Examination of a Hazardous Waste Disposal Plant in the Context of Occupational Health and Safety

MERVE ERCAN[1], GÜLAY ÖZKAN[2], TUĞBA DEMİR ÇALIŞKAN[2], GÖKSEL ÖZKAN[1]

[1] Gazi University, Department of Chemical Engineering, 0570, Ankara, TURKEY
[2] Ankara University, Department of Chemical Engineering, 06100, Ankara, TURKEY

Abstract: - It is required to determine the factors that are dangerous in terms of occupational health and safety in hazardous waste disposal facilities, which is an area where multidisciplinary work is required. It is also needed to find solutions for preventing risks that may cause. In this study; probability, severity and frequency criteria were used as decision criteria and the importance weights of these criteria were determined with fuzzy analytical hierarchy process. Then, 46 risks identified for the five main processes such as entry of waste to the plant, waste analysis, intermediate storage of hazardous waste, disposal of hazardous waste, and auxiliary facilities; were evaluated by fuzzy TOPSIS method according to decision criteria and prioritized according to their level. It is found that the highest priority risks for all sub-process are "fire and explosion".

Key-Words: - Risk analysis, hazardous waste disposal, fuzzy logic, fuzzy analytical hierarchy process, fuzzy TOPSIS method
Received: August 21, 2021. Revised: April 16, 2022. Accepted: May 14, 2022. Published: June 8, 2022.

1 Introduction

Hazardous wastes, which continue to increase due to global production and consumption, are shown as one of the most important working areas of today. Today about 400 million tons of hazardous waste are produced annually in the world. The annual 1.5 million tons of hazardous waste are also produced in Turkey [1]. There are many risks in the ongoing process from the collection of hazardous wastes to their disposal. Chemical, flammable, explosive, toxic, reactive, etc. in each process. In addition to the damage to the environment, the presence of these substances threatens both employee health and public health. In this context, it is vital to control such high amounts of hazardous waste for both the environment and health. Therefore, the management hierarchy of hazardous wastes has been created. All options from the most important option to the last one are determined. They are such prevention, reduction, reuse, recycling, energy recovery and destruction steps. In addition, the main criteria in hazardous waste management to evaluate waste disposal programs can be divided into five different groups: finance, the environment, health and safety, community perception and life. Eskandari et al. tried to select the best place for solid waste disposal in terms of environmental, economic and social–cultural views for Marvdasht part of Iran [2]. They used an integrated multi-criteria decision making approach in their study. Chauhan et al.(2016) used hybrid method, for the selection of a sustainable location of healthcare waste disposal facility [3]. Furthermore, fuzzy-AHP, TOPSIS and Promethee methods were used to evaluation of hazardous waste transportation firms [4]. Arikan et al.(2017) used PROMETHEE and fuzzy TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) to select the most feasible solid waste treatment technology for the existing scheme [5]. For risk evaluation, several methods have been developed, such as analytic hierarchy process (AHP), fuzzy AHP, analytic network process (ANP), grey method, and extenics theory.

Hybrid multi criteria decision making model with a linear programming (LP) model to tackle the issue of safe disposal of hazardous and infectious healthcare waste helped the hospital management in selecting economically, socially, and environmentally sustainable healthcare waste disposal firm [6]. Also Multi-Criteria Decision-Support Model was developed for a zero-waste footprint for the iron and steel industry in developing Countries [7]. Integrated multi-criteria decision-making method (fuzzy analytic hierarchy process (FAHP) and fuzzy axiomatic design (FAD)) was used for hazardous waste disposal site selections [8]. There are no better or worse techniques, but some techniques better suit to particular decision problems than others do. Most of the researchers apply multi-criteria decision-analysis (MCDA) methods. One of the MCDA methods, TOPSIS under fuzzy environment, namely fuzzy TOPSIS, has been successfully applied in many practical, real-world challenges [9].

The aim of using Fuzzy logic-based risk assessment method is to eliminate the subjectivity which is one of the biggest cons of classical risk assessment applications. Therefore, we reach the results which are closer to the reality. In addition, Fuzzy Analytic Hierarchy Process (FAHP) provide an analytic tool to analyse the risk under incomplete and vague information. For occupational health and safety in hazardous waste disposal facilities, it is convenient to use Saaty's AHP approach since the aim of AHP is to choose the most suitable and important alternative by arranging from the most important to the least. This easy-to-use and simple method creates a hierarchy using the goal, decision criteria and decision alternatives and sorts the various alternatives according to their relative importance. Furthermore, AHP approach extended to fuzzy environment since decision makers need to express uncertainty with fuzzy numbers instead of real numbers. Fuzzy analytic hierarchy process can be defined as the combined of fuzzy set theory with the classical analytic hierarchy process developed by Saaty. The application of this combination is based on fuzzy severity. Their degrees of importance and their triangular fuzzy numbers are shown in Table 1 [10]. The aim of this research is to examine each process carried out in hazardous waste disposal facilities, and identify risks that may cause work accidents or occupational diseases. We also propose solutions to reduce the levels of identified risks in facilities. Herein, two analytical methods, (i) AHP and (ii) fuzzy logic to handle the complexity of the plant and no quantitative data are used. With these assessment methods, different risk factors are ranked according to their contributions to the hazardous risk and they allow the calculation of their relative priorities during decision making. Thus, environmental decision-makers can use them to develop alternative management strategies for proposed, ongoing, and completed a hazardous waste disposal plant. In this study; occupational health and safety risks in a hazardous waste disposal facility were examined in five (5) sub-processes.

