$

Step 6. Compute the total distance.

$$s_i = \sum_{j=1}^{n} t_{ij} \tag{6}$$

Figure 1. The steps of the MABAC method.

4 | Results

In this part, we discuss the results of the MABAC to evaluate the performance of electrocoagulation system. We used the 15 criteria and ten alternatives. The criteria and alternatives are listed in Figure 2.

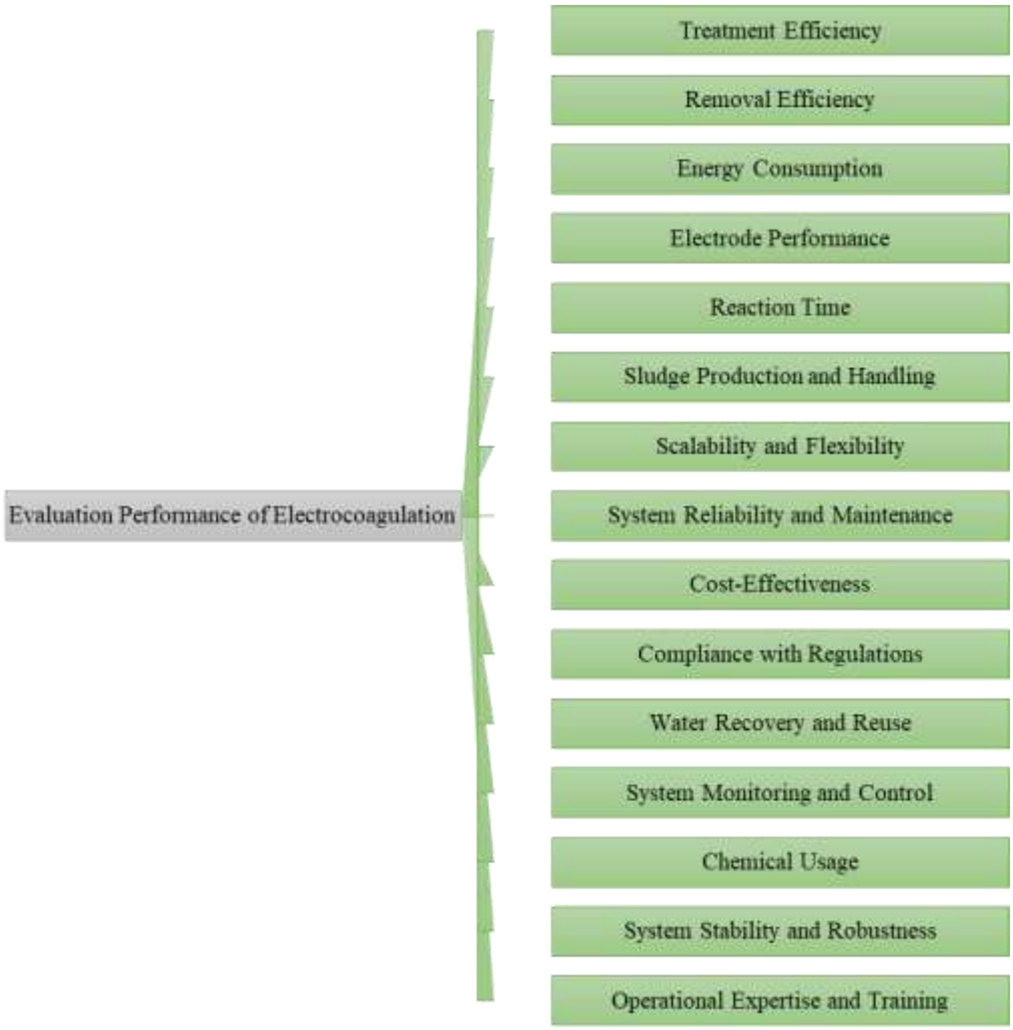

Figure 2. List of 15 criteria of electrocoagulation.

Step 1. Build an evaluation matrix between criteria and alternatives based on the opinions of experts.

Step 2. Normalize the evaluation matrix by using Eqs. (1) and (2) for cost and benefit criteria, cost effectiveness is a cost criterion and all criteria are benefit as shown in Table 1.

Table 1. Normalization evaluation matrix by the MABAC method.

