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TIBBİ ATIK BERTARAF TEKNİKLERİNİN SIFIR ATIK YAKLAŞIMI KAPSAMINDA DEĞERLENDİRİLMESİNE YÖNELİK ÇKKV MODEL ÖNERİSİ VE ÇÖZÜMÜ

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ÖZET

Bu çalışma, içerisinde çeşitli virüs, bakteri, mikroorganizma barındıran, hem çevre hem de insan sağlığına olumsuz etkileri olan tıbbi atıkların bertaraf tekniklerinin değerlendirilmesi amacıyla yapılmıştır. Çalışma kapsamında tıbbi atıklar ve bertaraf tekniklerinden oluşan çok kriterli bir karar verme modeli önerilmiş ve bu model iki aşamalı bir metodoloji ile çözülmüştür. Çözümün ilk aşamasında ENTROPİ yöntemi ile tıbbi atıklar önceliklendirilmiş, ikinci aşamada ise WASPAS ve EDAS yöntemleri ile alternatif bertaraf teknikleri değerlendirilmiştir. ENTROPİ yöntemine göre sağlık kurumlarında işlemler sonucunda oluşan en önemli tıbbi atıkların 0,1751 önem ağırlığı ile Radyoaktif atıklar olduğu tespit edilmiştir. Bu tıbbi atığı sırasıyla 0,1478 ve 0,1408 önem ağırlıklarıyla Amalgam atıklar ve Kimyasal atıklar takip etmiştir. Bu bulgular sonrasında WASPAS ve EDAS yöntemleri ile alternatif bertaraf teknikleri değerlendirilmiştir. WASPAS yöntemi sonuçlarına göre önerilen modelde tıbbi atıkların bertarafı için en uygun tekniğin 0,7761 bağıl önem değeri ile Mekanik işlemler tekniği olduğu bulunmuştur. Bu alternatif tekniği sırasıyla İrridasyon yöntemleri ve Sterilizasyon teknikleri izlemiştir. Ayrıca EDAS yöntemi sonuçlarına göre de 0,9328 değeriyle en uygun bertaraf tekniğinin mekanik işlemler tekniği olduğu belirlenmiştir. Her iki yöntemle elde edilen araştırma sonuçlarına göre tıbbi atık bertaraf tekniklerinin sıralanması aynı olarak elde edilmiştir.

Anahtar Kelimeler: *Atık yönetimi, Tıbbi Atık, ÇKKV, Entropi, WASPAS, EDAS*

MCDM MODEL PROPOSAL AND SOLUTION FOR EVALUATION OF MEDICAL WASTE DISPOSAL TECHNIQUES WITHIN THE SCOPE OF ZERO WASTE APPROACH

ABSTRACT

This study is carried out in order to evaluate the disposal techniques of medical wastes, which contain various viruses, bacteria, microorganisms and have negative effects on both the environment and human health. Within the scope of the study, a multi-criteria decision-making model consisting of medical wastes and disposal techniques have been proposed and this model has been solved with a two-stage methodology. In the first stage of the solution, medical wastes have been prioritized with the ENTROPY method, and in the second stage alternative disposal techniques have been evaluated with the WASPAS and EDAS methods. According to ENTROPY method, it was found that the most important medical waste generated as a result of the processes in health institutions was Radioactive waste with an importance weight of 0.1751. This medical waste was followed by Amalgam waste and Chemical waste medical wastes with the importance weights of 0.1478 and 0.1408, respectively. After these findings, alternative disposal techniques have been evaluated with the WASPAS and EDAS methods. According to WASPAS method results the Mechanical operations technique was found to be the most appropriate technique for the disposal of medical wastes in the proposed model with 0.7761 relative importance value. This alternative technique was followed by Irridation methods and Sterilization techniques, respectively. In addition, according to the results of the EDAS method, it was determined that the mechanical processes technique was the most suitable disposal technique with a value of 0.9328. According to the research results obtained with both methods, the ranking of medical waste disposal techniques was obtained as the same.

Keywords: *K Waste management, Medical Waste, MCDM, Entropy, WASPAS, EDAS*

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1. Introduction

People benefit from the resources offered by nature to provide their vital activities. While these resources can be renewed by nature's own balance, the unconscious and excessive use of people disrupts this balance, and as a result, difficult or even impossible situations arise for both people and nature. In addition, the amount of waste is increasing day by day as a result of reasons such as increasing population in the world, changing consumption habits, increasing immigration to cities due to attractive living conditions in the city, industrialization and natural disasters [1]. These wastes must be managed with a sustainable and applicable waste plan.

Improper waste management creates problems and hazards for humans, animals, environment and threatens health [2]. In order to prevent all these hazards, it is necessary to take the necessary steps of waste management and adopt a zero waste approach. The zero waste approach aims to reduce and eliminate the waste at its source by reviewing the causes of its formation [3]. Implementing a properly functioning waste management within the framework of the zero waste approach will contribute to the improvement of people's quality of life and to live in a peaceful and healthy environment [4-5].

In this study, it was aimed to evaluate the disposal techniques of medical wastes under the zero waste management approach, and for this purpose, a multi-criteria decision-making (MCDM) model was established. Entropy, WASPAS and Evaluation based on distance from average solution (EDAS) methods were used to solve the model and compare alternative disposal techniques, respectively.

When the literature studies are examined, it is possible to come across a few studies on the evaluation of health waste disposal techniques. For example, Menekşe and Akdağ (2023) made medical waste disposal planning for healthcare units using spherical fuzzy CRITIC-WASPAS. In this research, five alternative disposal techniques (Incineration, electromagnetic wave sterilization, landfill, encapsulation, chemical disinfection) were evaluated according to eight criteria (Human resource requirement, treatment efficiency, health effects, reliability, treatment system capacity, annual operating cost, infrastructure requirement, waste residuals) [6]. Mishra et al. (2020) assessed healthcare waste disposal technologies using new parametric divergence measure [7]. In this research four disposal techniques (Landfill disposal, steam sterilization, incineration, microwave) were evaluated according to six criteria (Public acceptance, treatment effectiveness, reliability, release with health effects, waste residuals, cost) with EDAS method. Ju et al. (2020) used a new framework for health-care waste disposal alternatives selection with multi granular linguistic distribution assessment and EDAS method [8]. In this research, four disposal techniques (Chemical disinfection, electromagnetic wave sterilization and sanitary landfill, pressure steam sterilization, pyrolysis incineration at high temperature) were evaluated according to six criteria (Advancement of processing technology, treatment effectiveness, health effects of emissions, waste residuals, processing cost, public attitude). Liu et al. (2013) assessed of health-care waste disposal methods using a VIKOR-based fuzzy MCDM method [9]. In this research four alternative disposal techniques (Landfill, microwave, steam sterilization, incineration) were evaluated according to six criteria (Public acceptance, treatment effectiveness, reliability, release with health effects, waste residuals, cost). Dursun et al. (2011) used a fuzzy multi criteria group decision making framework for evaluating health-care waste disposal alternatives [10]. In this research four alternative disposal techniques (Landfill disposal, microwave, steam sterilization, incineration) were evaluated according to four main criteria (Social, technical, environmental, economic).

