



Research Article

## Three-Dimensional (3D) Airport Runway Design Model for Tunceli Province

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**Abstract:** This research article addresses the design of an airport runway for the province of Tunceli, which is characterized by a geographically challenging topography. The study highlights the inadequacies of traditional two-dimensional (2D) analyses in complex terrains and proposes a decision support approach based on three-dimensional (3D) modelling. In this context, two alternative sites were evaluated. The first site, assessed using conventional 2D methods, was found unsuitable due to excessive natural slope and significant obstacle penetrations. The second site, analyzed through a 3D environment using Digital Elevation Model (DEM) data in Blender, enabled the volumetric modelling of Obstacle Limitation Surfaces (OLS) and provided a more realistic representation of terrain-obstacle interactions. In this study, the Boeing 737-800 classified under ICAO Code 4C and widely used in Türkiye's domestic flights, was selected as the reference aircraft for the airport runway design. Considering site-specific altitude and temperature conditions, the required runway length was calculated as 3200 m. The 3D analyses indicated full compliance with approach, takeoff-climb and inner horizontal surface criteria for the north-south orientation. Overall, the results demonstrate that 3D data-driven methods offer a more reliable and precise framework for airport planning in mountainous regions compared with traditional 2D approaches.

**Keywords:** airport runway design, 3D modeling, blender, obstacle analysis.

Araştırma Makalesi

## Tunceli İli İçin Üç Boyutlu (3B) Havalimanı Pist Tasarımı Modeli

**Özet:** Bu araştırma makalesi, coğrafi olarak zorlu bir topoğrafyaya sahip olan Tunceli ili için bir havalimanı pisti tasarımını ele almaktadır. Çalışma, karmaşık arazilerde geleneksel iki boyutlu (2B) analizlerin yetersizliklerini vurgulamakta ve üç boyutlu (3B) modellemeye dayalı bir karar destek yaklaşımı önermektedir. Bu kapsamda iki alternatif saha değerlendirilmiştir. Geleneksel 2B yöntemlerle analiz edilen ilk saha, aşırı doğal eğim ve belirgin mania penetrasyonları nedeniyle uygun bulunmamıştır. Sayısal Yükseklik Modeli (DEM) verilerinin Blender yazılımında kullanıldığı üç boyutlu ortamda analiz edilen ikinci saha ise, Mania Sınırlandırma Yüzeylerinin (OLS) hacimsel olarak modellenmesine imkân tanımış ve arazi-engel etkileşimlerinin daha gerçekçi biçimde temsil edilmesini sağlamıştır. Bu çalışmada, ICAO Kod 4C sınıfında yer alan ve Türkiye'de iç hat uçuşlarında yaygın olarak kullanılan Boeing 737-800 uçağı, havalimanı pisti tasarımı için referans uçak olarak seçilmiştir. Saha özelindeki rakım ve sıcaklık koşulları dikkate alındığında gerekli pist uzunluğu 3200 metre olarak hesaplanmıştır. Üç boyutlu analizler, kuzey-güney doğrultusundaki pist yerleşiminin

yaklaşma, kalkış tırmanışı ve iç yatay yüzey kriterlerinin tamamıyla uyumlu olduğunu göstermiştir. Genel olarak elde edilen sonuçlar, 3B veri odaklı yöntemlerin dağlık bölgelerdeki havalimanı planlamalarında geleneksel 2B yaklaşımlara kıyasla daha güvenilir ve daha hassas bir değerlendirme çerçevesi sunduğunu ortaya koymaktadır.

**Anahtar Kelimeler:** havalimanı pist tasarımı, 3B modelleme, blender, mania analizi.

## 1. Introduction

In recent years, the increasing global demand for air transportation has brought the planning of new airport infrastructures and the expansion of existing capacities to the forefront [1]. This situation necessitates more precise engineering designs, especially in regions with complex topography, limited settlement areas, or challenging geological conditions [2,3]. The geographical diversity of Türkiye often renders conventional planar analyses insufficient during airport site selection processes [1,4].

Tunceli, one of the mountainous provinces of the Eastern Anatolia Region, has limited transportation infrastructure. Although the existing road network provides partial adequacy for long-distance transportation, geographical barriers make air transportation a strategic necessity for the region [1]. However, due to its narrow valleys, significant elevation differences, and limited flat terrain, Tunceli's topography presents notable engineering challenges for airport site selection [5,6]. Under these conditions, runway planning must be evaluated not only based on slope data but also through multidimensional parameters such as obstacle (mania) analysis, wind orientation, elevation, and temperature [2,3,6].

This study aims to comparatively examine classical two-dimensional (2D) analytical methods and three-dimensional (3D) modelling-based engineering approaches in the context of Tunceli province, and to reveal the effectiveness of 3D analyses in airport runway design.

In the literature, runway designs are generally handled using two-dimensional (2D) analytical methods, where parameters such as slope, elevation, and temperature are evaluated through profile-based calculations [1,4,7]. However, these approaches fail to adequately represent the three-dimensional effects of obstacle surfaces in regions with complex topography, which may lead to inaccuracies in determining runway orientation and safety zones [4,8].

Therefore, in recent years, Digital Elevation Models (DEMs), Geographic Information Systems (GIS), and 3D modelling software have been widely utilized in engineering projects [7]. Open-source 3D modelling platforms such as Blender enable volumetric examination of topographic analyses and enhance visual validation [7,9].

This study covers two different runway design alternatives proposed for Tunceli province. The first design is based on the classical engineering approach, where topographic profiles, slope, and obstacle analyses were evaluated through two-dimensional methods [10,11]. The second design was carried out through volumetric analyses in Blender using Shuttle Radar Topography Mission (SRTM)-based digital elevation data [7,9]. Both methods were compared in terms of engineering accuracy, obstacle compliance, and decision-support capability.

Recent studies highlight the increasing use of Geographic Information Systems (GIS), Digital Elevation Models (DEMs), and 3D modelling tools in airport site selection and runway design, particularly

in regions with complex topography [12,13,14]. Three-dimensional terrain analysis has been shown to provide more accurate evaluations of obstacle limitation surfaces, approach paths, and slope characteristics compared with traditional 2D methods [12,13]. Such advancements demonstrate the importance of 3D modelling in supporting safe and efficient airport planning processes [14].

Consequently, this research highlights the limitations of conventional two-dimensional approaches and emphasizes the advantages of three-dimensional modelling-based methods in engineering design, flight safety, and decision-making processes [10]. Thus, the study demonstrates the future potential of 3D data-driven analyses in regional airport planning. Unlike previous studies that rely solely on two-dimensional evaluations, this research provides a comparative framework demonstrating how 3D volumetric analysis can significantly improve runway orientation, obstacle assessment, and site suitability decisions in mountainous regions.