	ELC_1	ELC_2	ELC_3	ELC_4	ELC_5	ELC_6	ELC_7	ELC_8	ELC_9	ELC_{10}	ELC_{11}	ELC_{12}	ELC_{13}	ELC_{14}	ELC_{15}
ELA_1	0.333333	1	0	0.666667	0.142857	0.2	0.5	1	0.4	0	0.428571	0	0.6	0.75	1
ELA_2	0	0	0	0.5	1	0	0.5	0	0.2	0.571429	1	0.166667	0.8	0.5	0
ELA_3	0.833333	0.142857	0	0.5	0	0.2	0.75	0.333333	0.4	1	0.857143	0.666667	0	0.25	0.142857
ELA_4	1	0.428571	0.666667	1	0.857143	0.6	0	0.5	1	0.857143	0.714286	1	0.2	0.75	0.285714
ELA_5	0.666667	0.571429	0.666667	0.5	0.714286	0.8	0.25	1	0.6	0.857143	0.571429	0.333333	0.8	0	0.428571
ELA_6	0.5	0.714286	0.333333	1	0.428571	0	0.75	1	0.6	0.857143	0	0.5	1	1	0.571429
ELA_7	0.166667	0.857143	0.666667	0.166667	0.285714	1	0	0.5	1	0.857143	1	0.833333	0.8	0.25	0.714286
ELA_8	0.166667	1	1	1	0.857143	0.6	1	0.333333	0.6	0.857143	0.571429	1	0.6	0.75	0.857143
ELA_9	0.333333	0.285714	0.333333	0	0.285714	0.6	0.25	0.333333	1	0.714286	0.857143	0.5	1	1	1
ELA_{10}	0	0.714286	0.666667	0.833333	0.714286	0.4	1	0.166667	0	0.428571	0.571429	0.833333	0.6	1	0.857143

Step 3. Compute the weighted normalized matrix. The weights of criteria are computed as shown in Figure 3. The treatment efficiency is the highest weight and operations training is the least weight. Then we compute the weighted normalized matrix as shown in Table 2 by Eq. (3).

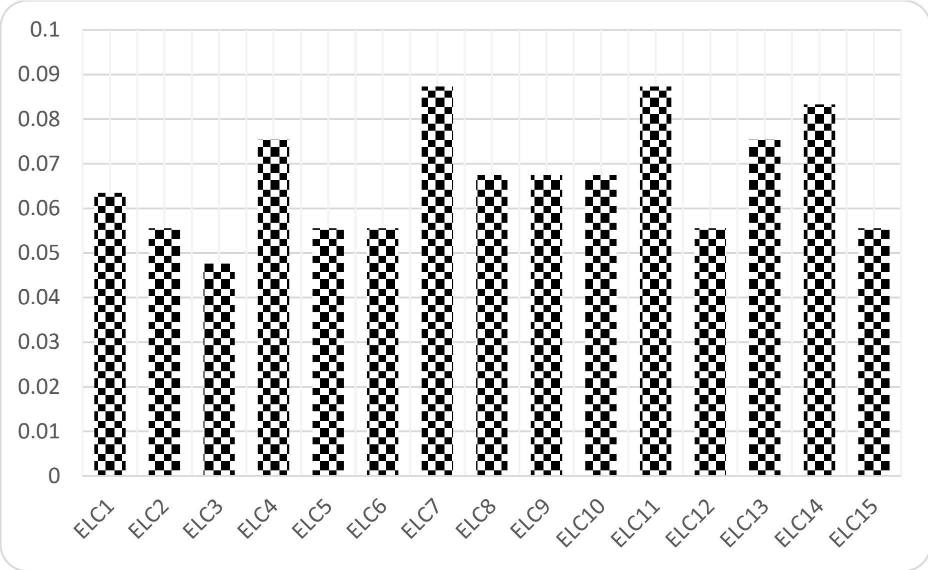

Figure 3. The weights of 15 criteria.

Table 2. Weighted normalization evaluation matrix by the MABAC method.