On the other hand, when a literature research is made in terms of the techniques used in the study, it is seen that the three techniques used in this study are not included at the same time in any research, but they are applied to various sector problems with various combinations. For example, there are some researches that used Entropy and EDAS methods. Singh et al. (2023) optimized the tribological properties of natural fiber reinforced brake friction composite materials [11]. Anilkumar et al. (2021) selected the phase change material for solar box cooker integrated with thermal energy storage unit [12]. Yazdani et al. (2020) evaluated renewable energy resources [13]. Ghafari et al. (2020) investigated the ecological potentials of trees, shrubs and hedge species for urban green spaces [14]. Furthermore, there are some researches that used Entropy and WASPAS methods together. For example, He et al. (2023) investigated the challenges of IoT-based applications in high-risk environments, health and safety industries in the Industry 4.0 era, Akgün et al. (2023) selected the carbon-based nanomaterials in phase change materials, Deveci et al. (2022) selected aircraft type, Vaid et al. (2022) made a case study of Silent Genset, Ali et al. (2021) applied these methods for decision making under uncertain evaluations, Zhu et al. (2021) evaluated road safety performance of Chinese provinces [15-20].

As a result of the literature research, it is clear that this study will contribute to the literature with both the MCDM model it proposes and the MCDM solution techniques used in this field. This study, in which the importance of medical wastes is obtained and the techniques that can be used in the disposal of these wastes are evaluated, will guide future studies and professionals interested in the subject.

Considering the researchers conducted in previous years and the reports published by scientists, it was predicted years ago that there will be more pandemics in the globalizing world and that these diseases will affect all societies indiscriminately. The severity of pandemics, where it is not possible to predict from which source, when and how they will arise due to their nature, is determined by how political decision-making mechanisms manage the situation and which health management tools they use.

2. Medical Waste Concept

Healthcare facilities play a crucial role in society, providing essential services for the well-being of individuals. However, the generation of health waste is an unavoidable consequence of medical activities.

The concept of waste can be defined as substances that must be disposed of as a result of production, consumption and some activities carried out by institutions, organizations, factories or individuals during their daily lives, and are undesirable and obligatory. While wastes occur in areas where many activities such as health, education, industry, economy, and cultural activities are carried out in daily life, their harmful effects can be minimized by ensuring their disposal and recycling with appropriate technologies [21-22].

Medical wastes are biological and hazardous wastes. These wastes are formed as a result of the activities of various health institutions. If they are not released into the environment in accordance with regulations due to the microorganisms, bacteria and viruses they contain, they pose a serious danger to the environment and human health.

Medical wastes interact directly or indirectly with humans and the environment from the moment they are formed to their disposal. They negatively affect human and environmental health either directly due to the disease-causing and infectious substances they contain, or indirectly because they are a source of nutrition and reproduction for living things such as flies and mice.

Medical wastes have many negative effects on people and the environment, such as diseases such as plague, cholera, malaria, rabies that can be transmitted directly or indirectly, water and gases leaking from landfills, and random waste [23]. These negative effects can be eliminated with proper medical waste management.

2.1 Medical waste management

The aim of the medical waste management is to dispose of medical wastes resulting from the processes carried out in health institutions with minimum cost by minimizing the negative effects in terms of human and environmental health. It is important to implement a good waste management plan in healthcare institutions, as an unsafe medical waste management can lead to disability and death.

Health waste encompasses a wide range of materials, including sharps, pharmaceuticals, laboratory specimens, and contaminated equipment. Such waste poses significant health risks if not handled and disposed of properly. Improper disposal can lead to the spread of infectious diseases, environmental contamination, and harm to wildlife. By ensuring the appropriate management of health waste, potential threats that pose to individuals, healthcare workers, and the general population can be minimized.

Proper disposal of health waste is crucial for preventing the transmission of infectious diseases. Sharps, such as needles and syringes, if not disposed of correctly, can cause injuries and act as a medium for the transmission of bloodborne pathogens [24]. Similarly, contaminated laboratory specimens and biological samples must be handled with care to prevent accidental exposure. By adhering to strict protocols for waste segregation, packaging, and disposal, healthcare facilities can significantly reduce the risk of infections among patients, staff, and the community at large [6].

The significance of proper health waste disposal extends beyond human health. Inappropriate management of biomedical waste can have adverse effects on the environment. Some pharmaceutical compounds, when discarded incorrectly, may contaminate water sources or soil, affecting ecosystems and potentially leading to the development of drug-resistant organisms [25-26]. By implementing safe disposal methods, such as incineration, autoclaving, or chemical treatment, healthcare facilities can mitigate the environmental impact of health waste, safeguarding ecological balance and biodiversity.

Health institutions cannot dispose of their own medical waste. Medical waste can only be disposed of at officially authorized facilities. Appropriately, collected medical wastes are transported by authorized personnel and vehicles and brought to the relevant disposal facilities. Various methods are applied for the disposal of medical wastes in these facilities.

3. MCDM Model Proposal and Solution for Medical Waste Minimization in Healthcare Institutions

It is very important to dispose of medical wastes in order to prevent the harm they may cause to humans and the environment due to their biological, chemical and physical characteristics. Appropriate disposal of medical wastes comes first in field applications for the purpose of ensuring occupational safety and protecting employee health in order to prevent occupational accidents and occupational diseases arising from medical waste in health institutions.

Medical wastes, which contain microorganisms showing infectious disease characteristics and pose many dangers, cause epidemics, disability and even death if they are not disposed of or if appropriate disposal methods are not used for disposal. These hazards caused by medical wastes can occur through direct contact, pollution of the environment or water resources, and air transport. In order not to encounter the harms of medical wastes, they should be handled with great care and must be collected with suitable garbage bags and disposed of with appropriate methods.

3.1 Purpose of research

In this study, it is aimed to evaluate the techniques used in the elimination of wastes originating from health institutions, which are very dangerous for human and environmental health, and to list the appropriate disposal methods. In addition, in order to achieve this goal, it is aimed to guide the comprehensive evaluations to be made for health institutions by considering the idea of zero waste.

3.2. Proposed research model

In the processes carried out in the health sector, many wastes that have quite different characteristics and are effective on human and environmental health are generated. These wastes must be disposed with appropriate techniques in order to eliminate the harmful effects they have on the world.