## 2. Materials and Methods

In this section, the engineering approach, data types, computational methods, and modelling tools used in the proposed airport runway design are systematically presented.

The runway design process has been structured through the combined evaluation of geotechnical, topographic, and meteorological data [2,10].

Conducted in accordance with both international and national standards, this process was supported by numerical data specific to the application site and structured through a multi-criteria engineering framework [2,10].

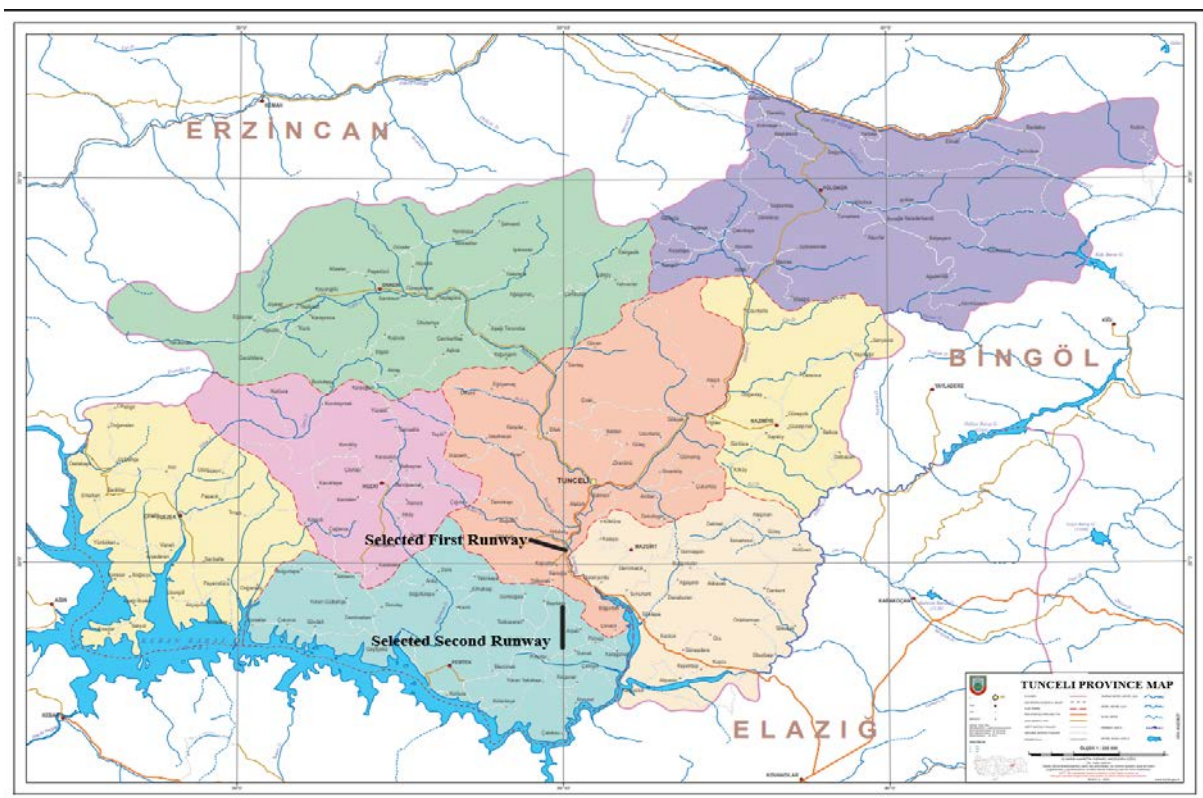
### 2.1. Study Area

This study examines the geographical and topographic conditions of the engineering design for the proposed airport runway within the administrative boundaries of Tunceli province.

In the first stage, an area located in the Aktuluk region, connected to the Tunceli city center, was evaluated. However, due to the high natural slope, complex obstacle (mania) profile, and extensive cut-and-fill requirements, this site was deemed unsuitable for implementation [2,3,10].

As an alternative, a second site was selected between the villages of Kacarlar, Arpalı, and Sumak, located southwest of the city. This area is bordered by the Munzur River to the east and mountainous masses to the west, forming a natural topographic corridor extending in a north-south direction [5].

The site is approximately 20 km away from the city center and lies close to the D885 highway, providing advantages in terms of accessibility and construction logistics [16]. The locations and orientations of both proposed runways are illustrated in Figure 1.



**Figure 1.** Location and orientation of the selected runways [15]

The terrain is generally characterized by moderately sloped valleys and occasional alluvial plains. The geomorphology of the region allows the preservation of the natural drainage network and provides a suitable alignment for the runway orientation. In addition, due to its location away from dense urban development, the site possesses a low obstacle (mania) risk and a favorable environmental configuration [5,6].

During the site selection process, high-resolution topographic images obtained from the General Directorate of Mapping (HGM) and the Google Earth platform were utilized [6,15]. These datasets were analyzed within a Geographic Information Systems (GIS) environment, enabling comparative evaluation among multiple site alternatives [7].

As a result, the Kacarlar-Arpalı-Sumak region was identified as the optimum site in terms of both topographic suitability and engineering accessibility [1,2,7,10].

## 2.2. Aircraft Type, ICAO Codes, and Their Effects on Runway Design

Airport runway design is directly dependent on the physical and operational requirements of the aircraft it serves [2]. Geometric parameters such as runway length, width, slope, load-bearing capacity, and shoulder area are directly related to the aircraft's maximum take-off weight (MTOW), wingspan, main gear wheel track, and take-off-landing performance [1,2,10].

Therefore, in runway planning, a design aircraft is typically identified, and all dimensional parameters are determined based on the operational requirements of this aircraft [1,2,8,10].

The International Civil Aviation Organization (ICAO) uses a two-character Reference Code System for the classification of airports [10]. The first character of the code represents the minimum runway length required for the aircraft, while the second character indicates the wingspan and main gear wheel span [1,2,10]. Accordingly, runway geometries can be planned in compliance with standardized criteria [2,10]. A general classification of this code system defined by ICAO is presented in Table 1. Table 2 provides the ICAO Code Letter classification, which defines the aircraft wingspan limits and main gear wheel span ranges used in determining runway and taxiway geometric standards [10].

