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Use of UAVs in Earthquakes and UAV Base Location Selection for a Possible Marmara Earthquake

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Abstract

UAV's are widely used in many fields today, and one of the most important of these fields is disaster management. The most significant disaster that comes to mind when mentioning disasters is undoubtedly earthquakes. UAV's are used to support search and rescue operations before and especially after an earthquake. As Türkiye is located in an earthquake zone, earthquakes have affected and will continue to affect us from past to present. The Marmara earthquake, which is predicted to occur in the coming years, will cause great destruction considering the population density of the region. In this study, the use of UAV's in earthquakes and the selection of the most suitable UAV base location for quick intervention without being affected by a potential Marmara earthquake was conducted using the TOPSIS method, which is one of the multi-criteria decision-making methods with criteria weights. As for the UAV class, MALE class UAV's, which are produced by Türkiye and classified by NATO, were preferred due to their mission duration and payload capacity. While determining the alternatives, seven airports close to the Marmara region but not on the fault line were selected. The criteria and their weights were determined based on the opinions of five UAV pilots, and a total of six criteria were chosen. As a result of applying the TOPSIS method, Sivrihisar Aviation Center was determined to be the most suitable UAV base for intervention in a potential Marmara earthquake, being the closest to the ideal solution among the selected alternatives.

1. Introduction

With the advancement of technology, Unmanned Aerial Vehicles (UAVs) have become widespread and are actively used in many areas, ranging from reconnaissance and surveillance to disaster management, air security, traffic control, and agricultural applications. As one of the few countries capable of producing UAVs in this field, Türkiye manufactures and exports tactical and operational-level UAVs.

Disaster management is one of the most common areas where UAVs are used, and their role in supporting search and rescue operations, especially after disasters, is significant. In Türkiye, the payloads on tactical and operational-level UAVs, which are primarily used in military applications, are also utilized in post-earthquake search and rescue operations to provide aerial support to personnel and to offer mobile base station support in areas where communication disruptions occur.

Due to the fact that Türkiye is located in an earthquake-prone region, many earthquakes have occurred from the past to the present, impacting Türkiye socially and economically. Considering the population density, a potential future Marmara earthquake could have devastating effects.

In this study, the use of UAVs in earthquakes has been briefly examined, and the selection of the most suitable location for establishing a UAV base that can rapidly respond to a possible Marmara earthquake has been made using the TOPSIS method, one of the multi-criteria decision-making processes.

This study also aims to raise awareness about the importance of using UAVs during earthquakes, highlight the significance of the anticipated Marmara earthquake, and provide insights for other researchers on possible locations for UAV operations in response to this earthquake. Additionally, the study seeks to demonstrate once again that multi criteria decision making methods can be effectively utilized in base selection problems.

2. Literature Review

In the literature, some studies have been conducted on the use of UAVs in earthquakes. In their study, Halat, M., and Özkan, Ö. (2020) determined the flight path that a UAV, launched within 24 hours after a possible Istanbul earthquake, should take to observe damage assessment activities.

In her study, Gülüm, P. (2021) utilized multi-criteria decision-making methods to accurately identify and analyze fires that may occur after an earthquake, and investigated how these fires could be intervened with unmanned aerial vehicles.

In his study, Sarıyıldız, H.İ. (2021) attempted to detect damaged structures after an earthquake using unmanned aerial vehicles and satellite images in combination with deep learning algorithms, achieving an accuracy rate exceeding 95%.

In his study, Canözü, Ö. (2022) used a photogrammetric point cloud in conjunction with the cadastral map of the area to automatically detect damaged or collapsed buildings from UAV images after an earthquake.

In their study, Maraş, E.E., and Sarıyıldız H.İ. (2023) tried to detect damaged structures after an earthquake using unmanned aerial vehicle images and deep learning algorithms, achieving an accuracy rate exceeding 95%.

In their study, Milev, N. et al. (2023) attempted to analyze and detect landslides that may occur after an earthquake using unmanned aerial vehicle images.