While the correct disposal of medical wastes has great importance, the disposal methods used in the meantime also carry various risks. For example; if the wastes will be disposed of by incineration, a suitable gas control system should be used in order to prevent the gases emitted from the incinerators to cause problems, or if the burial method is to be used, the area to be buried should be at a certain distance from the living areas and water channels. Otherwise, it is possible for the living creatures and living in the close environment to be poisoned and to catch infectious diseases.

In order to avoid these and similar problems, the research criteria and alternatives that constitute the research model of this study, which was carried out to evaluate the techniques that can be used in the disposal of medical wastes, are listed and explained below. According to the literature review there is no research that recognized waste types as criteria to evaluating disposal techniques. Because of this innovation this research is differ from the previous ones.

RESEARCH CRITERIA: The medical wastes have been accepted as criteria in the research model in the MCDM structure.

- Infectious waste (MW_1): It is the waste formed by all materials that can be infected, such as surgical materials, dialysis wastes.
- Pathological waste (MW_2): It is the waste formed by body parts, tissues or organs that originate from the operating room or morgue.
- Sharp penetrating waste (MW_3): It is the waste that has the danger of cutting and drilling and can cause injury as a result.
- Radioactive waste (MW_4): It is the waste generated as a result of radiation therapy or laboratory procedures in health institutions.
- Pharmaceutical waste (MW_5): It is the waste such as unused drug or vaccine.
- Amalgam waste (MW_6): It is the waste that occurs in the dental department of health institutions.
- Wastes containing heavy metals (MW_7): It is the waste that consisting of heavy metal powders or paints containing heavy metals.
- Contaminated packaging waste (MW_8): It is the waste that is created by the materials or packaging used in the outer coating of hazardous wastes.
- Pressure vessel waste (MW_9): Pressure vessels, which are widely used in the health sector, are containers that contain toxic gases.
- Chemical waste (MW_{10}): It is the waste that arises from the gases used in health institutions for sterilization of medical equipment or for anesthesia.

RESEARCH ALTERNATIVES: The disposal techniques that will eliminate health wastes have been accepted as alternatives in the research model in the MCDM structure.

- Sterilization (AT_1): It is the process of exposing the wastes to high pressure steam and heat in order to render the medical wastes harmless [6-9; 24].
- Incineration (AT_2): It is the process of incineration of hazardous medical wastes in official authorized facilities [7-9; 24].

- Regular and planned storage (AT_3): It is the procedure of accumulating wastes before they undergo any process such as recycling and disposal [24].
- Mechanical operations (AT_4): It is the process of separating wastes according to their physical properties and ensuring their recycling and recovery.
- Irradiation methods (AT_5): It is the process of breaking down medical wastes with high energy of electron [24].
- Embedding to the soil (AT_6): It is the process of disposing of medical wastes by burying them in a suitable waste pit [6-9; 24].

The MCDM model, which consists of 10 criteria and 6 alternatives proposed within the scope of this study, is shown in Fig. 1.

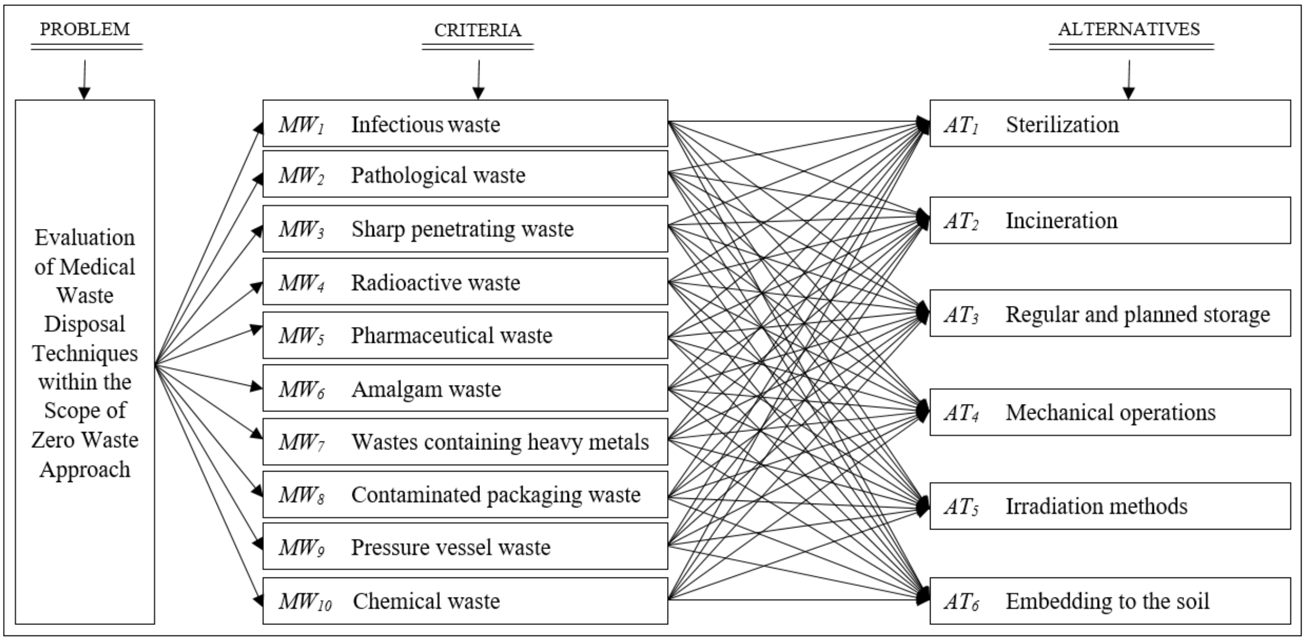

Figure 1. The proposed research model with 10 criteria and 6 alternatives

3.3. A two-stage solution for the research problem

A two-stage solution methodology has been proposed for the solution of the problem discussed in this study, and the proposed MCDM model has been solved in two stages with MCDM techniques.

In the first stage of the solution, the Entropy method has been used to find the importance weights of the criteria, that is health wastes, that make up the model. After the Entropy method, which measures the amount of useful information provided by the existing data set and finds objective results, alternative medical waste disposal techniques have been evaluated by using WASPAS and EDAS methods in the second stage of the solution, and they have been ranked. With this last stage of the solution, the results and rankings obtained with these two techniques have been compared.

Since the entropy method is a suitable scale to be used to evaluate different decision-making processes, it was used to determine the weights in this study. In addition, the method is very useful because it uses the initial matrix to obtain the criterion weights and there is no need to evaluate the criteria.

WASPAS method was developed as a combination of Weighted Sum Model and Weighted Product Model. WASPAS was preferred in the solution phase of this study because it is an MCDM method based on accuracy by using these two methods together, and the aim of the method is to increase the ranking accuracy of alternative techniques.