2 Materials and Methods:

According to 2016 data, the number of hazardous waste disposal facilities in Turkey is 8. Data which is used in this study collected in any hazardous waste dısposal plant. General hazardous waste disposal facilities work flow chart is given in Figure 1. Flowchart of BAHS and BTOPSIS risk analysis method is given in Figure 2. The characteristics of the facility, where field visits, technical studies are done and risk assessment is conducted, are given Table 3. The fuzzy analytical hierarchy process (BAHS) was used to calculate the significance weights of decision variables used in the fuzzy risk assessment method. Fuzzy TOPSIS method was also used to calculate the importance weights of identified risks.

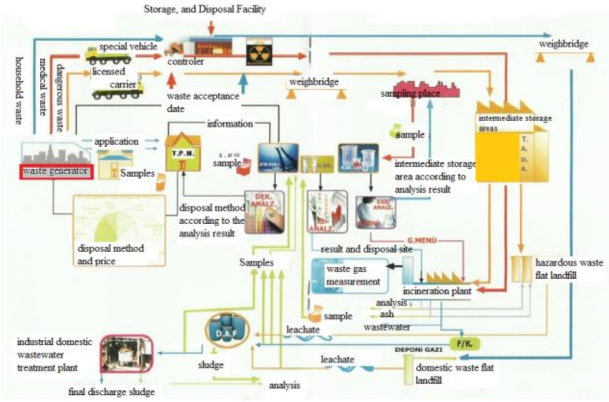

Figure 1. Hazardous Waste Disposal Facilities Work Flow Chart

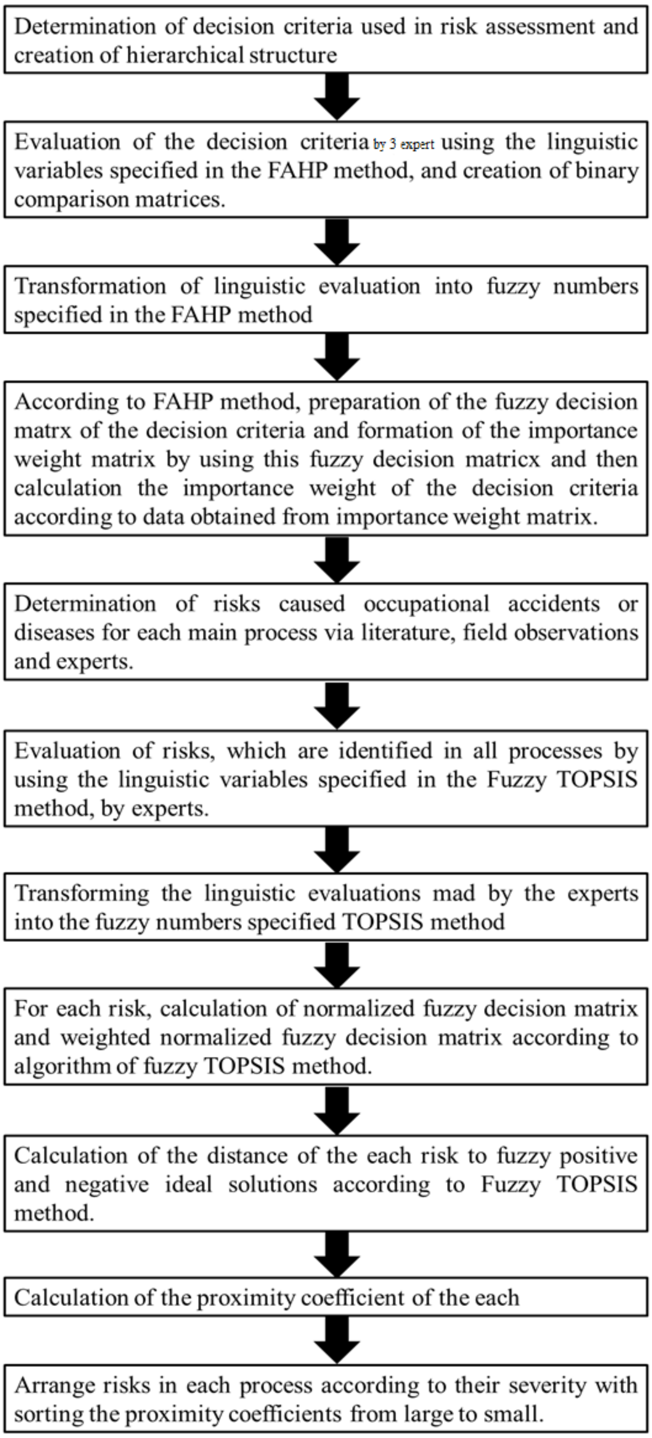

Figure 2. Flowchart of BAHS and BTOPSIS risk analysis method

2.1 Fuzzy Analytic Hierarchy Process

FAHP consists of three parts which can be considered as identification, analysis and decision stages. At the identification stage, objectives, criteria and alternatives are determined. In the analysis stage, importance coefficients are calculated and the decision stage is made [11]. In the FAHP, objectives and decision criteria are determined. Then, the pairwise comparison matrix are formed according to fuzzy logic rules. In this method, a lower limit value, an upper limit value and a high probability of occurrence are specified instead of defining a single and definite value in order to determine the superiority or priority of these two criteria [12,13]. The elements of pair-wise comparison matrices are composed of triangular fuzzy numbers (μ=(l, m, u)). The triangular fuzzy comparison matrix is shown in Eq(1).