In his study, Chen Z. (2024) utilized UAVs equipped with sensors that perform temperature and image analysis for the early detection and monitoring of earthquake, flood, and landslide disasters.

3. Earthquake Disasters

Earthquakes are defined as the phenomenon of vibrations suddenly arising from sudden fractures within the Earth's crust, spreading in wave form through the environment and shaking the Earth's surface. In essence, an earthquake is a natural event that demonstrates the Earth's dynamic nature, which is an indispensable aspect of life, and that can potentially cause loss of life for humans (AFAD, 2024).

Earthquakes occur due to the influence of many factors and can lead to various negative consequences. Earthquakes have affected Türkiye at different times from psychological, economic, demographic, social, and environmental perspectives. Being in an earthquake-prone region necessitates the evaluation of the severity and negative impacts of these effects (Aktan and Arık, 2024).

Türkiye is located in the Alp-Himalayan belt, one of the world's significant earthquake zones. Due to its complex geological structure and geodynamic position, Türkiye has many active fault lines (MTA, 2023). Due to these active and living faults, both small and large-scale earthquakes occur from time to time. In the post-Republic period, 15 different earthquakes with magnitudes of M≥7.0 can be mentioned. These earthquakes include: 26.06.1926 Datça Offshore (MS 7.7), 26.12.1939 Erzincan (MS 7.9), 20.12.1942 Erbaa-Tokat (MS 7.0), 26.11.1943 Ilgaz-Çankırı (MS 7.2), 01.02.1944 Gerede-Bolu (MS 7.3), 18.03.1953 Çanakkale (MS 7.2), 26.05.1957 Düzce-Bolu (MS 7.1), 06.10.1964 Karacabey-Bursa (MS 7.0), 28.03.1970 Kütahya (MS 7.2), 24.11.1976 Çaldıran-Van (Mw 7.0), 17.08.1999 Gölcük-Kocaeli (Mw 7.6), 12.11.1999 Düzce-Bolu (Mw 7.1), 23.10.2011 Van (Mw 7.1), 06.02.2023 Pazarcık-Kahramanmaraş (Mw 7.7), 06.02.2023 Elbistan-Kahramanmaraş (Mw 7.6) (AFAD, 2024).

Along with all these earthquakes, examining the earthquake-prone areas map shows that 92% of Türkiye is within an earthquake zone (İşçi, 2008). As can be seen from the earthquake zone map in Figure 1, there are three fault lines affecting Türkiye. These fault lines are named the North Anatolian Fault Line, the East Anatolian Fault Line, and the West Anatolian Fault Line. Fault lines refer to the points where the Earth's crust has been fractured or cracked. Since these fault lines cover many regions of Türkiye, there is a risk of earthquakes of varying magnitudes at any moment in every region of Türkiye (Canözü, 2022).

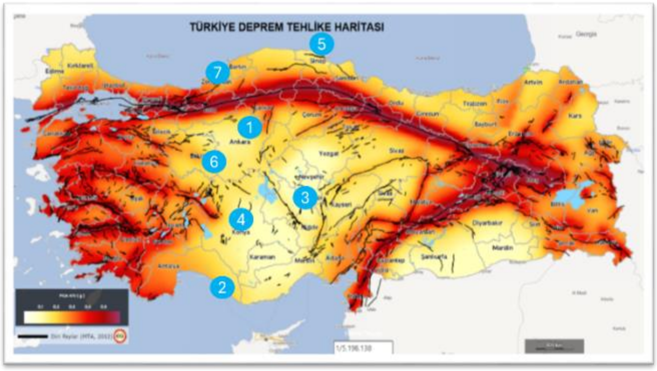

Figure 1. Earthquake Danger Map (AFAD, 2024) and Alternatives Used in TOPSIS Method

4. Unmanned Aerial Vehicles

Any vehicle capable of flying unmanned, remotely controlled, or autonomously operated through a program, carrying lethal or non-lethal payloads, is referred to as an Unmanned Aerial Vehicle (UAV) (Eisenbeiss, 2004). Additionally, terms such as "Drone," "Pilotless Aircraft," and "Remotely Piloted Aircraft" are also used to describe UAVs (Akyürek et al., 2012). Furthermore, the International Civil Aviation Organization (ICAO) classifies UAVs into three types: Remotely Piloted Aircraft (RPAs), Autonomous Aircraft, and Model Aircraft (ICAO-RPAS, 2015).