	ELC_1	**ELC_2**	**ELC_3**	**ELC_4**	**ELC_5**	**ELC_6**	**ELC_7**	**ELC_8**	**ELC_9**	**ELC_{10}**	**ELC_{11}**	**ELC_{12}**	**ELC_{13}**	**ELC_{14}**	**ELC_{15}**
ELA_1	0.084656	0.111111	0.047619	0.125661	0.063492	0.066666667	0.130952	0.134921	0.094444	0.06746	0.124717	0.055556	0.120635	0.145833	0.111111
ELA_2	0.063492	0.055556	0.047619	0.113095	0.111111	0.055555556	0.130952	0.06746	0.080952	0.106009	0.174603	0.064815	0.135714	0.125	0.055556
ELA_3	0.116402	0.063492	0.047619	0.113095	0.055556	0.066666667	0.152778	0.089947	0.094444	0.134921	0.162132	0.092593	0.075397	0.104167	0.063492
ELA_4	0.126984	0.079365	0.079365	0.150794	0.103175	0.088888889	0.087302	0.10119	0.134921	0.125283	0.14966	0.111111	0.090476	0.145833	0.071429
ELA_5	0.10582	0.087302	0.079365	0.113095	0.095238	0.1	0.109127	0.134921	0.107937	0.125283	0.137188	0.074074	0.135714	0.083333	0.079365
ELA_6	0.095238	0.095238	0.063492	0.150794	0.079365	0.055555556	0.152778	0.134921	0.107937	0.125283	0.087302	0.083333	0.150794	0.166667	0.087302
ELA_7	0.074074	0.103175	0.079365	0.087963	0.071429	0.111111111	0.087302	0.10119	0.134921	0.125283	0.174603	0.101852	0.135714	0.104167	0.095238
ELA_8	0.074074	0.111111	0.095238	0.150794	0.103175	0.088888889	0.174603	0.089947	0.107937	0.125283	0.137188	0.111111	0.120635	0.145833	0.103175
ELA_9	0.084656	0.071429	0.063492	0.075397	0.071429	0.088888889	0.109127	0.089947	0.134921	0.115646	0.162132	0.083333	0.150794	0.166667	0.111111
ELA_{10}	0.063492	0.095238	0.079365	0.138228	0.095238	0.077777778	0.174603	0.078704	0.06746	0.096372	0.137188	0.101852	0.120635	0.166667	0.103175

Step 4. Calculate the BAA by using Eq. (4).

Step 5. Compute the distance matrix by using Eq. (5) as shown in Table 3.

Step 6. Compute the total distance by using Eq. (6) as shown in Figure 4.

Table 3. Distance matrix by the MABAC method.

	ELC_1	ELC_2	ELC_3	ELC_4	ELC_5	ELC_6	ELC_7	ELC_8	ELC_9	ELC_{10}	ELC_{11}	ELC_{12}	ELC_{13}	ELC_{14}	ELC_{15}
ELA_1	-0.90363	-0.8754	-0.91491	-0.89433	-0.9203	-0.9112661	-0.89638	-0.86737	-0.91196	-0.94633	-0.9129	-0.9317	-0.90082	-0.88495	-0.87629
ELA_2	-0.9248	-0.93096	-0.91491	-0.9069	-0.87268	-0.9223721	-0.89638	-0.93483	-0.92545	-0.90778	-0.86302	-0.92244	-0.88574	-0.90578	-0.93185
ELA_3	-0.87189	-0.92302	-0.91491	-0.9069	-0.92823	-0.9112661	-0.87456	-0.91234	-0.91196	-0.87887	-0.87549	-0.89466	-0.94606	-0.92662	-0.92391
ELA_4	-0.86131	-0.90715	-0.88316	-0.8692	-0.88061	-0.8890438	-0.94003	-0.9011	-0.87148	-0.88851	-0.88796	-0.87615	-0.93098	-0.88495	-0.91598
ELA_5	-0.88247	-0.89921	-0.88316	-0.9069	-0.88855	-0.87793277	-0.91821	-0.86737	-0.89846	-0.88851	-0.90043	-0.91318	-0.88574	-0.94745	-0.90804
ELA_6	-0.89305	-0.89127	-0.89903	-0.8692	-0.90442	-0.9223772	-0.87456	-0.86737	-0.89846	-0.88851	-0.95032	-0.90392	-0.87066	-0.86412	-0.9001
ELA_7	-0.91422	-0.88334	-0.88316	-0.93203	-0.91236	-0.86682166	-0.94003	-0.9011	-0.87148	-0.88851	-0.86302	-0.8854	-0.88574	-0.92662	-0.89217
ELA_8	-0.91422	-0.8754	-0.86729	-0.8692	-0.88061	-0.88904388	-0.85273	-0.91234	-0.89846	-0.88851	-0.90043	-0.87615	-0.90082	-0.88495	-0.88423
ELA_9	-0.90363	-0.91508	-0.89903	-0.9446	-0.91236	-0.88904388	-0.91821	-0.91234	-0.87148	-0.89815	-0.87549	-0.90392	-0.87066	-0.86412	-0.87629
ELA_{10}	-0.9248	-0.89127	-0.88316	-0.88177	-0.88855	-0.90015499	-0.85273	-0.92359	-0.93894	-0.91742	-0.90043	-0.8854	-0.90082	-0.86412	-0.88423