$$A = (a_{ij})_{nxn} = \begin{bmatrix} a_{11} & a_{12} \dots & a_{1n} \\ a_{11} & a_{22} \dots & a_{2n} \\ \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} \dots & a_{nn} \end{bmatrix} =$$

$$\begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \dots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) \dots & & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) \dots & & (1,1,1) \end{bmatrix} \quad (1)$$

The condition specified in Eq(2) must be provided when fuzzy comparison matrices are generated.

$$a_{ij}=(l_{ij},m_{ij},u_{ij})=a_{ji}^{-1}=(1/u_{ji},1/m_{ji},1/l_{ji}) \quad (2)$$

Where l_{ij} is the lower limit value for comparison of the criteria i and j, m_{ij} is the highest probability value in comparing i and j criteria, u_{ij} is the upper limit value for comparison of the criteria i and j. For each criteria after fuzzy pair-wise comparison matrices are made; fuzzy number values generated by the decision makers' evaluations are calculated with the geometric mean technique shown in Eq (3) and a single fuzzy value is generated.

$$r_i = (a_{i1} * a_{i2} * a_{i3} * \dots * a_{in})^{1/n} \quad (3)$$

Where a_{in} is fuzzy comparison value of criteria i to criteria n, thus, r_i is geometric mean of fuzzy comparison value of criteria i to each criteria. After the calculated single fuzzy values, it is necessary to calculate the fuzzy weights of the criteria defined as the ratio of any r_i value to the sum of the r_i values. Fuzzy weights of criteria is shown as follows

$$w_i = r_i * (r_1+r_2+r_3+\dots+r_n)^{-1} \quad (4)$$

Where w_i is the fuzzy weight of the ith criteria and r_i is geometric mean of fuzzy comparison value of criteria i to each criteria. After this process, the calculation of the exact values must be done in order to eliminate the unclearity. The fuzzy weight values are freed from fuzziness by the formula shown in Eq(5) and the final important fuzzy weight values are calculated for each decision criteria.

w_i=[(uw_i–lw_i)+(mw_i–lw_i)]*1/3+lw_i (5)

2. 2. Fuzzy Topsis Method

Chen X, et al., 2014 developed fuzzy TOPSIS method to solve MCDM problems [14]. This method is based on that the alternative chosen is closest to the positive ideal solution and remoteness from the negative ideal solution. In other words, with the TOPSIS method, the preferences by calculating the degree of closeness to ideal solutions are sort. It is also known that fuzzy TOPSIS method is a result of the synthesis of fuzzy set theory with TOPSIS method. The greatest advantage of fuzzy TOPSIS method is MCDM method that eliminates the uncertainties caused by human thoughts. The basis of the fuzzy TOPSIS method is similar to the TOPSIS method. The selected alternative is based on the closest fuzzy positive ideal solution and remoteness from the fuzzy negative ideal solution. First of all, the decision-makers subjectively determine the importance levels of the decision criteria. Then, according to these decision criteria the alternatives are evaluated using the linguistic variables shown in Table 2. Finally, the necessary mathematical calculations and alternatives are listed using these evaluations converted to fuzzy numbers. A fuzzy MCDM matrix with n criteria and m alternatives and a criteria weight vector are shown in Eq(6).

$$D = \begin{matrix} & \begin{matrix} C_1 & \dots\dots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ . \\ A_m \end{matrix} & \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \end{matrix} ;W= [w_1 \;\; w_2 \dots . w_n] \quad (6)$$

Where all i and j values of xij and wij are composed of linguistic variable. xij = (aij, bij, cij) and wj = (wj1, wj2, wj3) are triangular fuzzy number. D: fuzzy decision matrix W: weights matrix of decision criteria. When looking at the data specific to the criteria on the basis of alternatives, situations such as the data being qualitative or quantitative, and the size of the quantitative data differing according to each other arise. Therefore, after the fuzzy decision matrix is created, the decision matrix should be normalized. By applying the process called normalization in TOPSIS method, it is ensured that large or small values are reduced to [0-1] in their own column in a proportional sense. The normalized fuzzy decision matrix is shown in Eq (7)

$$R = [r_{ij}]_{mxn}, i = 1,2, \dots, m, \quad j = 1, 2, \dots, n \quad (7)$$

Creations of normalized fuzzy decision is done in two different ways in the BTOPSIS method. The first of these is the determination of the largest (cj *) of the third components of the fuzzy significance weights expressed in triangular fuzzy numbers for each utility criteria using Eq(8). The second (If the decision criteria is chosen as the cost criteria) is to determine the smallest (aj-) of the first components of the fuzzy significance weights expressed in triangular fuzzy numbers for each cost criteria using Eq (9).

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \quad j\in B, \; c_j^* = \max c_{ij} \quad (8)$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad j\in C, \; a_j^- = \max a_{ij} \quad (9)$$

After the creation of the normalized fuzzy decision matrix, the weighted normalized fuzzy decision matrix is expressed as in Eq (10).

$$V = [v_{ij}]_{mxn}, i = 1,2, \dots, m, \; j = 1, 2, \dots, n \quad (10)$$

$$v_{ij} = r_{ij} * w_j \quad (11)$$

After normalized fuzzy importance weight calculations, the fuzzy positive ideal solution (FPIS) (A*) and fuzzy negative ideal solution (FNIS) (A-) were calculated as in Eq(12)

$$A^* = (v_1^*, v_2^*, \dots, v_n^*) \,; A^- = (v_1^-, v_2^-, \dots, v_n^-) \quad (12)$$

Since this study has three decision criteria, according to Chen's model, the fuzzy positive ideal solution (FPIS) (A*) and fuzzy negative ideal solution (FNIS) (A-) are shown as

A^* = [(1, 1, 1) (1, 1, 1) (1,1,1)] and A^- = [(0, 0, 0) (0, 0, 0) (0, 0, 0)].