In this study, a medium-class passenger aircraft capable of accommodating both regional flight traffic and the potential passenger capacity of Tunceli was selected as the reference. Among the most widely used narrow-body jets in domestic Turkish air transport, the Boeing 737-800 was adopted as the design aircraft [17]. This aircraft belongs to the ICAO Code 4C category, with a runway length requirement of at least 1,800 meters and a wingspan range of 24-36 meters, placing it among medium-range jet aircraft [1,10,11,17]. The main technical characteristics of the selected aircraft and its relation to the ICAO code category are presented in Table 3 [10,17]. This table summarizes the Boeing 737-800's key operational parameters, confirming its compliance with the ICAO Code 4C classification and validating its selection as the reference aircraft for this study.

The runway design process was carried out based on ICAO Annex 14, FAA Advisory Circular 150/5300-13A, and the SHGM Airport Design Criteria directive [2,10,18]. These standards were accepted as the basis for determining runway gradients, length corrections, safety strips, and obstacle limitation surfaces [2,10,18]. Detailed computational methods and results are presented in the subsequent sections (Results and Discussion).

**Table 1.** ICAO Code Number Classification [10]

Code Number (1-4)	Runway Length (m)
1	Less than 800 m
2	From 800 m up to (but not including) 1200 m
3	From 1200 m up to (but not including) 1800 m
4	1800 m and above

**Table 2.** ICAO Code Letter Classification [10]

Code Letter (A-F)	Wingspan (m)	Main Gear Wheel Span (m)
A	Up to but not including 15 m	Up to but not including 4.5 m
B	From 15 m up to but not including 24 m	From 4.5 m up to but not including 6 m
C	From 24 m up to but not including 36 m	From 6 m up to but not including 9 m
D	From 36 m up to but not including 52 m	From 9 m up to but not including 14 m
E	From 52 m up to but not including 65 m	From 9 m up to but not including 14 m
F	65 m and above	14 m and above

**Table 3.** Technical Specifications of Boeing 737-800 [10], [17]

Parameter	Value
ICAO Code Category	4C
Maximum Take-Off Weight (MTOW)	79,000 kg
Wingspan	35.8 m
Main Gear Wheel Track	6.2 m
Tail Height	12.5 m
Minimum Take-Off Distance	≈ 2000 m (ISA, Sea Level)
Minimum Runway Width Requirement	≥ 45 m (ICAO Code 4C)

### 2.3. Runway Length Calculation

The design of runway length is determined by considering both environmental and topographic conditions to meet the performance requirements of the selected design aircraft. In this study, the calculations were planned based on the Sequential Multiplication Method recommended by the International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA) [8,10].

The basis of this method involves applying altitude (R), temperature (T), and slope (S) correction factors sequentially to the basic runway length ( $L_0$ ), which is defined under sea-level and International Standard Atmosphere (ISA) conditions. This approach allows the individual effect of each parameter on runway length to be monitored, while the total correction ratio is determined through a multiplicative process [1,10].

The general computational relationship is defined as follows:

$$L_{final} = L_0 \times (1 + R) \times (1 + T) \times (1 + S) \quad (2.1)$$

Where:

- **L<sub>0</sub>**: Basic runway length the reference value under sea level and ISA conditions (e.g., 2000 m for the Boeing 737-800) [17].
- **R**: Altitude correction factor compensates for the reduction in air density due to the elevation of the runway site.
- **T**: Temperature correction factor proportional to the deviation of the mean temperature from the standard atmosphere.
- **S**: Longitudinal slope correction factor accounts for the loss of acceleration caused by runway gradient.

These parameters are applied sequentially, and the total effect is obtained by multiplication rather than addition. This methodology represents the standard computational approach proposed by ICAO Annex 14 and FAA Advisory Circular AC 150/5325-4B [8,10].

In the implementation of the model:

- **L<sub>0</sub>** is taken from the manufacturer's Airport Planning Manual (e.g., take-off and landing distances for the Boeing 737-800) [17].
- **R** is determined according to the 7% per 300 m elevation rule or FAA performance charts [8].

- **T** is calculated using long-term average temperature data and design day conditions obtained from the Turkish State Meteorological Service (MGM) [6], [8], [10].
- **S** is determined based on the mean longitudinal slope measured along the runway alignment [8], [10].

The results are presented in tabular form in the following sections, illustrating the contribution of each correction factor to the final runway length. This method has been adopted for its compliance with the principles of computability, traceability, and standardization.

#### 2.4. Obstacle Limitation Criteria and Obstacle-Free Zones

In airport runway design, not only the runway length and orientation but also the configuration of surrounding natural and artificial obstacles play a crucial role in ensuring flight safety. Therefore, ICAO Annex 14 and the Obstacle Limitation Surfaces Directive (SHT-Mania Planı) issued by the Directorate General of Civil Aviation (SHGM) define the obstacle limitation surfaces (OLS) that establish the areas to be kept free from obstacles around the runway [4,10].

These surfaces consist of different zones such as approach, take-off climb, inner horizontal, and conical surfaces, each defined by specific parameters of length, width, and slope [4,10]. In this study, obstacle (mania) analyses were carried out in accordance with the standards defined for ICAO Code 4C runways. The main objective of these analyses is to identify potential obstacles that may affect flight safety along the runway alignment and to evaluate these obstacles volumetrically within a three-dimensional topographic framework. The geometric limits of each surface were derived directly from the corresponding standards, with the runway centerline used as the reference axis [4,10].

The approach surface forms an inclined corridor rising from each runway end, while the take-off climb surface defines the area ensuring safe aircraft climb-out. The inner horizontal and conical surfaces create a broad protective zone surrounding the runway, allowing for the control of structural developments within defined limits.

During the numerical analysis phase, the NASA Shuttle Radar Topography Mission (SRTM)-based Digital Elevation Model (DEM) was used, and the study area was positioned within the QGIS environment [7,18]. Subsequently, this dataset was transferred to Blender 3.6 software for three-dimensional modelling and analysis [9]. In the Blender environment, the runway axis and the obstacle limitation surfaces were modelled three-dimensionally, and the intersections between the surfaces and the terrain were visually evaluated [9].

For the second site, a high-resolution terrain model consisting of approximately 65,000 vertices was generated using Shuttle Radar Topography Mission (SRTM)-based elevation data [7]. The dataset was imported into Blender as a digital elevation mesh, where the vertical scale, coordinate alignment, and unit consistency (meters) were manually calibrated. The accuracy of the elevation values was verified by comparing several reference points with Google Earth [15] and topographic elevation data provided by the General Directorate of Mapping [16].