The EDAS method was used in this study because it is very effective in decision-making problems with some conflicting criteria. In this method, the best alternative is determined according to its distance from the average solution. Therefore, there is no need to calculate the ideal and rare solution in the EDAS method.

Fig. 2 shows the flowchart of the proposed two-stage solution methodology.

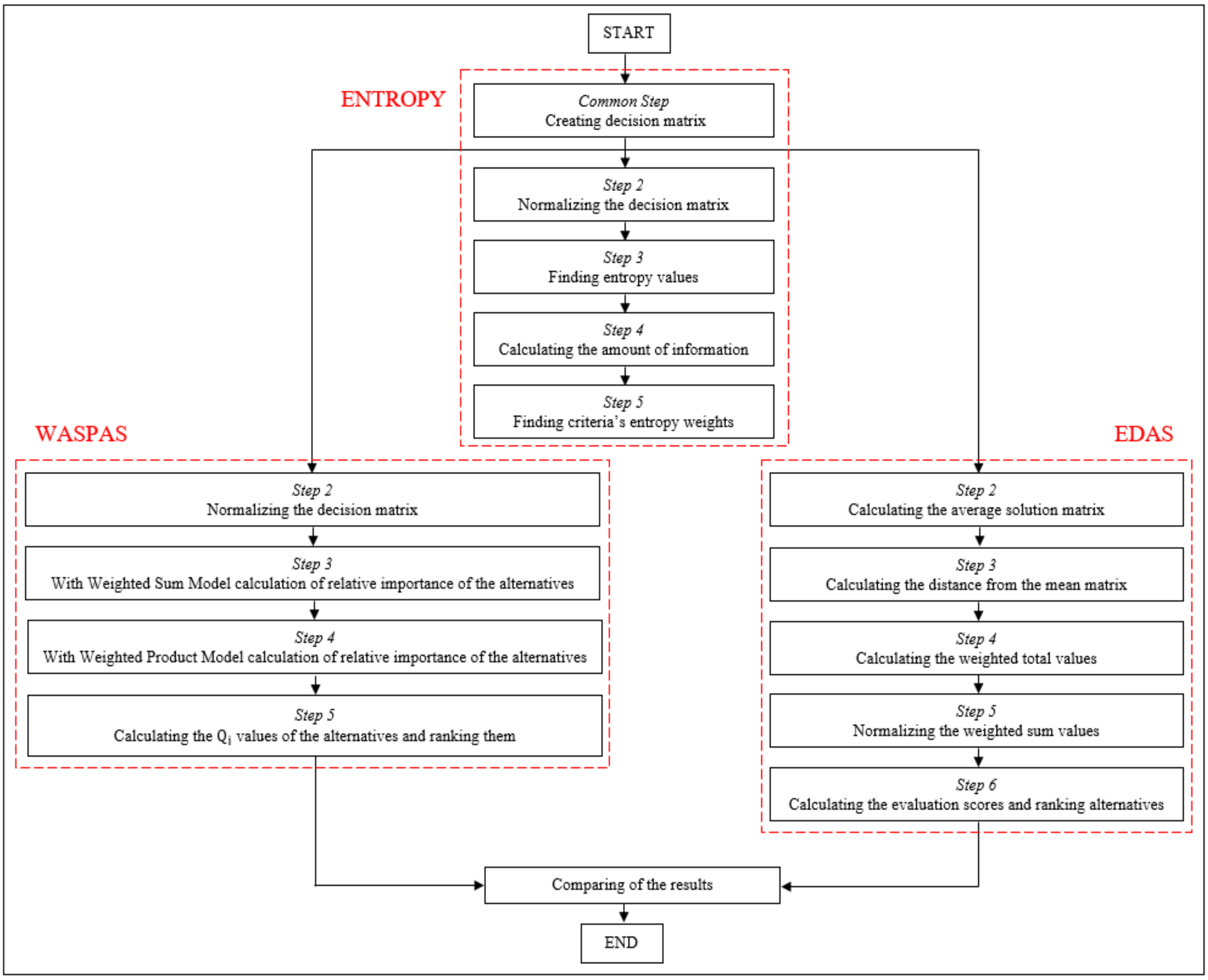

Figure 2. The flowchart of the proposed two-stage solution methodology

3.3.1 Determining of medical wastes importance weights with ENTROPY method

Entropy is one of the objective criteria weighting methods used in MCDM techniques. The concept, formulated according to probability theory, is defined as a measure of uncertainty in information theory. The higher differences between the performances of the alternatives according to any criterion j, the smaller entropy, that is, the less uncertainty. This shows that the relevant criterion contains more information and becomes important in decision making. In other words, the smaller entropy value, the greater the discriminating power of the criterion to the alternatives [13; 17].

Calculation of criterion weights with the entropy method includes the following steps [17-18]:

Step 1 Creating decision matrix: A mxn dimensional $X = \left[x_{ij}\right]_{m \times n}$ decision matrix consisting of m alternatives and n criteria is created as shown in Eq. (1). Here, x_{ij} is the performance value of alternative i for criterion j.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \qquad i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n \tag{1}$$

The initial decision matrix of the MCDM model, which consists of 10 criteria and 6 alternatives proposed within the scope of this study, is shown in Table 1.

The decision matrix is created by taking the average of the evaluations made by a group of experts who are health professionals and managers. There are 8 experts for making the evaluations. While 3 of the experts who made the evaluation are managers in health institutions, 3 of them are experienced experts in recycling, zero waste and disposal techniques (These experts are public employees and made their evaluations within the framework of the legislation, not based on their personal judgment), and 2 of them are academicians related to the subject.

Experts involved in the evaluation phase of the study were asked to evaluate alternative techniques that could be used to eliminate medical waste included in the proposed MCDM model. In this evaluation, experts used a scale ranging from 0 to 100. According to this scale, if the alternative waste disposal technique is more effective in eliminating the relevant criterion, it is evaluated with a higher score.

In this table *MV* shows medical wastes and *AT* shows alternative waste disposal techniques.

Table 1. Initial decision matrix.

	MW_1	MW_2	MW_3	MW_4	MW_5	MW_6	MW_7	MW_8	MW_9	MW_{10}
AT_1	95.0	30.0	85.0	10.0	30.0	80.0	15.0	40.0	80.0	25.0
AT_2	45.0	70.0	20.0	5.0	15.0	20.0	50.0	85.0	5.0	5.0
AT_3	5.0	10.0	70.0	15.0	55.0	10.0	10.0	5.0	65.0	10.0
AT_4	30.0	40.0	75.0	100.0	70.0	90.0	95.0	50.0	30.0	85.0
AT_5	70.0	60.0	25.0	20.0	60.0	25.0	60.0	10.0	100.0	55.0
AT_6	80.0	90.0	100.0	30.0	40.0	5.0	5.0	60.0	55.0	15.0

Step 2 Normalizing the decision matrix: The decision matrix X is normalized in order to convert the criteria values to the common unit. The p_{ij} normalized values of alternative i according to criterion j are calculated with Eq. (2).