According to Vertex method; distance from two fuzzy number A = (A_1, A_2, A_3) and B = (B_1, B_2, B_3) was calculated as

$$d(A,B)=[1/3x[(A_1-B_1)^2+(A_2-B_2)^2+(A_3-B_3)^2]]^{1/2} \quad (13)$$

and also fuzzy-free distance (d_i* ve d_i^-) was calculated as:

$$d_i^* = \sum_{j=1}^n d(v_{ij}, v_j^*), \quad i = 1,2, \dots, m \quad (14)$$

$$d_i^- = \sum_{j=1}^n d(v_{ij}, v_j^*), \quad i = 1,2, \dots, m$$

After this process, the distances to the positive and negative ideal solutions are calculated to determine the proximity coefficients (CCI) for each alternatives. The proximity coefficient handles the distances to fuzzy positive and negative solutions together. Proximity coefficient for each risk was carried out using Eq (15). The approximation coefficient of an alternative approached to 1 indicates that this alternative approaches the fuzzy positive ideal solution and moves away from the fuzzy negative ideal solution. Mathematically, if A_i = A * or A_i = A-; CC_i =1 or CC_i = 0, respectively. The ranking of this alternative is made according to the proximity coefficients. According to this ranking, the closer the coefficient of affinity is to 1, the higher the likelihood of the alternative being chosen.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad , \quad i = 1,2,\ldots,m \qquad (15)$$

2. 3 Algorithm for the Application Method

According to the algorithm of the FAHS method, the fuzzy decision matrix of the decision criteria, the fuzzy significance weight matrix is formed and the decision criteria based on these data are calculated from the fuzziness-free significance weights.

2.4 Evaluation of decision criteria using linguistic variables

The risk level is determined by using probability, violence and frequency values in classical risk assessment methods. These three components were used as decision criteria. The decision criteria were evaluated by three different experts using the linguistic variables given in Table 1, and the binary comparison matrices were prepared (Table 4-5).

Table 1. The linguistic variables and fuzzy number values.

Linguistic variables	Fuzzy numbers
Too Strong	2, 5/2 , 3
Very Strong	3/2, 2, 5/2
Strong	1, 3/2 , 2
Less Strong	1,1, 3/2
Equal	1,1,1
Less Weak	2/3,1, 1
Weak	1/2, 2/3, 1
Very Weak	2/5, 1/2, 2/3
Too Weak	1/3, 2/5, 1/2

Table 2. Linguistic variables and scale of fuzzy numbers used in fuzzy TOPSIS method

Variables	Fuzzy numbers
Very low	0, 0, 1
Low	0, 1, 3
Medium Low	1, 3 , 5
Medium	3,5,7
Medium High	5,7,9
High	7,9,10
Very high	9, 10, 10

Table 3. The characteristics of the facility

	Facility
Disposal Methods	Intermediate Storage; Disposal by Incineration; Disposal with Regular Storage
Hazard Class	Very dangerous
General classification of economic activities in the European Communities	Treatment and disposal of hazardous wastes (operation of plants for the treatment of hazardous wastes, disposal of used products for the removal of hazardous wastes, etc.) (except radioactive waste)

Table 4. Binary comparison matrix based on the first, second and third expert's evaluations

Expert's	Prob	Sever	Freq
Prob 1st	Equal	-	-
Sever 1st	M. Low	Equal	-
Freq 1st	M.High	High	Equal
Prob 2st	Equal	-	-
Sever 2st	M. Low	Equal	-
Freq 2st	High	V High	Equal
Prob 3st	Equal	-	-
Sever 3st	V. Low	Equal	-
Freq 3st	High	M High	Equal

Table 5. The expression of the triangular fuzzy numbers of the binary comparison matrix evaluated by the first, second and third expert's

Expert's	Prob	Sever	Freq
Prob 1st	1, 1,1	2/3, 1, 1	2/3, 1, 1
Sever 1st	2/3, 1, 1	1, 1, 1	2/5, 1/2, 2/3
Freq 1st	1, 1, 3/2	3/2, 2,5/2	1, 1,1
Prob 2st	1, 1,1	1,1,3/2	1/2,2/3,1
Sever 2st	2/3,1,1	1,1,1	1/3,2/5,1/2
Freq 2st	3/2, 2	2, 5/2, 3	1, 1, 1
Prob 3st	1, 1, 1	3/2, 2, 5/2	-2/5, 1/2, 2/3
Sever 3st	2/5, 1/2, 2/3	1, 1,1	2/3, 1,1
Freq 3st	3/2, 2, 5/2	1, 1, 3/2	1, 1, 1

2.5 Calculation of important weights of decision criteria

In this section, fuzzy decision matrices were formed using the fuzzy binary comparison matrices formed as a result of the opinions of the experts. Importance weights of decision criteria were calculated by using this matrix. Fuzzy decision matrix was formed by taking arithmetical average of all elements of paired comparison matrices formed by triangular fuzzy numbers. If the value of probability according to frequency is defined as Ma_{12} in the fuzzy decision matrix; $Ma_{12} = (M_1a_{12} + M_2a_{12} + M_{3a12})/3 = [(1 , 1 , 3/2) + (1 , 3/2 , 2) + (3/2 , 2 , 5/2)]/3 = (1,166 , 1.5 , 2)$ calculations were made using Table 5 and was created Table 6. After establishing the fuzzy decision matrix of the decision criteria, a single fuzzy number value was calculated for each decision criteria by taking the geometric mean of the fuzzy number values obtained for each decision criteria using Eq(3)