Following terrain validation, the Obstacle Limitation Surfaces (OLS) were manually constructed in Blender using parametric modelling tools [9]. Each regulatory surface including the approach, takeoff-climb, inner horizontal, conical, and transitional surfaces was defined as a three-dimensional volumetric

envelope based on the slope ratios and elevation criteria specified in ICAO Annex 14 [10] and EASA CS-ADR-DSN [11]. The surfaces were generated by extruding reference profiles along the proposed runway axis and applying precise geometric constraints to maintain the correct inclinations and lateral extents.

Blender's geometry nodes, mesh Boolean operations, and viewport overlay functions were then used to inspect the interaction between the OLS volumes and the terrain model [9]. Intersection and collision visualization tools allowed the detection of terrain penetrations in real time, enabling a fully volumetric assessment of runway feasibility, obstacle clearance, and surface compliance. This approach provided a level of spatial accuracy that is not achievable with conventional 2D profile-based analysis model.

This approach provides a much more realistic topographic assessment compared to conventional two-dimensional sectional analysis of obstacle limitation surfaces [7,9]. The resulting 3D models will be examined comparatively in the Results and Discussion section, particularly focusing on the effects of different runway orientations on flight safety and obstacle clearance violations.

### 3. Results and Discussion

This section presents and discusses the calculations, results, graphs, and analyses obtained throughout the study. Where necessary, the results are supported with figures and tables, and comparisons with relevant literature are provided. The presentation of results should be both clear and concise.

In the discussion section, excessive citation and extended literature reviews should be avoided; instead, the key findings of the study are emphasized.

#### 3.1. Runway Length Calculations for the First Site

For the first site, the runway length was determined using the Sequential Multiplication Method, which accounts for the effects of environmental factors. In this method, the basic runway length ( $L_0$ ) represents the take-off distance of the selected design aircraft under sea-level and International Standard Atmosphere (ISA) conditions. Subsequently, altitude (R), temperature (T), and slope (S) correction factors were applied sequentially.

##### 3.1.1. Altitude Correction

According to FAA guidelines, a correction of approximately 7% is applied to runway length for every 300 m increase in elevation [8]. In the examined area, the elevation values range between 940 m and 1045 m, with an average altitude of 993 m.

Accordingly:

$$(R) = \frac{993}{300} \times 7 = 23,17\%$$

High-altitude conditions reduce air density, leading to decreased engine performance and longer take-off distances. Therefore, this correction is mandatory to maintain flight safety.

### 3.1.2. Temperature Correction

According to the Turkish State Meteorological Service (MGM), the mean maximum temperature in summer is approximately 33 °C [6]. To calculate the temperature correction, the standard atmosphere temperature ( $T_{ISA}$ ) corresponding to the mean altitude was first determined. Under the International Standard Atmosphere (ISA) model, the temperature at sea level is assumed to be 15 °C, decreasing by roughly 2 °C per 1000 ft of altitude [1].

The mean altitude of 993 m was converted to feet as follows:

$$T_{ISA} = 15 - \left( \frac{3258}{1000} \times 2 \right) = 15 - 6,516 = 8,484 \text{ °C}$$

$$33 \text{ °C} - 8,484 \text{ °C} = 24,516 \text{ °C}$$

According to FAA recommendations, a 1% correction is applied for every 1 °C temperature deviation [8].

Hence, the temperature correction percentage is:

$$(T) = 24,516 \times 1\% = 24,516\%$$

As a result, the runway length should be increased by approximately 24.52% due to the temperature effect. This correction is critical for compensating reduced engine performance, increased take-off distance, and decreased air density during summer operations.

### 3.1.3. Slope Correction

Topographic analyses indicated a natural slope of 3.09% along the runway alignment. This value exceeds the limits permitted by ICAO and FAA standards [1,2]. Through engineering interventions, the slope was reduced to 1.0%. Slope correction is typically applied when the longitudinal gradient exceeds 1%, and for every additional 1% slope, a 10% increase in runway length is recommended [8]. Since the average slope was stabilized at 1.0%, it remained within acceptable limits, and no additional correction was applied. Moreover, this value does not produce any significant operational performance difference.

### 3.1.4. Final Runway Length and Evaluation

Applying the corrections sequentially, the runway length was determined as follows:

$$L_{final} = L_0 \times (1+R) \times (1+T) = 2000 \times 1.2317 \times 1.2452 = 3066 \text{ m}$$

Thus, the required runway length for the first site was calculated as approximately 3066 m. However, due to the steep and irregular topography of the area, constructing a runway of this length is not feasible.

The required cut-and-fill operations would not only increase costs but also negatively affect ground stability. Therefore, this site was found to be less favorable than the second alternative in terms of both operational safety and construction feasibility.

## 3.2. Obstacle (Mania) Control and Analysis for the First Runway

To determine the suitability of the runway's position and orientation for flight safety, analyses were conducted in accordance with ICAO Annex 14 and the SHGM Airport Design Standards Guide (2019) [1,3].

The concept of obstacles and surface types has been explained previously; this section presents only the results specific to the first runway site. The analysis covered the take-off climb, approach, and inner horizontal surfaces, while conical and transitional surfaces were excluded during the preliminary planning stage.

Terrain elevation data were obtained from Google Earth Pro (2024). As shown in Figure 2, the runway alignment was plotted on the site, and a longitudinal elevation profile was generated along this line [17]. This approach provides a practical method for early-stage engineering decision-making in complex topographic areas.