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad 1 \leq i \leq m \text{ and } 1 \leq j \leq n \tag{2}$$

Table 2 shows the normalized version of the initial decision matrix created for the research problem.

Table 2. Normalized decision matrix.

	MW_1	MW_2	MW_3	MW_4	MW_5	MW_6	MW_7	MW_8	MW_9	MW_{10}
AT_1	0.2923	0.1000	0.2267	0.0556	0.1111	0.3478	0.0638	0.1600	0.2388	0.1282
AT_2	0.1385	0.2333	0.0533	0.0278	0.0556	0.0870	0.2128	0.3400	0.0149	0.0256
AT_3	0.0154	0.0333	0.1867	0.0833	0.2037	0.0435	0.0426	0.0200	0.1940	0.0513
AT_4	0.0923	0.1333	0.2000	0.5556	0.2593	0.3913	0.4043	0.2000	0.0896	0.4359
AT_5	0.2154	0.2000	0.0667	0.1111	0.2222	0.1087	0.2553	0.0400	0.2985	0.2821
AT_6	0.2462	0.3000	0.2667	0.1667	0.1481	0.0217	0.0213	0.2400	0.1642	0.0769

Step 3 Finding entropy values: By using normalized p_{ij} values, the entropy value (e_j) of each j criterion, that is, the uncertainty measure, is obtained by Eq. (3).

$$e_j = -K \sum_{i=1}^{m} \left(p_{ij} \ln(p_{ij})\right), \qquad K = \frac{1}{\ln(m)} \tag{3}$$

Step 4 Calculating the amount of information: The degree of differentiation of information, that is, the amount of information (d_j) contained in the criterion, is calculated by Eq. (4).

$$d_j = 1 - e_j \tag{4}$$

Step 5 Finding criteria's entropy weights: Using the calculated d_j values, the entropy weight (w_j) of each criterion is obtained by Eq. (5).

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{5}$$

Table 3 shows the calculated e_j, d_j and w_j values for all criteria.

Table 3. The calculated e_j, d_j and w_j values for all criteria.

	MW_1	MW_2	MW_3	MW_4	MW_5	MW_6	MW_7	MW_8	MW_9	MW_{10}
e_j	0.8891	0.9124	0.9270	0.7459	0.9465	0.7856	0.8013	0.8546	0.8910	0.7957
d_j	0.1108	0.0875	0.0729	0.2540	0.0534	0.2143	0.1986	0.1453	0.1089	0.2042
w_j	0.0764	0.0603	0.0503	0.1751	0.0368	0.1478	0.1369	0.1001	0.0751	0.1408

According to the values shown in Table 3, it was found that the most important medical waste generated as a result of the processes in health institutions was Radioactive waste (MW_4) with an importance weight of *0.1751*. This medical waste was followed by Amalgam waste (MW_6) and Chemical waste (MW_{10}) medical wastes with the importance weights of *0.1478* and *0.1408*, respectively. Again according to Table 3, among the 10 medical wastes that make up the proposed MCDM model, the one that has the lowest importance weight, that is, the one that is considered to be the least dangerous, is Pharmaceutical waste (MW_5) with a value of *0.0368*.

After finding the weights of the medical wastes by the entropy method, the WASPAS method is used to evaluate and rank the alternative waste disposal techniques according to the proposed methodology.

3.3.2 Evaluating of research alternatives with WASPAS method

The WASPAS method based on the weighted sum model (WSM) and weighted product model (WPM) was proposed by Zavadskas et al. WASPAS is a decision-making method that allows decision-makers to evaluate alternatives based on multiple criteria. It combines the weighted sum model and the weighted product model to calculate the aggregated scores of alternatives. By incorporating weights and preference functions, WASPAS can provide a comprehensive assessment of different criteria in decision-making processes [19-20].

Evaluation and ranking of alternatives with WASPAS method includes the following steps [17-18]:

Step 1 Creating decision matrix: The first steps of the entropy and WASPAS methods are common. Therefore, the initial decision matrix created with Eq. (1) is also used for the WASPAS method.

Step 2 Normalizing the decision matrix: According to the WASPAS method, the normalization process is done for the benefit based criteria whose values should be maximized with Eq. (6), and for the cost-based criteria whose values should be minimized with Eq. (7).

$$\breve{x}_{ij} = \frac{x_{ij}}{max_i(x_{ij})} \tag{6}$$

$$\breve{x}_{ij} = \frac{min_i(x_{ij})}{x_{ij}} \tag{7}$$

Since all medical wastes in this study must be eliminated by waste disposal techniques, all decision criteria are accepted as benefit-based, normalization process is carried out and the normalized decision matrix is shown in Table 4.

Table 4. Normalized decision matrix with WASPAS method.

	MW_1	MW_2	MW_3	MW_4	MW_5	MW_6	MW_7	MW_8	MW_9	MW_{10}
w_j	0.0764	0.0603	0.0503	0.1752	0.0369	0.1478	0.1369	0.1002	0.0751	0.1408
AT_1	1.0000	0.3333	0.8500	0.1000	0.4286	0.8889	0.1579	0.4706	0.8000	0.2941
AT_2	0.4737	0.7778	0.2000	0.0500	0.2143	0.2222	0.5263	1.0000	0.0500	0.0588
AT_3	0.0526	0.1111	0.7000	0.1500	0.7857	0.1111	0.1053	0.0588	0.6500	0.1176
AT_4	0.3158	0.4444	0.7500	1.0000	1.0000	1.0000	1.0000	0.5882	0.3000	1.0000
AT_5	0.7368	0.6667	0.2500	0.2000	0.8571	0.2778	0.6316	0.1176	1.0000	0.6471
AT_6	0.8421	1.0000	1.0000	0.3000	0.5714	0.0556	0.0526	0.7059	0.5500	0.1765

Step 3 With Weighted Sum Model calculation of relative importance of the alternatives: The total relative importance of alternative *i* is calculated according to *WSM* with Eq. (8).

$$Q_i^{(1)} = \sum_{j=1}^{n} \breve{x}_{ij}.w_j \tag{8}$$

Step 4 With Weighted Product Model calculation of relative importance of the alternatives: The total relative importance of alternative *i* is calculated according to *WPM* with Eq. (9).

$$Q_i^{(2)} = \prod_{j=1}^{n} (\breve{x}_{ij})^{w_j} \tag{9}$$

Step 5 Calculating the Q_i values of the alternatives and ranking them: With Eq. (10), the alternatives' Q_i values are calculated and the alternatives are ranked. The alternative with the largest Q_i value is the best alternative.

$$Q_i = 0.5 \sum_{j=1}^{n} \check{x}_{ij} w_j + 0.5 \prod_{j=1}^{n} (\check{x}_{ij})^{w_j} \tag{10}$$

Table 5 shows the calculated ${Q_i}^{(1)}$, ${Q_i}^{(2)}$and Q_i values for all alternatives.