Moreover, there are Ground Control Stations, Ground Data Terminals, and other equipment that enable the flight and operation of UAVs. Systems formed by including these types of equipment are called Unmanned Aerial Systems (UAS) (Akyürek et al., 2012). Unmanned Aerial Systems are mostly used for military purposes, particularly for air vehicles with high payload capacity and takeoff weight.

UAVs were initially developed to meet military needs and became widespread through applications in military fields such as reconnaissance and surveillance, intelligence, and unmanned research. Nowadays, especially with the integration of digital cameras into lightweight UAVs, their use has become widespread in fields such as photography and AI-supported image processing (Ruzgiene et al., 2015).

4.1. Classification of UAVs

UAV systems are classified in various ways according to many different criteria. These classifications are fundamentally based on qualitative and quantitative approaches. Classifications made according to characteristics such as the duration of UAV operations, the weight of the payload carried, or the takeoff weight can be considered qualitative approaches. The classification where the total flight time and operational altitude are decisive factors is a quantitative approach. In the quantitative approach, the priority is the operational altitude. In quantitative classification, UAVs are commonly divided into four main groups: mini, tactical, operational, and strategic (Haser, 2010).

In Türkiye, the civil aviation authority, which is the authority on civil aviation, the Directorate General of Civil Aviation (DGCA), classifies UAVs according to their weight. Accordingly, UAVs are categorized into four groups based on their maximum takeoff weight (SHGM, SHT-UAV, 2016).

Table 1. Classification of UAVs (DGCA)

Class	Mass
UAV0	500 gr to 4 kg
UAV1	4 kg to 25 kg
UAV2	25 kg to 150 kg
UAV3	More than 150 kg

UAVs used for military purposes are classified by the NATO Joint Air Power Competence Centre (JAPCC) based on their takeoff weight, operational altitude, and mission radius (Haser, 2010).

Table 2. Classification of UAVs (NATO)

CLASS	CATEGORY	Employment	Mission Altitude	Mission Radius
Class I (Lesss than 150 kg)	Small (more than 20 kg)	Tactical Unit	Up to 5000 ft AGL	50 km (LOS)
	Mini (2 kg to 20 kg)	Tactical Sub-unit	Up to 3000 ft AGL	25 km (LOS)
	Micro (Less than 20 kg)	Tactical, Individual	Up to 200 ft AGL	5 km (LOS)
Class II (150kg to 600 kg)	Tactical	Tactical Formation	Up to 10.000 ft AGL	200 km (LOS)
Class III (More than 600 kg)	Strike/Combat	Strategic /National	Up to 65.000 ft AGL	Unlimited (BLOS)
	HALE (High Altitude Long Endurance)	Strategic /National	Up to 65.000 ft AGL	Unlimited (BLOS)
	MALE (Medium Altitude Long Endurance)	Operational	Up to 45.000 ft AGL	Unlimited (BLOS)

4.2. Use of UAVs in Earthquake

UAVs are widely used in all natural or natural disasters, including earthquakes, where they are effectively utilized. Although UAVs are employed in pre-disaster, during-disaster, and post-disaster operations, they are primarily used in post-disaster operations to map affected areas, assist in damage assessment and search and rescue operations using collected images, and facilitate communication in the affected regions (Bravo and Leiras, 2015).