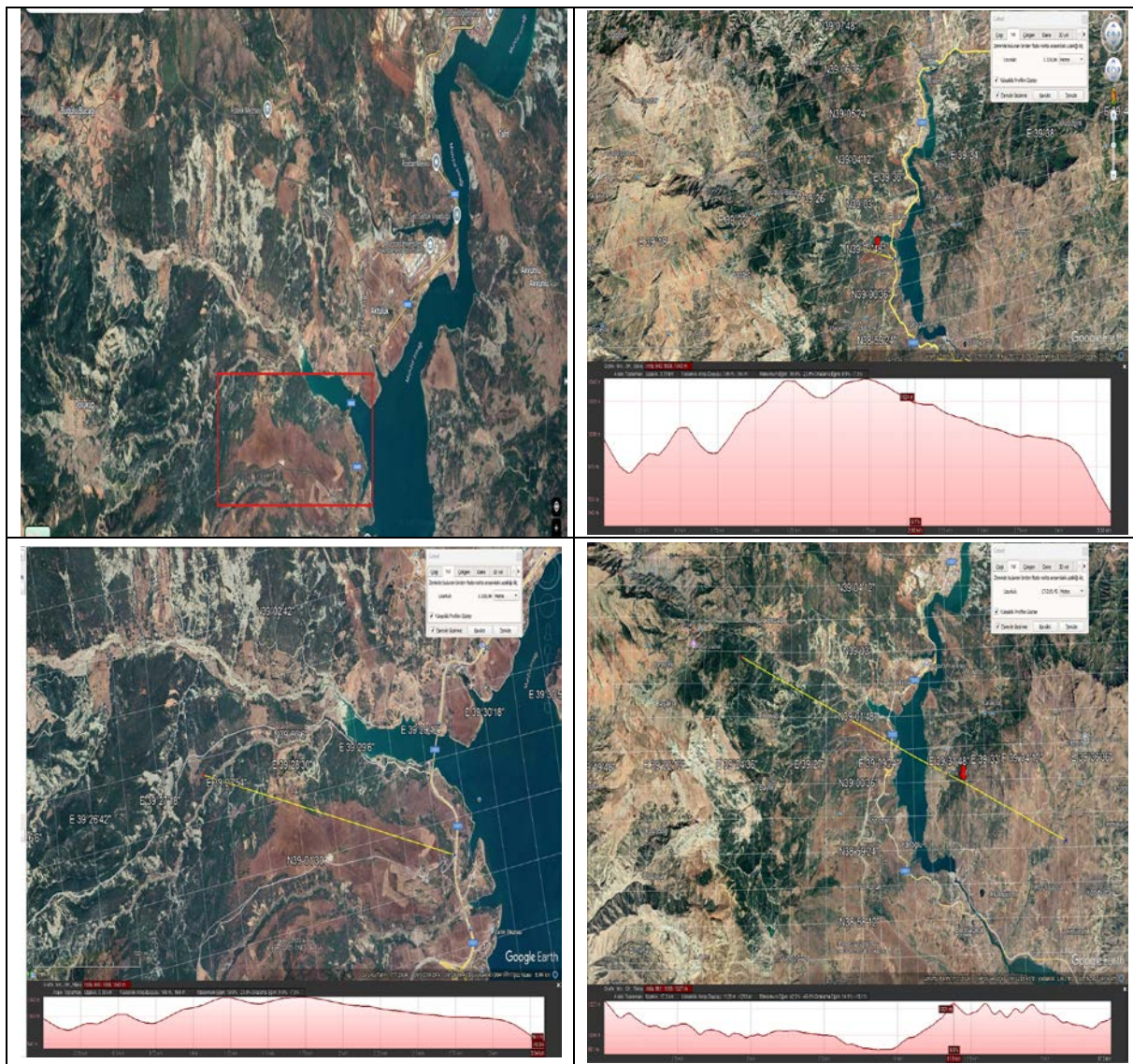


Figure 2. Wide-area view of the selected first runway [15]

### 3.2.1. Take-off Surface Analysis

The take-off surface is defined as a three-dimensional volume rising at a 1:50 slope (2%) over a distance of 3000 m from the runway threshold [1]. In this analysis, obstacle (mania) assessments were

conducted along the runway centerline for both the eastern and western ends. The average runway elevation was determined as 993 m, and with a 1% longitudinal slope, the eastern and western thresholds were modelled at 977.7 m and 1008.3 m, respectively.

According to Google Earth data, terrain elevations located 3000 m from the runway were measured as 1180 m in the east and 1071 m in the west [15].

When compared with ICAO limits, the following obstacle penetrations were identified:

- East side: 142.3 m
- West side: 2.7 m

Based on these findings, the western penetration can be considered marginally acceptable, whereas the eastern side's 142.3 m exceedance represents a critical safety violation [1].

### 3.2.2. Approach Surface

The approach surface is defined as a trapezoidal protection volume rising at a 2.0% slope over a distance of 15,000 m from the runway end [1,3]. Measurements taken toward the eastern direction (Runway End No. 1) indicate that the terrain elevation at 15,000 m is 1344 m, which remains below the ICAO-defined limit of 1352.7 m. However, in the western direction (Runway End No. 2), the terrain elevation at the same distance is 1830 m, exceeding the allowable 1383.3 m by approximately 447 m.

This result demonstrates a significant obstacle intrusion in the western direction, rendering approach operations unsafe. Although the eastern direction appears relatively acceptable, bidirectional approach conditions could not be achieved for the entire runway.

### 3.2.3. Inner Horizontal Surface

The inner horizontal surface is defined as a circular area with a 4000 m radius, positioned 45 m above the average runway elevation [1,3]. Assuming an average runway elevation of 993 m, the inner horizontal surface was modelled at 1038 m. According to Google Earth data, the highest natural terrain elevation within this boundary is 1020 m, remaining below the horizontal surface [15]. Therefore, no obstacle penetrations were identified in this region.

This condition provides sufficient engineering flexibility for the placement of aprons, terminals, and auxiliary facilities, and establishes a safe operational zone for low-altitude maneuvers.

### 3.3. Elimination Criteria for the First Runway

Based on the engineering analyses, the first runway site did not satisfy ICAO and SHGM standards [1,3]. In particular, obstacle penetrations of 142 m were detected on the eastern take-off surface, and 447 m on the western approach surface. These violations directly jeopardize flight safety and restrict the operational usability of the site.

Moreover, the natural longitudinal slope of 3.09 % significantly exceeds the ICAO limit of 1.5 % [1,2]. Stabilizing the slope at 1.0 % would require extensive cut-and-fill operations, increasing both construction complexity and cost. In addition, the computed runway length of 3066 m further raises earthwork volume, construction expenses, and subgrade stability risks.

Consequently, the site was deemed inadequate in terms of engineering feasibility and operational safety. Since bidirectional operations could not be safely maintained along the runway axis, the area was considered unsuitable for a sustainable airport infrastructure.

Therefore, the site was eliminated, and the design process was continued on an alternative location possessing more favorable topographical conditions.

### **3.4. Limitations of the Conventional 2D Approach and the Enhanced 3D Modelling Method**

The first runway site was analyzed considering runway length, altitude and temperature corrections, slope evaluation, and obstacle clearance. Conventional two-dimensional (2D) analyses based on Google Earth topographic data revealed that the site exceeded engineering constraints in multiple aspects [15]. Severe obstacle infringements were detected on obstacle-limitation surfaces, while the steep natural slope rendered the construction of a stable and economical runway platform impractical.

These findings demonstrate that traditional 2D engineering methods are inadequate for decision-making in complex terrains. Analyses based solely on longitudinal profiles and numerical values fail to represent the volumetric interaction between terrain and obstacle surfaces, increasing the potential for alignment and layout errors [1-3].