$R^{Fuzzy}_{(Prob.)}=[(1x0.577x1.166)^{1/3},(1x0.833x1.5)^{1/3},(1x0.888x2)^{1/3}]= (0.876,1.077,1.386)$

$R^{Fuzzy}_{(Sever.)}= [(1.166*1*1.5)^{1/3}, (1.333*1*1.833)^{1/3}, (1.833*1*2.333)^{1/3}]= (0.609, 1.347, 1.623)$

$R^{Fuzzy}_{(Freq.)}=[(0.522*0.466*1)^{1/3},(0.722*0.633*1)^{1/3}, (0.888*0.722*1)^{1/3}]= (0.624, 0.770, 0.862)$

Table 6. Fuzzy decision matrix of decision criteria

	Probability	Severity	Frequency
P.	1, 1, 1	0.578,0.833,0.888	1.166, 1.5,2
S.	1.166,1.333,1.833	1, 1, 1	1.5,1.833,2.333
F.	0.522,0.722,0.888	0.466, 0.633,0.722	1, 1, 1

Fuzzy weights of criteria were calculated from Eq (4) as followings and given in Table 7.

$W^{Fuzzy}_{(Prob.}= (0.876, 1.077, 1.386)* [(0.876, 1.077, 1.386) + (0.609, 1.347, 1.623) + (0.624, 0.770, 0.862)]^{-1} = (0.226, 0.337, 0.657)$

$W^{Fuzzy}_{(Sever)} =(0.609, 1.347, 1.623) * [(0.876, 1,077, 1,386) + (0.609, 1.347, 1.623) + (0.624, 0.770, 0.862)]^{-1} = (0.157, 0.422, 0.770)$

$W^{Fuzzy}_{(Freq.)} = (0.624, 0,770, 0,862) * [(0.876, 1.077, 1.386) + (0.609, 1.347, 1.623) + (0.624, 0.770, 0.862)]^{-1} = (0.161, 0.241, 0.409)$

Table 7. Fuzzy importance weights (FW) of decision criteria

	Probability	Severity	Frequency
FW	0.226,0.337,0.657	0.157,0.422,0.770	0.161, 0.241,0.409

The fuzzy values of the decision criteria are freed from the fuzziness using Eq(5) and the non-fuzzy exact weights of each decision criteria are shown in Table 8.

$W^{Fuzzy}_{(Probability)}=[(0.657 – 0.226) + (0.337 + 0.226)] /3 + 0.226 = 0.557$

While determining the risk level of any risk, it can be said that the most weighted decision criteria is the value of Severity of that risk.

Table 8. Non-fuzzy importance of weights (NFW) of decision criteria

	Probability	Severity	Frequency
NFW	0.557	0.554	0.378

2.6 Investigation of risks in hazardous waste disposal facilities

There are five main process in hazardous waste disposal facilities; such as the entrance of the waste into the facility, waste analysis, intermediate storage of hazardous waste, disposal of hazardous waste and auxiliary facilities. The risks identified for each process are prioritized by the fuzzy TOPSIS method. The calculations for the entrance of the waste into the facility are listed below (Table 9-13) [15]. The determined risks were evaluated by three experts on the basis of linguistic assessments by probability, severity and frequency criteria. Evaluation of Table 9 risks determined by the linguistic variables for the process of entry of waste to the plant. The triangular numbers are used, given as Table 2. The linguistic evaluations are translated into the triangular numbers

And the arithmetic mean of the triangular fuzzy scores expressed for each risk was taken and the fuzzy significance weight of each risk was calculated as a single triangular fuzzy number.

Table 9. Risks of occupational health and safety specified during the introduction/entrance of waste disposal into the facility.

Code	Risk	Reason of Risk
R1$_e$	Hazardous waste carrying vehicle rollover	Due to the fact that the loads are very heavy, a shift in the position of the load during transportation causes the vehicle to in stabilize and tip over.
R2$_e$	Fire and explosion	Reaction of transported waste disposal with each other or with air or contact with ignition source causes fire and explosion
R3$_e$	Pollution transportation of hazardous waste transportation vehicles on the site	Waste disposal transportation vehicles carry the pollution out of the facility by the wheels and create environmental pollution
R4$_e$	Collision with other vehicles in traffic	Arrival to hazardous waste disposal facilities by narrow and uneven roads, inadequate roads in facilities, inadequacy of warning signs and traffic rules are not followed.
R5 $_e$	Unsuitable types of waste entry into the field	Entrance of any wastes other than waste codes licensed by hazardous waste disposal facilities into the facility (eg radioactive waste), no sampling or any analysis
R6$_e$	Chemical exposure of person who is sampling	Chemical exposure through gas leakage, contact etc. during sampling process.
R7$_e$	Injury during sample collection	Injurıes may result from working with hazardous substances during sampling, working alone etc.