UAVs can be used in earthquakes in the following areas before, during, and after the disaster (Erdelj et al., 2017):

- Making predictions by analyzing information gathered through environmental monitoring as part of prevention efforts,
- Ensuring the accurate flow of information during natural disasters,
- Assessing the situation, evacuation, and logistical support after the disaster,
- Supporting field personnel in detecting and rescuing people trapped under rubble during search and rescue operations,
- Identifying and assessing damaged structures in damage assessment efforts,
- Detecting and preventing other disasters such as fires, chemical/radioactive leaks, and landslides that may occur due to the earthquake,
- Ensuring public order in affected areas and preventing potential crimes,
- Supporting communication infrastructure in case of damage to communication systems.

Türkiye have actively used UAVs in recent earthquakes. Specifically, during the Kahramanmaraş earthquakes on February 6, 2023, UAVs were employed in supporting search and rescue operations, damage assessment efforts, detection of other disasters caused by the earthquake, maintaining public order in the region, and supporting communication infrastructure (Anadolu Ajansı, 2023).

5. UAV Base Location Selection for a Possible Marmara Earthquake

The rapid initiation of search and rescue operations after an earthquake is crucial for saving as many lives as possible. Given the significant impact anticipated from a possible Marmara earthquake, it is emphasized in both research and statements from experts that a very swift response is necessary. Therefore, this study aims to select the location for an UAV base that can respond most rapidly to such an earthquake using the multi-criteria decision-making method TOPSIS. As for the UAV class, MALE (Medium Altitude Long Endurance) class UAVs, which are both produced in Türkiye and preferred due to their mission duration and payload capacity according to NATO classification, have been chosen. The criteria used in the study are determined based on the capabilities and features of MALE class UAVs, while the alternatives are identified as airports that are least likely to be damaged in a possible earthquake and are also close to the Marmara region.

6. TOPSIS Method

The TOPSIS method, initially developed by Hwang and Yoon (1981), is one of the multi-criteria decision-making methods that uses "n" decision criteria and "m" decision alternatives. The TOPSIS method is fundamentally based on ranking decision alternatives according to their distances from the computed positive ideal and negative ideal solution points. When the objective is to maximize returns, proximity to the positive ideal solution point maximizes returns and minimizes costs, while proximity to the negative ideal solution point minimizes returns and maximizes costs (Behzadian et al., 2012).

6.1. Steps of TOPSIS Method

The TOPSIS method begins with the construction of the decision matrix, followed by the normalization and weighting of this matrix. The positive ideal and negative ideal solution values are then determined, and the proximity of the alternatives to these values is calculated. Finally, the process is completed by calculating the relative closeness to the ideal solution.

Step 1: Construction of the Decision Matrix

In the TOPSIS method, the first step before proceeding with the solution is to construct the decision matrix. In this matrix, the rows represent the decision alternatives to be compared in terms of their superiority, and the columns represent the decision criteria used to compare the alternatives (Ömürbek and Kınay, 2013). The decision matrix has dimensions of "m x n" and is shown below in Equation 1.

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{m1} & \cdots & a_{nj} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

In matrix A, "m" represents the number of decision alternatives, and "n" represents the number of decision criteria.

Step 2: Construction of the Normalized Decision Matrix

To construct the normalized decision matrix, the column totals are calculated by taking the sum of the squares of the elements in each column for each a_{ij} element. Then, each a_{ij} element is normalized by dividing it by the square root of the column total in which it is located (Alp and Engin, 2011). This process is shown below in Equation 2.

$$r_{ij}=\frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^{2}}}\ (i=1,\ldots,m\ ve\ j=1,\ldots,n) \tag{2}$$

The normalized decision matrix is shown in Equation 3.

$$R=\begin{bmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1n} \\ \vdots & & \vdots & & \vdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & & \vdots & & \vdots \\ r_{m1} & \cdots & r_{nj} & \cdots & r_{mn} \end{bmatrix} \tag{3}$$