To overcome these limitations, a three-dimensional (3D) modelling-based approach was developed in the second phase of the study. A  $40 \times 40$  km<sup>2</sup> Digital Terrain Model (DTM) was obtained via the TouchTerrain platform in .STL format and modelled at real scale within the Blender environment [8], [9]. Within the model, the runway axis, obstacle-limitation surfaces, and terrain elevations were represented precisely.

The approach, take-off climb, and inner horizontal surfaces defined in ICAO Annex 14 were converted into volumetric objects, enabling visual detection of intersections between the runway and obstacle volumes [1]. This method went beyond conventional calculations by providing both analytical accuracy and visual intuition, forming an integrated engineering framework that supports the decision-making process.

The 3D analysis results clearly illustrated the obstacle and terrain problems encountered at the first runway site and enabled the identification of an alternative area with lower slope, minimal fill requirements, and no obstacle infringements. Thus, the study demonstrated that 3D-modelling-assisted design offers a far more effective solution than classical 2D methods, especially in mountainous and complex regions.

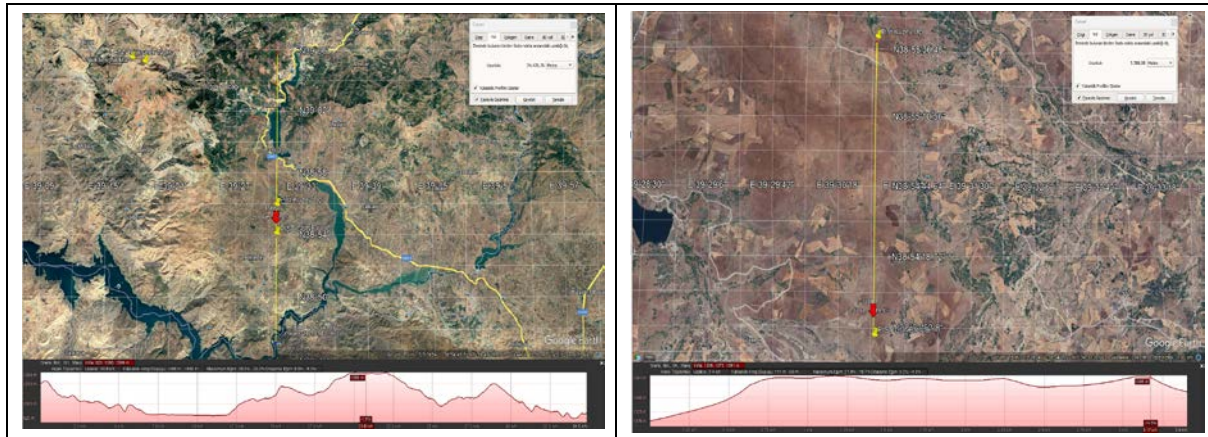
### **3.5. Design and Implementation of the Second Runway**

This section presents the runway design process conducted at the second selected site within the province of Tunceli. Due to the steep slopes, obstacle risks, and alignment restrictions observed at the first site, this alternative location was found to be technically more suitable thanks to its regular topography, low obstacle profile, and greater accessibility.

The selected site is located between the villages of Kacarlar, Arpalı, and Sumak, approximately 20 km south of Tunceli city center. It is bordered by the Munzur River to the east and mountainous ridges

to the west [17]. The region forms a natural topographic corridor extending in the north-south direction, providing a favorable natural orientation for runway placement.

The absence of dense settlements and the limited extent of environmental influence zones offer significant advantages for operational safety and environmental sustainability (see Figure 3).



**Figure 3.** Top view of the selected second site [15]

Despite the topographical difficulties and obstacle infringements identified in the first site, this new area offers lower slope values, a favorable ground structure, and a more suitable runway orientation. Although certain cut-and-fill operations are still required, the proximity to the D885 highway and the ease of access to the city center provide a logistical advantage for construction activities.

In the site-specific analyses, a high-resolution Digital Elevation Model (DEM) obtained from the TouchTerrain platform was exported in .STL format and imported into the Blender environment [8,9]. Within this 3D model, the runway alignment, obstacle volumes, and slope adjustments were evaluated, confirming that the proposed design is engineeringly feasible and sustainable for field implementation.

### 3.5.1. Determination of Runway Orientation and Preliminary Terrain Analysis

During the runway orientation determination process, a north-south axis approximately 34.5 km long was defined on Google Earth Pro, and a broad-area elevation profile was extracted along this line [15]. The analyses revealed the presence of high topographic barriers causing obstacle risks in the east and west directions, while the north-south alignment proved to be the most suitable orientation in terms of both obstacle clearance and slope uniformity [1,3].

According to the Turkish State Meteorological Service (MGM), the prevailing wind direction in Tunceli is northeast-southwest during summer and southeast-northwest during winter [6]. The determined runway alignment shows a high degree of compatibility with these wind patterns, enabling bidirectional flight operations.

Following all technical and environmental evaluations, a runway axis approximately 3389 m long oriented north-south was established. The southern end elevation was measured as 1325 m, and the northern end elevation as 1391 m, yielding a natural longitudinal slope of 1.95 %. The runway platform is planned to be graded to a uniform slope of 0.5 %.

This orientation was assessed as the most appropriate solution in terms of wind conditions, obstacle safety, and topographic continuity, providing an optimal balance between operational safety, construction feasibility, and economic efficiency across the entire site.

### 3.5.2. Runway Length and Slope Calculation

In this section, the runway length for the selected second site was calculated based on the performance criteria defined in ICAO and FAA standards [1,2]. The design aircraft selected for this study is the Boeing 737-800, one of the most commonly used models in domestic Turkish routes. Under International Standard Atmosphere (ISA) conditions and at sea level, this aircraft requires a take-off runway length of approximately 2000 m [16].

However, actual site conditions including elevation (1380 m), average maximum temperature (27 °C), and longitudinal slope (0.5 %) directly affect runway performance. Therefore, the sequential correction method was applied to determine the final runway length considering these environmental factors.

#### 3.5.2.1. Altitude (Elevation) Correction

The average elevation along the runway axis was calculated to be approximately 1380 m. According to the FAA AC 150/5300-13A document, a correction factor of 7 % increase in runway length is required for every 300 m increase in elevation [2].

Accordingly:

$$\text{Altitude Correction} = \left(\frac{1380}{300}\right) \times 7 = 32.2 \%$$

By applying this correction to the reference runway length (2000 m), the updated runway length is obtained as:

$$L_1 = 2000 \times (1 + 0.322) = 2644 \text{ m}$$

Therefore, when considering only the altitude parameter, the runway length must be at least 2644 m to maintain safe take-off performance.