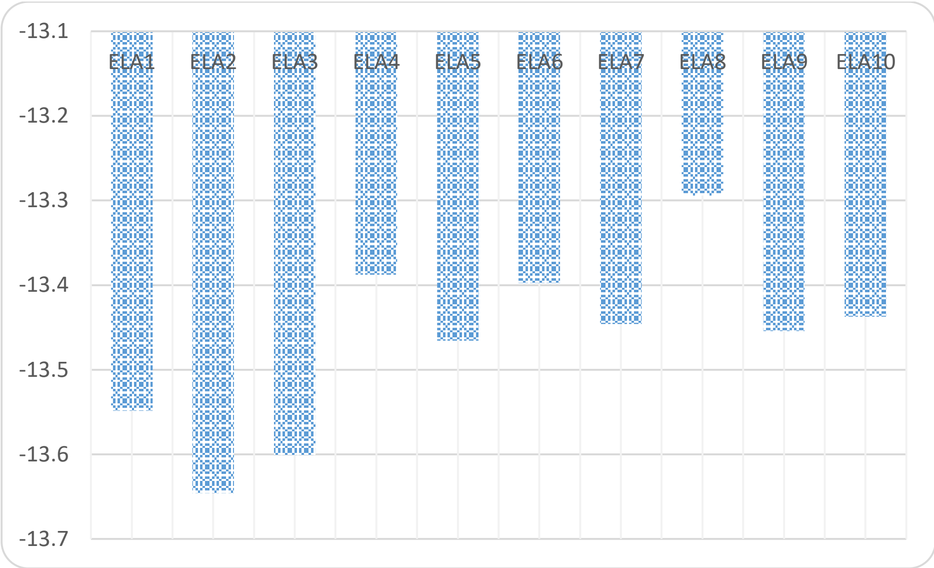

Figure 4. The total distance between alternatives.

5 | Sensitivity Analaysis

We change the weights of criteria and check the rank of alternatives under different weights to ensure the stability of the results. We change the weights of criteria under 15 cases, first case we put first criterion with 0.07 weight and other criteria are equal and so on as shown in Figure 5.

Then we compute the rank of ten alternatives with the MABAC method under different cases. We observe the alternative 8 is the best in all cases and alternative 2 is the worst in all cases as shown in Figure 6.

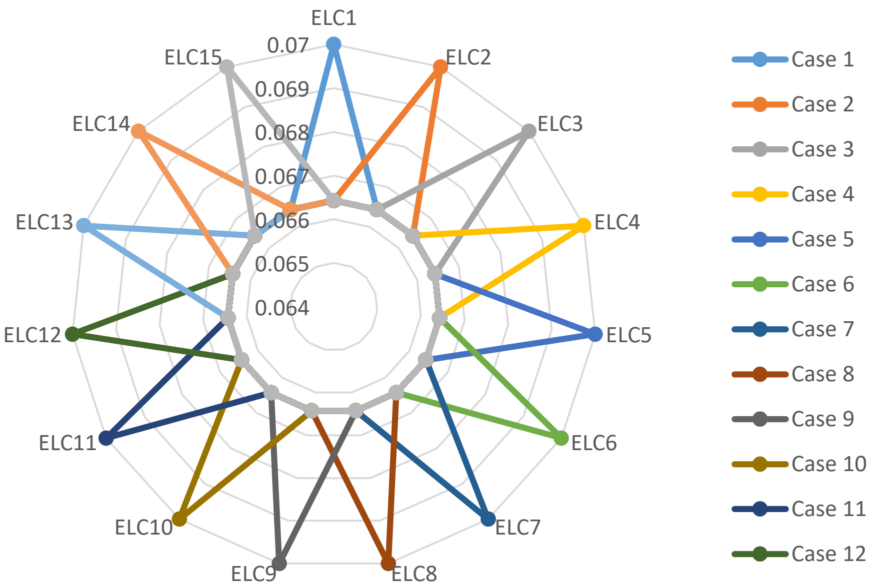

Figure 5. The 15 cases weights of criteria.