Step 3: Construction of the Weighted Normalized Decision Matrix

Each element in the normalized decision matrix is weighted by a w_i value. The w_i values, or criterion weights, must sum to 1. During the weighting process, each column in the Normalized Decision Matrix (R) is multiplied by the corresponding weight value (Alp and Engin, 2011). Since each column represents a decision criterion, the criteria are effectively multiplied by their respective weights. This results in the weighted standardized decision matrix (V), as shown in Equation 4.

$$V=\begin{bmatrix} w_1r_{11} & \cdots & w_jr_{1j} & \cdots & w_nr_{1n} \\ \vdots & & \vdots & & \vdots \\ w_1r_{i1} & \cdots & w_jr_{ij} & \cdots & w_nr_{in} \\ \vdots & & \vdots & & \vdots \\ w_1r_{m1} & \cdots & w_jr_{nj} & \cdots & w_nr_{mn} \end{bmatrix} \tag{4}$$

Step 4: Obtaining Positive Ideal and Negative Ideal Solution Values

To obtain the Positive Ideal solution values (A^*), the largest values of the columns in the Weighted Normalized Decision Matrix (or the smallest if the decision criterion is for minimization) are selected. This selection is carried out using the equation $A^*=\{(maxv_{ij}|j \in J)\}$ and is represented as $A^*=(v_1^*,v_2^*,\ldots,v_n^*)$. Similarly, to obtain the Negative Ideal solution values (A^-), the smallest values of the columns in the Weighted Normalized Decision Matrix (or the largest if the decision criterion is for minimization) are selected. This selection is derived from the equation $A^*=\{(minv_{ij}|j \in J)\}$, and is represented as $A^-=(v_1^-,v_2^-,\ldots,v_n^-)$ (Ömürbek and Kınay, 2013).

Step 5: Calculating the Distances to Positive Ideal and Negative Ideal Points

In this step, the distances of the decision alternatives from the Positive Ideal and Negative Ideal solutions are calculated. The Euclidean distance approach is used for this calculation. The distance of each decision alternative to the Positive Ideal point is shown in Equation 5 (Kallo, 2015).

$$S_i^+=\sqrt{\sum_{j=1}^{n}\left(v_{ij}-v_j^*\right)^2} \tag{5}$$

As a result, there will be S_i^+ and S_i^- values for each decision alternative.

Step 6: Calculating the Relative Closeness to the Ideal Solution

To calculate the relative closeness of the decision alternatives to the ideal solution, the distances obtained in the previous step from the positive ideal and negative ideal points are utilized. This calculation is performed by dividing the distance of each alternative to the negative ideal point by the total distance, as shown in Equation 7.

$$C_i^*=\frac{S_i^-}{S_i^-+S_i^+} \tag{7}$$

Here, the C_i^* value is $0 \leq C_i^* \leq 1$. A C_i^* value of 1 indicates that the decision alternative is absolutely close to the ideal solution, while a C_i^* value of 0 indicates that the decision alternative is absolutely close to the negative ideal solution (Çağlı, 2010).

7. UAV Base Location Selection for a Possible Marmara Earthquake with TOPSIS Method

In this study, the location for establishing a MALE-class UAV base that can respond to a possible Marmara earthquake as quickly as possible was evaluated using the TOPSIS method. After discussing the alternatives and criteria used in the application below, the alternatives will be evaluated based on these criteria.

7.1. Alternatives Used in Application

MALE-class UAVs have been considered the most effective UAV class for post-earthquake support activities due to their flight endurance (up to 40 hours) and the type and amount of payload they carry (such as electro-optic/infrared cameras, base stations). Therefore, it was preferred to establish a MALE-class UAV base in the study. These UAVs, as they perform take-offs and landings from runways, were selected as alternative airports in the application.

When selecting airports, civil airports were chosen that are not located on any active fault lines according to the Türkiye Earthquake Map, to avoid being affected by a possible earthquake, and that are within a 600 km distance from the

Marmara Region to ensure quick access to the area post-earthquake. The airports that meet these criteria and were used as alternatives in the application include Ankara/Esenboğa (1), Gazipaşa-Alanya (2), Konya (3), Nevşehir/Kapadokya (4), Sinop (5), Sivrihisar Aviation Center (6), and Zonguldak (7) Airports. These alternatives have been shown in Figure 1, respectively.