Table 5. The calculated ${Q_i}^{(1)}$, ${Q_i}^{(2)}$, Q_i values and the ranking of alternatives.

		${Q_i}^{(1)}$	${Q_i}^{(2)}$	Q_i	*Ranking*
AT_1	Sterilization	0.4743	0.3521	0.4131	3
AT_2	Incineration	0.3270	0.1884	0.2577	5
AT_3	Regular and planned storage	0.2033	0.1398	0.1716	6
AT_4	Mechanical operations	0.8078	0.7445	0.7761	**1**
AT_5	Irradiation methods	0.4813	0.3933	0.4373	2
AT_6	Embedding to the soil	0.4009	0.2468	0.3239	4

Considering the values obtained as a result of the WASPAS method according to Table 5, the Mechanical operations (AT_4) technique was found to be the most appropriate technique for the disposal of medical wastes in the proposed model. This alternative technique was followed by Irridation methods (AT_5) and Sterilization (AT_1) techniques, respectively.

After the ranking of the alternatives is found with the WASPAS method, the research problem is solved with the EDAS method this time to analyze the consistency of the results.

3.3.3 Evaluating of research alternatives with EDAS method

The EDAS method based on determining the alternative rankings according to the positive and negative distances of each alternative from the ideal alternative was proposed by Ghorabaee et al. In the method, the evaluation of alternatives is done by looking at higher values of positive distance and smaller values of negative distance [7].

Evaluation and ranking of alternatives with EDAS method includes the following steps [13]:

Step 1 Creating decision matrix: The first steps of the entropy, WASPAS and EDAS methods are common. Therefore, the initial decision matrix created with Eq. (1) is also used for the EDAS method.

Step 2 Calculating the average solution matrix: Eq. (11) is used to calculate the average solution matrix by taking the average of all criteria.

$$AV = [AV_j]_{1\times m} AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{11}$$

Step 3 Calculating the distance from the mean matrix: Positive distance from the mean (*PDA*) and negative distance from the mean (*NDA*) values are calculated by Eq. (12) and Eq. (13), respectively.

$$PDA = [PDA_{ij}]_{n\times m} \tag{12}$$

$$NDA = [NDA_{ij}]_{n \times m} \tag{13}$$

If the criteria are benefit-based, PDA_{ij} and NDA_{ij} values are calculated with Eq. (14) and Eq. (15).

$$PDA_{ij} = \frac{max(0, (x_{ij} - AV_j))}{AV_j} \tag{14}$$

$$NDA_{ij} = \frac{max(0, (AV_j - x_{ij}))}{AV_j} \tag{15}$$

If the criteria are cost-based, PDA_{ij} and NDA_{ij} values are calculated with Eq. (16) and Eq. (17).

$$PDA_{ij} = \frac{max(0, (AV_j - x_{ij}))}{AV_j} \tag{16}$$

$$NDA_{ij} = \frac{max(0, (x_{ij} - AV_j))}{AV_j} \tag{17}$$

Table 6 and Table 7 show the *PDA* and *NDS* matrices generated for the research problem.

Table 6. *PDA* matrix.

	MW_1	MW_2	MW_3	MW_4	MW_5	MW_6	MW_7	MW_8	MW_9	MW_{10}
w_j	0.0761	0.0603	0.0503	0.1751	0.0369	0.1478	0.1369	0.1002	0.0751	0.1408
AT_1	0.7538	0.0000	0.3600	0.0000	0.0000	1.0870	0.0000	0.0000	0.4328	0.0000
AT_2	0.0000	0.4000	0.0000	0.0000	0.0000	0.0000	0.2766	1.0400	0.0000	0.0000
AT_3	0.0000	0.0000	0.1200	0.0000	0.2222	0.0000	0.0000	0.0000	0.1642	0.0000
AT_4	0.0000	0.0000	0.2000	2.3333	0.5556	1.3478	1.4255	0.2000	0.0000	1.6154
AT_5	0.2923	0.2000	0.0000	0.0000	0.3333	0.0000	0.5319	0.0000	0.7910	0.6923
AT_6	0.4769	0.8000	0.6000	0.0000	0.0000	0.0000	0.0000	0.4400	0.0000	0.0000

Table 7. *NDA* matrix.

	MW_1	MW_2	MW_3	MW_4	MW_5	MW_6	MW_7	MW_8	MW_9	MW_{10}
w_j	0.0761	0.0603	0.0503	0.1751	0.0369	0.1478	0.1369	0.1002	0.0751	0.1408
AT_1	0.0000	0.4000	0.0000	0.6667	0.3333	0.0000	0.6170	0.0400	0.0000	0.2308
AT_2	0.1692	0.0000	0.6800	0.8333	0.6667	0.4783	0.0000	0.0000	0.9104	0.8462
AT_3	0.9077	0.8000	0.0000	0.5000	0.0000	0.7391	0.7447	0.8800	0.0000	0.6923
AT_4	0.4462	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4627	0.0000
AT_5	0.0000	0.0000	0.6000	0.3333	0.0000	0.3478	0.0000	0.7600	0.0000	0.0000
AT_6	0.0000	0.0000	0.0000	0.0000	0.1111	0.8696	0.8723	0.0000	0.0149	0.5385

Step 4 Calculating the weighted total values: SP_i and SN_i values, which express the weighted sum of the positive distance from the mean and the negative distance from the mean, are calculated with the help of Eq. (18) and Eq. (19).

$$SP_i = \sum_{j=1}^{n} w_j . PDA_{ij} \quad (18)$$

$$SN_i = \sum_{j=1}^{n} w_j . NDA_{ij} \quad (19)$$

Step 5 Normalizing the weighted sum values: With the help of Eq. (20) and Eq. (21) SP_i and SN_i values are normalized.

$$NSP_i = \frac{SP_i}{max_i(SP_i)} \quad (20)$$

$$NSN_i = 1 - \frac{SN_i}{max_i(SN_i)} \quad (21)$$

Step 6 Calculating the evaluation scores and ranking alternatives: Based on the NSP_i and NSN_i values of each alternative, the evaluation score (*AS*) is calculated by Eq. (22). The alternative with the largest *AS* value is the best alternative.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \quad (22)$$

Table 8 shows the calculated SP_i, SN_i, NSP_i, NSN_i and AS_i values for all alternatives.