Table 10. Risks of occupational health and safety specified during the process of the waste analysis

Code	Risk	Reason of Risk
R1 $_a$	Injury during analysis	Injuries during sample preparation (cutting, pressing etc.), manual transport of waste samples
R2 $_a$	Chemical exposure for analysis personnel	Chemical exposure due to the gas output or contact and lack of ventilation or insufficient ventilation system
R3 $_a$	Fell down as a result of slipping	Cables, objects and slippery floors
R4 $_a$	Incorrect disposal due to incorrect analysis	Decision of wrong disposal technique as a result of either incorrect analysis, or incorrect reporting or transportation of inappropriate waste type to the facility
R5 $_a$	Thermal comfort is not provided	Lack of any active heating and cooling system in laboratory
R6 $_a$	Fire and explosion	Reaction caused by the nature of hazardous wastes or contact of waste samples with a source of ignition, tipping of compressed gas cylinders, explosion as a result of improper storage
R7 $_a$	Electric shock	The occurrence of electrical leakage from the maintenance

Table 11. Risks of occupational health and safety specified during the process of intermediate storage of waste

Code	Risk	Reason of Risk
R1$_s$	Epidemic disease	Environmental pollution occurs as a result of improper long-term storage; leakage from tanks and barrels.
R2 $_s$	Fire and explosion	Storage of wastes that will react with each other in barrel storage area, bunker and tank farm; the presence of the ignition source around the waste; no warning sign; leakage from the tanks and barrels; explosion of aerosol-containing waste (deodorants, pesticides etc.)
R3 $_s$	Chronic toxicity	Chronic toxicity due to the odor exposure
R4 $_s$	Working in closed areas	Working in closed area during maintenance, repair etc.
R5 $_s$	Working at height	Working at heights during maintenance, repair etc. in the bunker or tank farms
R6$_s$	Environmental pollution	Diseases caused by biological agents.
R7$_s$	Chemical exposure	Inhalation of chemicals and contact with them in the work area; lack of good ventilation system

R8s	Non-ergonomic conditions	Problems such as low back pain may occur as a result of manual handling of waste.
R9s	Injury during falling waste disposal	Unsuitable design of tank; tipping over the tank as a result of improper selection of construction material of tank; failure of stacking properly in barrel storage area; storing of barrels above safe storage height, non-fixing of barrels; load drop or slip from forklift or waste transport vehicles
R10 s	Noise exposure	Noise occurrence due to forklift and waste transportation vehicles; exposure of workers and operators to noise; noise measurement is made and no precautions are taken.
R11s	Vibration exposure	Vibration occurrence due to forklift and waste transportation vehicles; exposure of workers and operators to vibration; no vibration measurement is made and no precautions are taken.

Table 12. Risks of occupational health and safety specified during in the disposal of hazardous waste

Code	Risk	Reason of Risk
R1 d	Environmental pollution	Environmental pollution caused by leakage, fire, explosion, release of the gases released after combustion into the atmosphere without purification, spillage after removal of slag and contact this slag with soil, air and water.
R2 d	Fire and explosion	During the medical waste sterilization process, working with high temperature and pressure equipment; wastes that can react with each other are not buried separately; not covering hazardous wastes buried in the regular storage area with the soil, feeding the wastes in uncontrolled amount and mixture during the burning of waster; uncontrolled rise in temperature and pressure in rotary kiln; clogging of compounds containing Cl in the rotary kiln; leakage from the barrel while the kettle is being fed to the rotary kiln combustion system; interaction with a source of ignition, air or a reactive substance; starting fire during the first ignition in the rotary kiln; explosion occurrence in diesel, propane and fuel oil tanks; battery waste explosion
R3 d	Working at height	Working at height during maintenance or repair in rotary kiln, pipeline and other sections
R4 d	Working in closed areas	Working in closed and narrow areas during maintenance or repair in Rotary kiln, pipeline, barrel conveyor belts sections
R5 d	Chronic toxicity	Chronic toxicity due to the odor exposure
R6 d	Epidemic disease	Diseases caused by biological agents
R7 d	Chemical exposure	Inhalation of existing chemicals in the work area, contact, lack of good ventilation system, release of gases after combustion to the atmosphere without purification
R8 d	Non-ergonomic conditions	Back pain may occur as a result of the barrel / IBC tank feeding on the barrel by hand.
R9 d	Injury during falling waste disposal	Stucking the conveyor belt during trimming on the conveyor belt, tipping over the small tank while removing slag after combustion, contacting the worker
R10 d	Noise exposure	Noise occurrence due to forklift and waste transportation vehicles; exposure of workers and operators to noise; noise measurement is made and no precautions are taken.
R11 d	Asbestos exposure	Asbestos exposure occurs -when waste may not have a special coating and not being buried in a separate lot in a regular storage area; - scattering and breathing as a result of opening the container of asbestos waste during disposal; -asbestos waste disposal may not be done by experts;

		-the location of the asbestos buried is not covered by soil; - when the employees do not take off the clothes properly, do not dispose of them, or take a shower after asbestos disposal
R12 $_d$	Machine accidents	Machine accidents occur -when construction machines (cars, trucks etc.) slipped or overturned in the landfill for the storage due to the rugged and soft soil. -due to lack of warning signs traffic signs and inadequate lightening, -speed limits not being set
R13 $_d$	Electrical accidents	Electrical accidents occur in the water pool in the landfill, people may get electric shock
R14 $_d$	Strangulation	Employees fall into the water pool in the landfill, there are slippery edges around the water tank pool, no warning signs, no safety fences around the pool
R15 $_d$	Vibration exposure	Vibration occurrence caused by due to forklift and waste transportation vehicles, workers and operators are exposed to vibration, vibration measurement is not done and precautions are not taken.