7.2. Determination of Criteria Used in the Application

In determining the criteria, factors such as meeting the needs of MALE-class UAVs, susceptibility to earthquakes, and the ability to respond quickly to earthquakes were considered. Six criteria were established based on the opinions of five UAV pilots. The criteria weights were also determined based on evaluations made by these five UAV pilots. Each of these five UAV pilots are actively flying MALE-class UAVs, with flight experience ranging from 3 to 5 years and between 1200 and 2500 flight hours. Additionally, three of the experts participated in UAV operations after the 2020 Elazığ/Sivrice and 2023 Kahramanmaraş earthquakes, while two were involved in operations after the 2023 Kahramanmaraş earthquakes. The criteria used in the study and their definitions are provided below:

Distance to Fault Lines: To ensure that the UAV base to be established is not damaged by earthquakes and that support activities can be carried out without disruption, the selected location should be far from fault lines. The distance to the nearest active fault for the alternatives was measured from the Türkiye Earthquake Hazard Map. This is a criterion that is desired to be maximized.

Distance to the Marmara Region: Since the goal is to select a location that can respond to a possible Marmara earthquake as quickly and effectively as possible, the distances of the alternatives to the Marmara Region and to Istanbul, which is the largest city in Türkiye, were measured. This is a criterion that is desired to be minimized.

Distance to City/Town Centers: To meet the basic, social, and cultural needs of the personnel who will work at the planned UAV base, the distance of the alternative airports from city centers is important. The road distances of the alternatives to the nearest city or town centers were measured. This is a criterion that is desired to be minimized.

Airport Traffic Density: Since UAV systems have lower descent and climb performance compared to manned aircraft, and due to potential traffic disruptions during UAV take-offs and landings, the daily flight numbers of the alternative airports were obtained from internet sites and Flight Radar applications. This is a criterion that is desired to be minimized.

Meteorological Conditions: UAVs cannot operate on cloudy and rainy days, so the annual average number of rainy days in the cities where the alternatives are located was obtained from the website of the General Directorate of Meteorology. This is a criterion that is desired to be minimized.

Runway Length: This is a necessary criterion for ensuring that aircraft used in UAV systems can take off and land safely. This is a criterion that is desired to be maximized.

7.3. Evaluation of Criteria and Alternatives by Decision Makers

The first step in using the method is the creation of the decision matrix. Based on the determined alternatives and criteria, the decision matrix, constructed according to Equation 1, is presented in Table 3.

Table 3. Decision Matrix

Alternatives	**Distance to Fault Lines (km) Max**	**Distance to the Marmara Region (km) Min**	**Distance to the City/Town Centers (km) Min**
Ankara/Esenboğa	85	354	13
Gazipaşa-Alanya	227	594	42
Nevşehir/Kapadokya	174	532	30
Konya	99	453	12
Sinop	94	521	7
Sivrihisar	144	284	21
Zonguldak	107	269	11

Alternatives	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Ankara/Esenboğa	253	103	3752
Gazipaşa-Alanya	15	74	2500
Nevşehir/Kapadokya	13	107	3000
Konya	16	83	3348
Sinop	2	132	2000
Sivrihisar	2	70	2131
Zonguldak	4	147	1810

After determining the decision matrix, the normalization process is carried out. The R Normalized Decision Matrix obtained using Equation 2 is shown in Table 4.