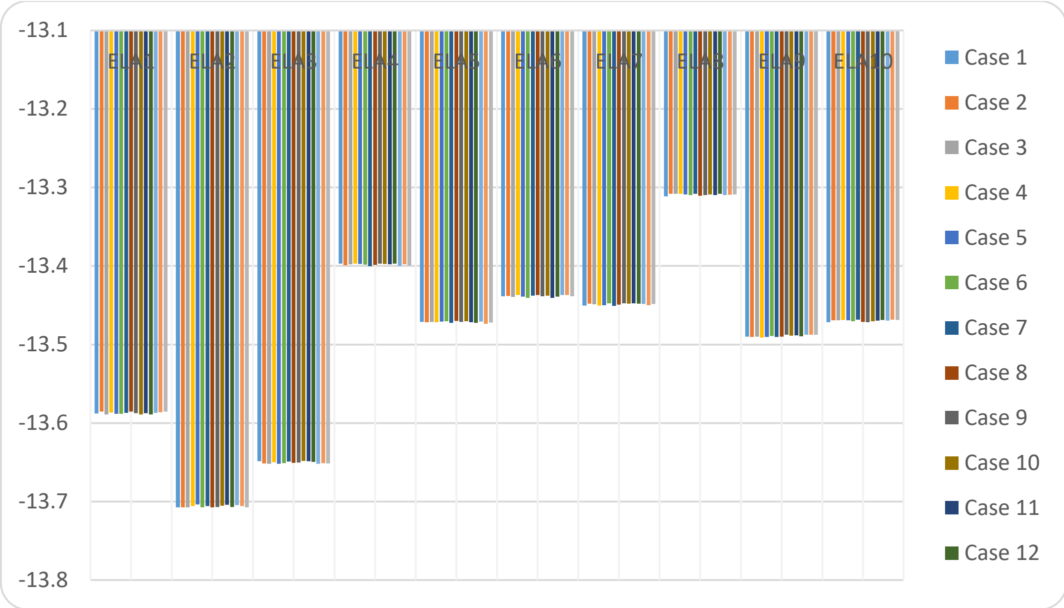

Figure 6. Rank of ten alternatives under sensitivity analysis.

6 | Conclusions

An electrocoagulation system's performance is essential in determining its effectiveness and suitability for treating wastewater or water. Organizations can make informed decisions and optimize the system's performance by evaluating various criteria. The assessment process involves considering treatment efficiency, removal efficiency, energy consumption, electrode performance, reaction time, sludge production and handling, scalability and flexibility, system reliability and maintenance, cost-effectiveness, compliance with regulations, pH and conductivity adjustment, water recovery and reuse, system monitoring and control, chemical usage, system footprint and installation, system stability and robustness, pilot testing and validation, operational expertise and training, case studies and references, and continuous improvement and innovation. Assessing the electrocoagulation system's performance ensures efficient removal of contaminants, optimization of energy consumption, electrode durability, compliance with regulations, and cost-effectiveness. It helps organizations select a system that meets specific treatment objectives, reduces environmental impact, and contributes to water quality improvements. Furthermore, the assessment process allows for identifying areas for optimization and improvement, such as pilot testing, system monitoring, and continuous innovation. Implementing an electrocoagulation system with a thorough assessment of its performance leads to improved water treatment outcomes, efficient operation, and long-term sustainability. We used MABAC as a MCDM methodology for evaluating the performance of the electrocoagulation system. We used 15 criteria and ten alternatives to select the best alternative. We compute the weights of the criteria. Treatment efficiency is the best criterion, and operations training is the worst criterion. We made a sensitivity analysis to ensure all ranks are stable.

Acknowledgments

The author is grateful to the editorial and reviewers, as well as the correspondent author, who offered assistance in the form of advice, assessment, and checking during the study period.

Author Contributaion

All authors contributed equally to this work.

Funding

This research has no funding source.

Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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