Table 8. The calculated SP_i, SN_i, NSP_i, NSN_i, AS_i values and the ranking of alternatives.

	SP_i	SN_i	NSP_i	NSN_i	AS_i	*Ranking*
AT_1	0.2689	0.2742	0.2487	0.5445	0.3966	3
AT_2	0.1662	0.4759	0.1537	0.2095	0.1816	5
AT_3	0.0265	0.6020	0.0245	0.0000	0.0122	6
AT_4	1.0812	0.0809	1.0000	0.6856	0.9328	**1**
AT_5	0.2764	0.2161	0.2556	0.6410	0.4483	2
AT_6	0.1590	0.3290	0.1470	0.4535	0.3002	4

Considering the values obtained as a result of the EDAS method according to Table 8, the Mechanical operations (AT_4) technique was found to be the most appropriate technique for the disposal of medical wastes in the proposed model. This alternative technique was followed by Irridation methods (AT_5) and Sterilization (AT_1) techniques, respectively.

3.4. Comparing the findings

The order of the alternatives shown in Table 5 and Table 8 by WASPAS and EDAS methods is the same. Although the relative importance value of the alternatives obtained by the WASPAS method and the evaluation scores of the alternatives obtained by the EDAS method are different from each other, as seen in Fig. 3, the results obtained by both methods form the same graphical pattern.

As a result, according to the model proposed in this study, in which the techniques to be used for the disposal of medical waste in health institutions are evaluated, the most appropriate and the most prioritized medical waste disposal technique to be used is the Mechanical operations. This technique is followed by Irradiation methods, Sterilization, Embedding to the soil, Incineration, Regular and planned storage methods, respectively.

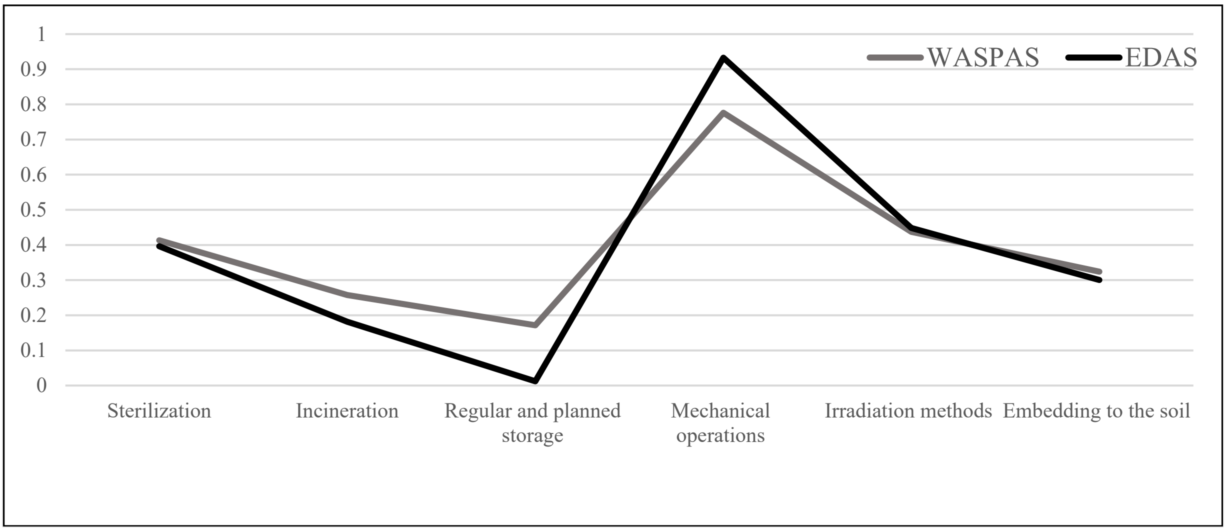

Figure 3. Comparison of WASPAS and EDAS methods results

This study was carried out emphasizes the importance of hospital waste management, as in study that is made by Öncel et al. (2023) [27]. Because hazardous medical wastes generated as a result of hospital activities are among the most important threats to human and environmental health.

After hospital wastes are subjected to appropriate separation conditions, waste collection and transportation optimization studies, as in Rızvanoğlu et al. (2020)'s study, can ensure rapid removal and disposal of waste [28]. Again, as in Karabulut et al. (2022)'s study, the dangerous effects of medical waste on the environment and human health can be reduced by studies on the placement of solid waste in regular landfills [29].

This study provides a great advantage to institutions and employees in making decisions regarding the selection of medical waste disposal techniques according to the type of waste. One of the important advantages of this study is that it determines the importance of medical wastes and guides healthcare institutions and employees in the management of these highly hazardous wastes. The disadvantage of this study is that a sufficiently in-depth result cannot be obtained due to the small number of experts whose opinions were taken.

4. Conclusion

One of the biggest problems of today's world is the unconscious storage of wastes without being collected separately at their source and their random release to the environment. This big problem poses a danger to both the environment and human health, and as a result, various health problems arise. In order to eliminate this big problem, it is necessary to collect the wastes consciously, by people who have been trained on this subject, in accordance with the regulations and to dispose of them with the help of the most appropriate disposal techniques.

In this study, it is aimed to find the most suitable disposal technique that can be used for the disposal of medical wastes in the health sector by solving a proposed MCDM model with MCDM techniques. In the solution of the proposed model within the scope of the study, the importance weights of medical wastes were determined with the Entropy method, and the disposal techniques were evaluated with the WASPAS and EDAS methods, and the results obtained by both methods were compared in terms of consistency.

In the definition, creation, modeling and analysis of the problem discussed in this study, information obtained from literature sources, various researches and expert opinions was used.

According to the calculation results, the ordering of the importance weights of medical wastes from the largest to the smallest is as radioactive waste, amalgam waste, chemical waste, wastes containing heavy metals, contaminated packaging waste, infectious waste, pressure vessel waste, pathological waste, sharp penetrating waste, and pharmaceutical waste. After this ranking, alternative disposal techniques were evaluated with WASPAS and EDAS methods according to waste importance weights. The results obtained with both evaluation methods were compared and it was found that the order of alternative medical waste disposal techniques was consistent and their ordering is as Mechanical operations, Irradiation methods, Sterilization, Embedding to the soil, Incineration, and Regular and planned storage, respectively.

In the light of this information, it is ensured that medical wastes are removed from the environment with minimum danger by applying the most appropriate disposal techniques to medical waste types.