Table 4. Normalized Decision Matrix

R	**Distance to Fault Lines (km) Max**	**Distance to the Marmara Region (km) Min**	**Distance to the City/Town Centers (km) Min**
Ankara/Esenboğa	0.22729	0.30017	0.21703
Gazipaşa-Alanya	0.60700	0.50367	0.70117
Nevşehir/Kapadokya	0.46528	0.45110	0.50084
Konya	0.26473	0.38411	0.20033
Sinop	0.25136	0.44177	0.11686
Sivrihisar	0.38506	0.24081	0.35058
Zonguldak	0.28612	0.22809	0.18364
R	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Ankara/Esenboğa	0.99478	0.36796	0.51855
Gazipaşa-Alanya	0.05898	0.26436	0.34551
Nevşehir/Kapadokya	0.05111	0.38225	0.41462
Konya	0.06291	0.29651	0.46271
Sinop	0.00786	0.47156	0.27641
Sivrihisar	0.00786	0.25007	0.29452
Zonguldak	0.01573	0.52515	0.25015

Table 5. Defuzzified Importance Weights

Importance Weights	**Defuzzified Values**
Very Low (VL)	0
Low (L)	0.1
Medium Low (ML)	0.3
Medium (M)	0.5
Medium High (MH)	0.7
High (H)	0.9
Very High (VH)	1

In the TOPSIS method, since the sum of the criterion weights must equal 1, the weights assigned by the five experts for each criterion were averaged. Then, each criterion's average was divided by the sum of all criterion weight averages to calculate the final criterion weights. The resulting W Importance Weights are shown in Table 6. The criterion weights, listed from highest to lowest, are as follows: distance to the Marmara Region, distance to fault lines, meteorological conditions, airport traffic density, distance to city/town centers, and runway length.

Table 6. Criteria Importance Weights

W	**Distance to Fault Lines (km) Max**	**Distance to the Marmara Region (km) Min**	**Distance to the City/Town Centers (km) Min**
Weights	0.19262	0.19672	0.13525
W	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Weights	0.16803	0.18033	0.12705

Subsequently, the importance weights of the criteria were associated with the normalized decision matrix using Equation 4, resulting in the weighted normalized decision matrix V as shown in Table 7.

Table 7. Weighted Normailzed Decision Matrix

V	Distance to Fault Lines (km) Max	Distance to the Marmara Region (km) Min	Distance to the City/Town Centers (km) Min
Ankara/Esenboğa	0.04378	0.05905	0.02935
Gazipaşa-Alanya	0.11692	0.09908	0.09483
Nevşehir/Kapadokya	0.08962	0.08874	0.06774
Konya	0.05099	0.07556	0.02709
Sinop	0.04842	0.08691	0.01581
Sivrihisar	0.07417	0.04737	0.04742
Zonguldak	0.05511	0.04487	0.02484

V	Airport Traffic Density (Number of Flights) Min	Meteorological Conditions (Day) Min	Runway Lenght (m) Max
Ankara/Esenboğa	0.16716	0.06635	0.06588
Gazipaşa-Alanya	0.00991	0.04767	0.04390
Nevşehir/Kapadokya	0.00859	0.06893	0.05268
Konya	0.01057	0.05347	0.05879
Sinop	0.00132	0.08504	0.03512
Sivrihisar	0.00132	0.04509	0.03742
Zonguldak	0.00264	0.09470	0.03178

The fourth step of the TOPSIS application involves finding the positive ideal and negative ideal solutions, or in other words, the maximum and minimum values. In this stage, the maximum and minimum values for each column are determined. Since there are 6 criteria in this study, there will be 6 maximum and minimum values. These values are determined and shown in Table 8.

Table 8. Positive Ideal and Negative Ideal Solutions

A^*	0.11692	0.04487	0.01581
A^-	0.04378	0.09908	0.09483
A^*	0.00132	0.04509	0.06588
A^-	0.16716	0.09470	0.03178

The fifth step of the TOPSIS method involves finding the distance values to the positive ideal and negative ideal points. In this stage, the distances from each decision point to the maximum and minimum values, i.e., the positive ideal and negative ideal points, are calculated. Since the decision points in this application are UAVs, there are 7 negative ideal and ideal distance values. The distances to the positive ideal and negative ideal points are determined using the calculations in Equations 5 and 6 and are provided in Table 9.