#### 3.5.2.2. Temperature Correction

Another environmental parameter that must be considered in runway length design is air temperature. In this study, the temperature correction was performed in accordance with FAA guidelines and based on the International Standard Atmosphere (ISA) model [2], [6].

The average runway elevation at the application site is 1380 m, which was converted to feet for the following calculation:

$$\text{Average Elevation (ft)} = 1380 \times 3.281 = 4527.8 \text{ ft}$$

The corresponding ISA temperature at this elevation is calculated as:

$$T_{\text{ISA}} = 15 - \left(\frac{4527}{1000} \times 2\right) = 5,944 \text{ °C}$$

According to data from the Turkish State Meteorological Service (MGM, 2023), the average maximum summer temperature in the region is 27 °C.

Thus, the temperature difference is:

$$\Delta T = 27 - 5.944 = 21.056 \text{ °C}$$

According to the FAA, a 1 % increase in runway length is required for each 1 °C deviation above ISA temperature.

Therefore:

$$\text{Temperature Correction} = 21.056 \times 1 \% = 21.056 \%$$

Due to this temperature difference, the runway length must be increased by approximately 21.06 %.

The temperature-adjusted runway length is calculated as:

$$L_2 = 2644 \times (1 + 0.21056) = 3200.7 \text{ m} \approx 3200 \text{ m}$$

### 3.5.2.3. Slope Correction

As a result of engineering adjustments made along the runway, the longitudinal slope was stabilized at 0.5 %. According to ICAO Annex 14 and FAA Advisory Circulars, as long as the slope value remains below 2 %, no additional correction for runway length is required [1,2]. Therefore, no slope correction was applied in the runway length calculations.

### 3.5.2.4. Final Runway Length

Considering the effects of altitude and temperature, the total required runway length was determined to be approximately 3200 m [1,2,10]. This value satisfies both the operational requirements of the Boeing 737-800 aircraft and the minimum runway length criteria prescribed for ICAO Code 4C [1,17].

For design and implementation practicality, this length was rounded to 3200 m and adopted as the final design value for site planning purposes. This selection ensures ease of application in drawing scales, layout plans, and alignment procedures, while remaining within acceptable engineering tolerances.

### 3.5.3. Modelling Process for Obstacle (Mania) Control of the Second Runway

In this section, the obstacle (mania) control for the selected second site was carried out based on ICAO Annex 14 and the Turkish Directorate General of Civil Aviation (SHGM) Airport Design Criteria [1,3]. The objective was to identify natural obstacles around the runway and assess their potential impact on flight safety.

During the analysis, the runway axis defined via Google Earth Pro was used as a reference, and a 40 × 40 km<sup>2</sup> Digital Elevation Model (DEM) focused on the site center was generated [15]. This dataset was obtained via the TouchTerrain platform, exported in .STL format, and imported into the Blender environment to create a three-dimensional topographic model (see Figure 4) [8,9].

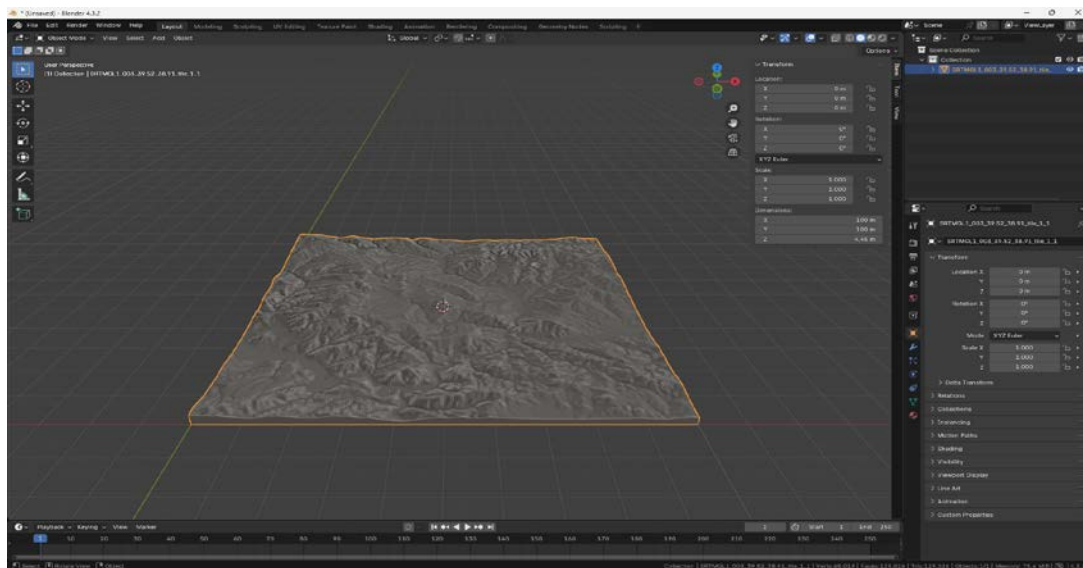


Figure 4. 40 km × 40 km Topographic Model Transferred into Blender

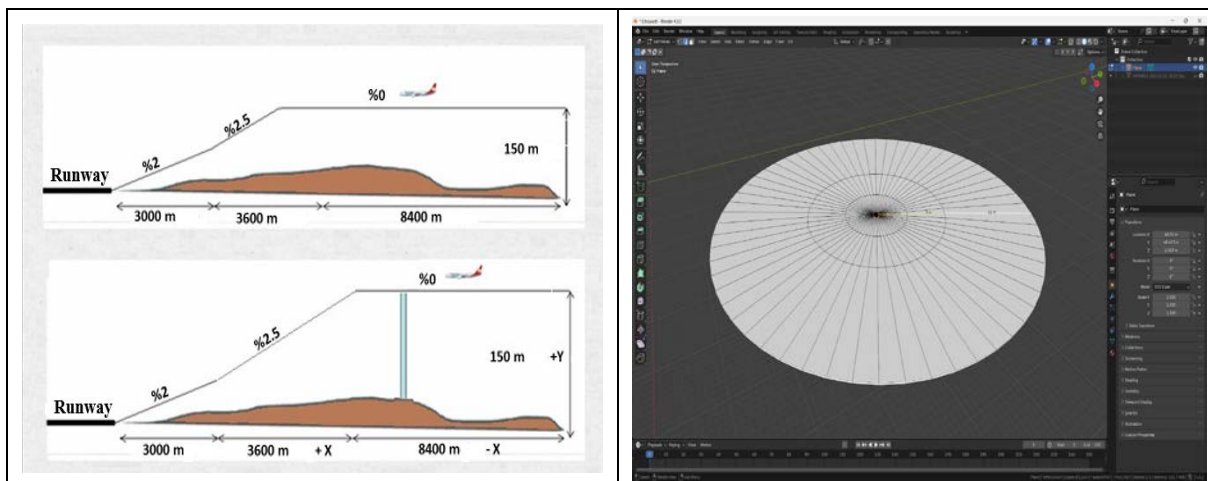
### 3.5.3.1. Approach Surface Modelling and Penetration Analysis