Table 13. Risks of occupational health and safety specified in the auxiliary facilities process

Code	Risk	Reason of Risk
R1 $_x$	Injury during analysis	Falling due to slippery ground; insufficient of warning signs; lack of appropriate work shoes for employees; jamming of limb during either operation or maintenance of machine and equipment.
R2 $_x$	Fire and explosion	Fire caused by electrical leakage; use of pressurized equipment such as compressors
R3 $_x$	Electric shock	Leakage current may occur during operation and cleaning of equipment such as sedimentation and ventilation pools, grills, filters, sand, oil trap, compressors and membranes. The cables are not suitable for the wet ground unexpert people are working there
R4 $_x$	Noise exposure	No noise measurement in the facility; no noise map of the facility; no regular maintenance of machine equipment; no follow-up of new technologies
R5 $_x$	Chronic toxicity	Chronic toxicity occurrence due to odor exposure
R6 $_x$	Epidemic disease	The occurrence of diseases caused by biological agents; drinking, eating around the wastewater treatment plant; not providing hygiene conditions

2.7 Determination of normalized fuzzy ımportance weight of risks by Fuzzy Topsis Method

For each risk, fuzzy importance weights calculated before was normalized using the linear normalization method. Normalization was carried out using the formulas given in Eq. (8- 9). In the study, the decision criteria are used to determine the most risky process. These criteria are considered as a criteria of benefit. Therefore, in each decision criteria column and the largest number in the third column of triangular fuzzy importance weights calculated for each risk was found. Then, other values are divide by this largest number to determine the normalized triangular fuzzy importance weight in [0-1] range. The maximum **SEVERITY** is found as 9.667 and then **R1**$_e$ was calculated as

(4.333/9.667; 6.333/9.667; 8.333/9.667) = (0.448; 0.655; 0.862)

2.8 Determination of weighted normalized fuzzy importance weights for risks with Fuzzy Topsis method

In this study, the triangular fuzzy numbers obtained by the normalization process for each risk and the decision criteria specified in Table 7 are used to determine the weighted normalized fuzzy importance weights of all risks. This calculation is carried out using Eq. (11).

$V_{11} = r_{11} * w_1 = (0.036, 0.143, 0.321) * (0.226, 0.337, 0.657) = (0.008, 0.048, 0.211)$

2.9 Determination of proximity coefficient by calculating distance to fuzzy positive and negative ideal solutions

According to Vertex method; distance from two fuzzy number A = (A_1, A_2, A_3) ve B = (B_1, B_2, B_3) was calculated using Eq(13).

As an example, for $R1_e$ risk the probability, severity, frequency, distance to fuzzy positive and fuzzy negative ideal solutions and proximity coefficients are calculated as followings

Probability $A_1 = (0.008, 0.048, 0.211)$

$$d(A_1, A^*) = [1/3 * ((0.008 - 1)^2 + (0.048 - 1)^2 + (0.211 - 1)^2)]^{1/2} = 0.915$$
$$d(A_1, A^-) = [1/3 * ((0.008 - 0)^2 + (0.048 - 0)^2 + (0.211 - 0)^2)]^{1/2} = 0.125$$

Severity $A_1 = (0.070, 0.276, 0.664)$

$$d(A_1, A^*) = [1/3 * ((0.070 - 1)^2 + (0.276 - 1)^2 + (0.664 - 1)^2)]^{1/2} = 0.708$$
$$d(A_1, A^-) = [1/3 * ((0.070 - 0)^2 + (0.276 - 0)^2 + (0.664 - 0)^2)]^{1/2} = 0.417$$

Frequency $A_1 = (0.008, 0.063, 0.237)$

$$d(A_1, A^*) = [1/3 * ((0.008 - 1)^2 + (0.063 - 1)^2 + (0.237 - 1)^2)]^{1/2} = 0.903$$
$$d(A_1, A^-) = [1/3 * ((0.008 - 0)^2 + (0.063 - 0)^2 + (0.237 - 0)^2)]^{1/2} = 0.142$$

For $R1_e$ risk, the distance to fuzzy positive and fuzzy negative ideal solutions (d_i*, d_i^-) are calculated using Eq(14)

$$d_1^* = 0.915 + 0.708 + 0.903 = 2.526$$

$$d_1^- = 0.125 + 0.417 + 0.142 = 0.684$$

Proximity coefficient for each risk was carried out using Eq(15),

For $R1_e$ risk,

$$CC_1 = d_1^- / (d_1^- + d_1^*) = 0.684 / (0.684 + 2.526) = 0.213$$

The same procedures were repeated for all processes and the significance levels of the risks were determined for each process (Table 14).

Table 14. Priority ranking according to proximity coefficient for risks during entry of waste to the plant, waste analysis, intermediate storage of hazardous waste, disposal of hazardous waste, and auxiliary facilities

Priority ranking	The entry of waste	The waste analysis	The intermediate storage	The disposal of waste	The auxiliary facilities
1	R2e	R6a	R2s	R2d	R2x
2	R7e	R3a	R8s	R11d	R4x
3	R6e	R2a	R7s	R13d	R3x
4	R4e	R1a	R6s	R8d	R6x
5	R3e	R7a	R1s	R6d	R5x
6	R1e	R5a	R9s	R12d	R1x
7	R5e	R4a	R11s	R1d	
8			R4s	R15d	
9			R5s	R7d	
10			R3s	R9d	
11			R10s	R4d	
12				R10d	
13				R14d	
14				R3d	
15				R5d	