Table 9. Distances to the Positive Ideal and Negative Ideal Points

Alternatives	Distances to the Positive Ideal Points	Distances to the Negative Ideal Points
Sivrihisar	0.03369	0,00786
Konya	0.00975	0,03243
Nevşehir/Kapadokya	0.00616	0,02919
Zonguldak	0.00562	0,03214
Sinop	0.00900	0,03402
Gazipaşa-Alanya	0.00364	0,03584
Ankara/Esenboğa	0.00753	0,03503

The sixth and final step of the TOPSIS method is the calculation of the relative closeness to the ideal solution. In this stage, the solution is reached and the performance values of the analyzed alternatives are determined by performing the calculations in Equation 7. In the final process, a ranking is made from the best alternative to the worst alternative as shown in Table 10.

Table 10. Ranking of Alternatives Based on Their Closeness to the Ideal Solution

Closeness to the Ideal Solution	Alternatives
0.907722808	Sivrihisar
0.851118387	Konya
0.825678903	Nevşehir/Kapadokya
0.823133448	Zonguldak
0.790765669	Sinop
0.768912139	Gazipaşa-Alanya
0.189111002	Ankara/Esenboğa

As a result of the ranking using the TOPSIS method, the most suitable airport for establishing a UAV base to respond to a possible Marmara earthquake is Sivrihisar Aviation Center. In contrast, Esenboğa received the lowest value among the other alternatives.

In the TOPSIS method, since expert opinions are utilized in the stages of determining and weighting the criteria, it should be noted that the results are aligned with these perspectives and are not entirely based on objective data. Changes made to the criteria and their weights may also affect the results.

8. Conclusion

In modern times, UAVs are used effectively in various fields, including disaster management. One of the most significant disasters that comes to mind is earthquakes. UAVs play a widespread role, especially in supporting search and rescue operations following an earthquake. In Türkiye, the role of UAVs in a potential Marmara earthquake is crucial. The selection of a UAV base location for the quickest and most effective response to such an earthquake can be determined using multi-criteria decision-making methods.

In this study, the focus was first on Unmanned Aerial Vehicles (UAVs), earthquake disasters, and the use of UAVs in earthquakes. Subsequently, the selection of a UAV base location for the quickest response to a potential Marmara earthquake was evaluated using the multi-criteria decision-making method, TOPSIS.

For the TOPSIS method, alternatives were chosen as airports near the Marmara Region (within 600 km) and located in areas not affected by earthquakes, including Ankara/Esenboğa, Gazipaşa-Alanya, Konya, Nevşehir/ Kapadokya, Sinop, Sivrihisar Aviation Center, and Zonguldak Airports.

When determining the criteria, factors such as meeting the needs of MALE-class UAVs, susceptibility to earthquakes, and the ability to respond quickly to earthquakes were considered. Six criteria were established based on the opinions of five UAV pilots. These criteria are distance to fault lines, distance to the Marmara Region, distance to city/town centers, airport traffic density, meteorological conditions, and runway length. The criteria weights were also determined based on the evaluations of these five UAV pilots.

As a result of applying the TOPSIS method, the selected alternatives were ranked from worst to best for their suitability as UAV bases in post-earthquake disaster operations in the Marmara region. The ranking was as follows: Esenboğa Airport, Gazipaşa Airport, Sinop Airport, Zonguldak Airport, Kapadokya Airport, Konya Airport, and Sivrihisar Aviation Center.

Researchers can explore the use of UAVs for other types of disasters in their future studies. Other methods such as deep learning and machine learning could be used alongside the TOPSIS method. Similar studies can also be conducted for different regions of the country. Furthermore, research can be done using the same alternatives but with different criteria and criteria weights. Additionally, the criterion weights can be determined using a multi criteria decision making method instead of expert opinion, or the impact of changing one or more criterion weights in the same application can be evaluated.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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