In future studies, new techniques can be added to waste disposal with the development of technology. With the increase in the number of alternative disposal techniques, new alternatives will support the model and opportunities can be provided to bring definite results to waste disposal.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Tulchinsky TH, Varavikova EA, Cohen MJ. Chapter 9 - Environmental and occupational health. The New Public Health. Academic Press Fourth Edition 2023; 681-750.
[2] Krisha D, Sachan HK. Chapter 22 - Hazardous biomedical waste management scenario in developing countries. Waste Management and Resource Recycling in the Developing World. Elsevier 2023; 505-519.
[3] Ma W, de Jong M, Zisopoulos F, Hoppe T. Introducing a classification framework to urban waste policy: Analysis of sixteen zero-waste cities in China. Waste Management 2023; 165: 94-107.
[4] Dong D, Tukker A, Steubing B, van Oers L, Rechberger H, Aguilar-Hernandez GA, Li H, der Voet EV. Assessing China's potential for reducing primary copper demand and associated environmental impacts in the context of energy transition and "Zero waste" policies. Waste Management 2022; 144: 454-467.
[5] Apollon W, Rusyn I, Gonzalez-Gamboa N, Kuleshova T, Luna-Maldonado AI, Vidales-Contreras JA, Kamaraj SK. Improvement of zero waste sustainable recovery using microbial energy generation systems: A comprehensive review. Science of the Total Environment 2022; 817: 153055.
[6] Menekşe A, Akdağ HC. Medical waste disposal planning for healthcare units using spherical fuzzy CRITIC-WASPAS. Applied Soft Computing 2023; 144: 110480.
[7] Mishra AR, Mardani A, Rani P, Zavadskas EK. A novel EDAS approach on intuitionistic fuzzy set for assessment of health-care waste disposal technology using new parametric divergence measures. Journal of Cleaner Production 2020; 272: 122807.
[8] Ju Y, Liang Y, Luis M, Gonzalez EDRS, Giannakis M, Dong P, Wang A. A new framework for health-care waste disposal alternative selection under multi-granular linguistic distribution assessment environment. Computers & Industrial Engineering 2020; 145: 106489.

[9] Liu HC, Wu J, Li P. Assessment of health-care waste disposal methods using a VIKOR-based fuzzy multi-criteria decision making method. Waste Management 2013; 33: 2744-2751.
[10] Dursun M, Karsak EE, Karadayi MA. A fuzzy multi-criteria group decision making framework for evaluating health-care waste disposal alternatives. Expert Systems with Applications 2011; 38: 11453-11462.
[11] Singh T, Singh V, Ranakoti L, Kumar S. Optimization on tribological properties of natural fiber reinforced brake friction composite materials: Effect of objective and subjective weighting methods. Polymer Testing 2023; 117: 107873.
[12] Anilkumar BC, Maniyeri R, Anish S. Optimum selection of phase change material for solar box cooker integrated with thermal energy storage unit using multi-criteria decision-making technique. Journal of Energy Storage 2021; 40(1): 102807.
[13] Yazdani M, Torkayesh AE, Santibanez-Gonzalez EDR, Otaghsara SK. Evaluation of renewable energy resources using integrated Shannon Entropy—EDAS model. Sustainable Operations and Computers 2020; 1: 35-42.
[14] Ghafari S, Kaviani B, Sedaghathoor S, Allahyari MS. Ecological potentials of trees, shrubs and hedge species for urban green spaces by multi criteria decision making. Urban Forestry & Urban Greening 2020; 55: 126824.
[15] He Y, He J, Wen N. The challenges of IoT-based applications in high-risk environments, health and safety industries in the Industry 4.0 era using decision-making approach. Journal of Innovation & Knowledge 2023; 8: 100347.
[16] Akgün H, Yapıcı E, Özkan A, Günkaya Z, Banar M. A combined multi-criteria decision-making approach for the selection of carbon-based nanomaterials in phase change materials. Journal of Energy Storage 2023; 60: 106619.
[17] Deveci M, Öner SC, Çiftçi ME, Özcan E, Pamucar D. Interval type-2 hesitant fuzzy Entropy-based WASPAS approach for aircraft type selection. Applied Soft Computing 2022; 114: 108076.
[18] Vaid SK, Vaid G, Kaur S, Kumar R, Sidhu MS. Application of multi-criteria decision-making theory with VIKOR-WASPAS-Entropy methods: A case study of silent Genset. Materials Today: Proceedings 2022; 50: 2416-2423.
[19] Ali J, Bashir Z, Rashid T. WASPAS-based decision making methodology with unknown weight information under uncertain evaluations. Expert Systems with Applications 2021; 168: 114143.
[20] Zhu JH, Chen J, Li GF, Shuai B. Using cross efficiency method integrating regret theory and WASPAS to evaluate road safety performance of Chinese provinces. Accident Analysis and Prevention 2021; 162: 106395.
[21] Bolan S, Padhye LP, Kumar M et al. Review on distribution, fate, and management of potentially toxic elements in incinerated medical wastes. Environmental Pollution 2023; 321: 121080.
[22] Hou Y, Jia L, Ma W, Hao JL. Analysing the factors affecting medical waste generation in China. Sustainable Chemistry and Pharmacy 2023; 32: 100975.
[23] Odonkor ST, Sallar AM. Correlates of household waste management in Ghana: implications for public health. Heliyon 2021; 7: e08227.
[24] Zhao H, Liu H, Wei G, Zhang N, Qiao H, Gong Y, Yu X, Zhou J, Wu Y. A review on emergency disposal and management of medical waste during the COVID-19 pandemic in China. Science of the Total Environment 2022; 810: 152302.
[25] Govindan K, Nosrati-Abarghooee S, Nasiri MM, Jolai F. Green reverse logistics network design for medical waste management: A circular economy transition through case approach. Journal of Environmental Management 2022; 322: 115888.
[26] Joneghani NM, Zarrinpoor N, Eghtesadifard M. A mathematical model for designing a network of sustainable medical waste management under uncertainty. Computers & Industrial Engineering 2022; 171: 108372.
[27] Öncel M, Yazıcı Karabulut B, Çelik H, Yeşilnacar Mİ. Şanlıurfa'da hastane atıklarının yönetimi bağlamında örnek bir çalışma. Türkiye'de Sıfır Atık: Tespitler, Beklentiler ve Fırsatlar, 25-26 Mart 2023, İstanbul, 134-141.

[28] Rızvanoğlu O, Kaya S, Ulukavak M, Yeşilnacar Mİ. Optimization of municipal solid waste collection and transportation routes, through linear programming and geographic information system: a case study from Şanlıurfa, Turkey. Environmental Monitoring and Assessment 2020; 192: 1-12.
[29] Karabulut Aİ, Yazici Karabulut B, Derin P, Yesilnacar Mİ, Cullu MA. Landfill siting for municipal solid waste using remote sensing and geographic information system integrated analytic hierarchy process and simple additive weighting methods from the point of view of a fast-growing metropolitan area in GAP area of Turkey. Environmental Science and Pollution Research 2022; 29(3): 4044-4061.