3 Results and Discussion

Three decision criteria as probability indicating the probability of occurrence of risk, severity which is indicated damage severity during risk and the frequency criteria of the occurrence of a risk were determined as 0.557, 0.554 and 0.378 recpectively (Table 8). After determining the importance weights of the decision criteria, occupational health and safety risks in a hazardous waste disposal facility were examined in five (5) sub-processes which are given in Table 9-13. As conclusion, a total of 46 risks and cause of the risk are identified in these tables. For all these five sub-processes, we sorted all identified risks according to the proximity coefficients. Priority ranking according to proximity coefficient for risks during entry of waste to the plant, waste analysis, intermediate storage of hazardous waste, disposal of hazardous waste, and auxiliary facilities were given in Table 14. It is found that the highest priority risks for all sub-process are "fire and explosion". In the process of the waste entry to the facility, the least risk is an unsuitable types of waste entry into the field. The least important risk for the waste analysis was determined as the risk of incorrect disposal as a result of incorrect analysis. In the process of intermediate storage of waste, the least risk is noise exposure. Chronic toxicity is the least risk in the process of the disposal of waste. As pointed out by [16], the second risk that has the highest importance in the process of disposal of hazardous waste is "asbestos exposure".

4 Conclusion

This study uses a fuzzy logic-based risk assessment approach which gives more objective results than different risk assessment studies in the field of occupational health and safety in the literature. In addition, it is determined that this approach can be used in hazardous waste disposal facilities. In future studies, the results of the conventional risk assessment approach and fuzzy logic-based risk assessment approach will be compared by taking the sampling from the whole sector. It can be tested whether the fuzzy logic-based method gives more objective results than the classical methods. Moreover, more comprehensive results can be obtained from the sector. Personnel working in these facilities may have some diseases such as cancer, reproductive problems due to the fact that they are exposed to hazardous chemicals, asbestos, harmful gases, biological agents. The detection of these diseases requires long-term work. Therefore, a national monitoring system can be established to increase the traceability of the periodic heath control system.

References:

[1] Mızrak Ö. P , Bulanık Önceliklendirme Metodu Ve Hata Türü Ve Etkileri Analizini Birleştiren Yeni Bir Risk Analizi Yöntemi, *J Fac Eng Archıt Gazi* Vol,4,2014,pp755-768.

[2] Eskandari M, Mahmodi S, An integrated multi-criteria approach for landfill siting in a conflicting environmental, economic and socio-cultural area, *Waste Manag* Vol.32,2012,pp1528-1538,

[3] Chauhan A, and Singh A , A hybrid MCDM making method approach for selecting a sustainable location of healthcare waste disposal facility, *J. Clean. Prod* Vol.139,2016,pp.1001-1010

[4] Kabir G,Sumi S, Hazardous Waste Transportation Firm Selection Using FAHP 7: 115

[5] Arıkan E, Simsit ZT, Vayvay Ö, Solid waste disposal methodology selection using MCDM methods and an application in Turkey, *J. Clean. Prod* Vol,142, 2015, pp 403–412

[6] Chauhan, A., Singh, S.P.,Selection of healthcare waste disposal firms using a multi-method approach, *Journal of Environmental Management* Vol.295,2021,pp.113117

[7] Yolandi S., Paul O.,Vernon S., A Zero-Waste Multi-Criteria Decision-Support Model for the Iron and Steel Industry in Developing Countries: A Case Study, *Sustainability*, Vol.13, 2021,pp.2832.

[8] Feng J, An integrated multi-criteria decision-making method for hazardous waste disposal site selection Environment, Development and Sustainability, Article in pres,2021.

[9] Palczewski K, Sałabun W,The fuzzy TOPSIS applications in the last decade, *Procedia Computer Science* vol.159,2019,pp. 2294–2303.

[10] Wang, Y.M., Chin, K.S., Poon, G., Yang, J, Risk Evaluation In Failure Mode And Effects Analysis Using Fuzzy Weighted Geometric, Mean, *Expert Syst. Appl*.Vol36,2009,pp.1195-1207.

[11] Aminbakhsh S, Gündüz M, Sönmez R (2013) Safety Risk Assessment Using AHP During Planning And Budgeting Of Construction Projects. *Journal Of Safety Research* ,vol46,2013,pp. 99-105.

[12] Chang D, Applications Of The Extent Analysis Method On FAHP, *Eur. J. Oper. Res*. Vol.95,1996,pp.649-655

[13] Mahdevari S, Shahriar K, Esfahanipour A. Human Health And Safety Risks Management in Underground Coal Mines Using FTOPSIS, Sci. *Total Environ*. Vol.482014,pp.85-99.

[14] Chen X, Li X, Extension of the TOPSIS based on prospect theory and trapezoidal intuitionistic fuzzy numbers for group decision making, *J Syst Sci Syst Eng*, Vol23, No2,2014,pp.231-247

[15] Ercan M, (2019)Bir tehlikeli atık bertaraf tesisinde iş sağlığı ve güvenliği risklerinin analizi, M.Sc.Thesis. University of Gazi, Ankara Turkey,120p,2019

[16] Li, J., Dong, Q., Yu, K., Liu, L. Asbestos and asbestos waste management in the Asian-Pacific region:trends, challenges and solutions, *J. Clean. Prod*, Vol.81,2014,pp. 218-226.

Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Merve Ercan and Gülay Özkan carried out the calculation of data.
Tugba D Çalışkan and Göksel Özkan have organized and collected of the data from the experts