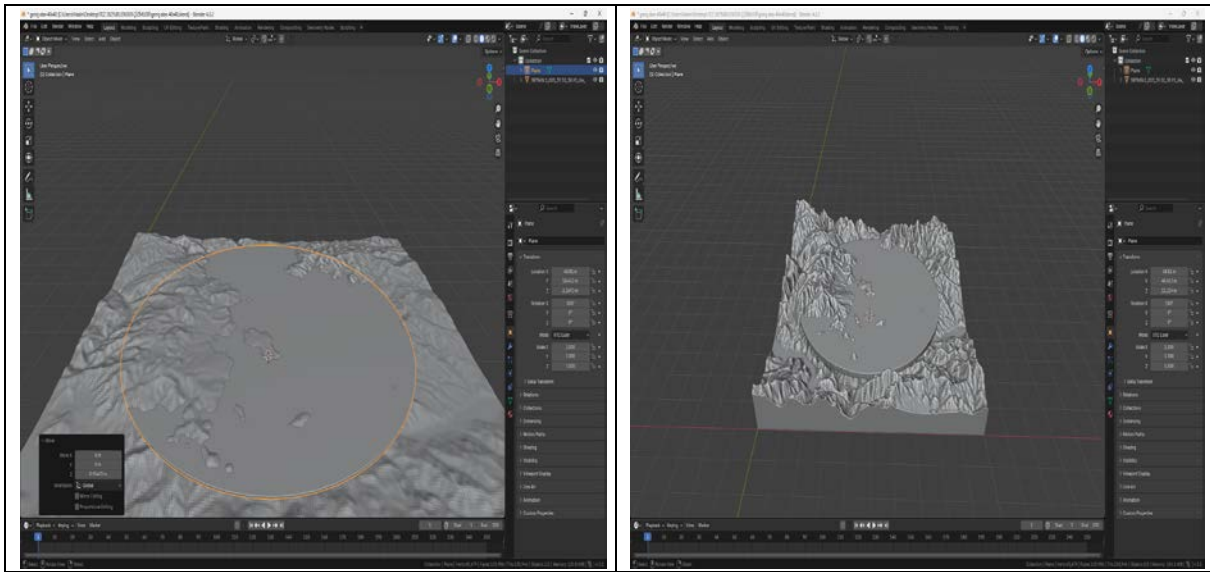
The approach surface was modelled in three dimensions based on the SHGM SHT-Mania Plan Directive [4]. According to this configuration, the surface rises at a 2 % slope for the first 3000 m from the runway threshold, then continues at a 2.5 % slope for the next 3600 m, reaching an altitude of 150 m, and extends an additional 8400 m horizontally thereafter.

A circular obstacle (mania) volume with a 15 km radius centered on the runway was created, enabling volumetric evaluation of all surrounding natural obstacles (see Figure 5).

In addition, the Z-axis of the model was vertically exaggerated by a factor of five to enhance the visual distinction of topographic differences.

Comparative analyses performed for both runway ends indicated no intersection between the approach surfaces and the terrain. These results demonstrated that the north-south alignment of the runway provides the most suitable configuration in terms of obstacle clearance, topographic compatibility, and operational safety.





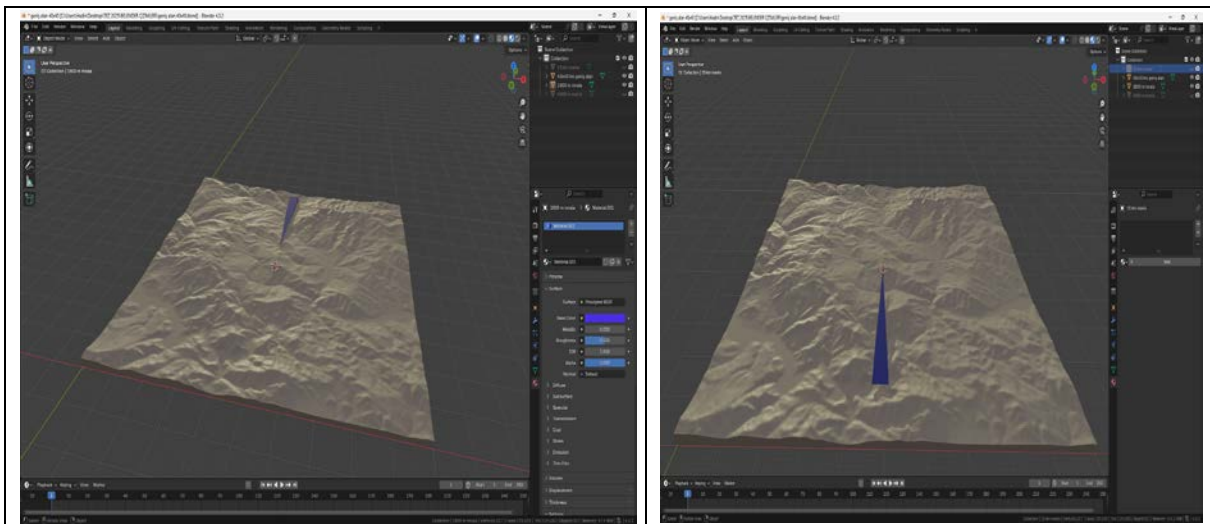
**Figure 5.** Approach Surface Modelling and Penetration Analysis [4], [8], [9]

### 3.5.3.2. Take-off Climb Surface Modelling and Analysis

The take-off surface was defined in accordance with ICAO Annex 14 and SHGM (2020) standards [1,3]. Beginning from the runway threshold, the surface was designed with an upward slope of 2 %, forming a trapezoidal volume that initially measures 180 m in width and expands to 1800 m at a distance of 3000 m from the threshold. The total modelled length of the surface was 15,000 m (see Figure 6).

In the analyses conducted within the Blender environment, the take-off climb surfaces were applied to both the northern and southern runway ends. No penetration (intersection) was detected between the take-off surfaces and the surrounding topographic model.

This finding confirms that the required safety corridor in the departure directions has been achieved, and that the runway configuration is suitable in terms of take-off performance and flight safety [9].

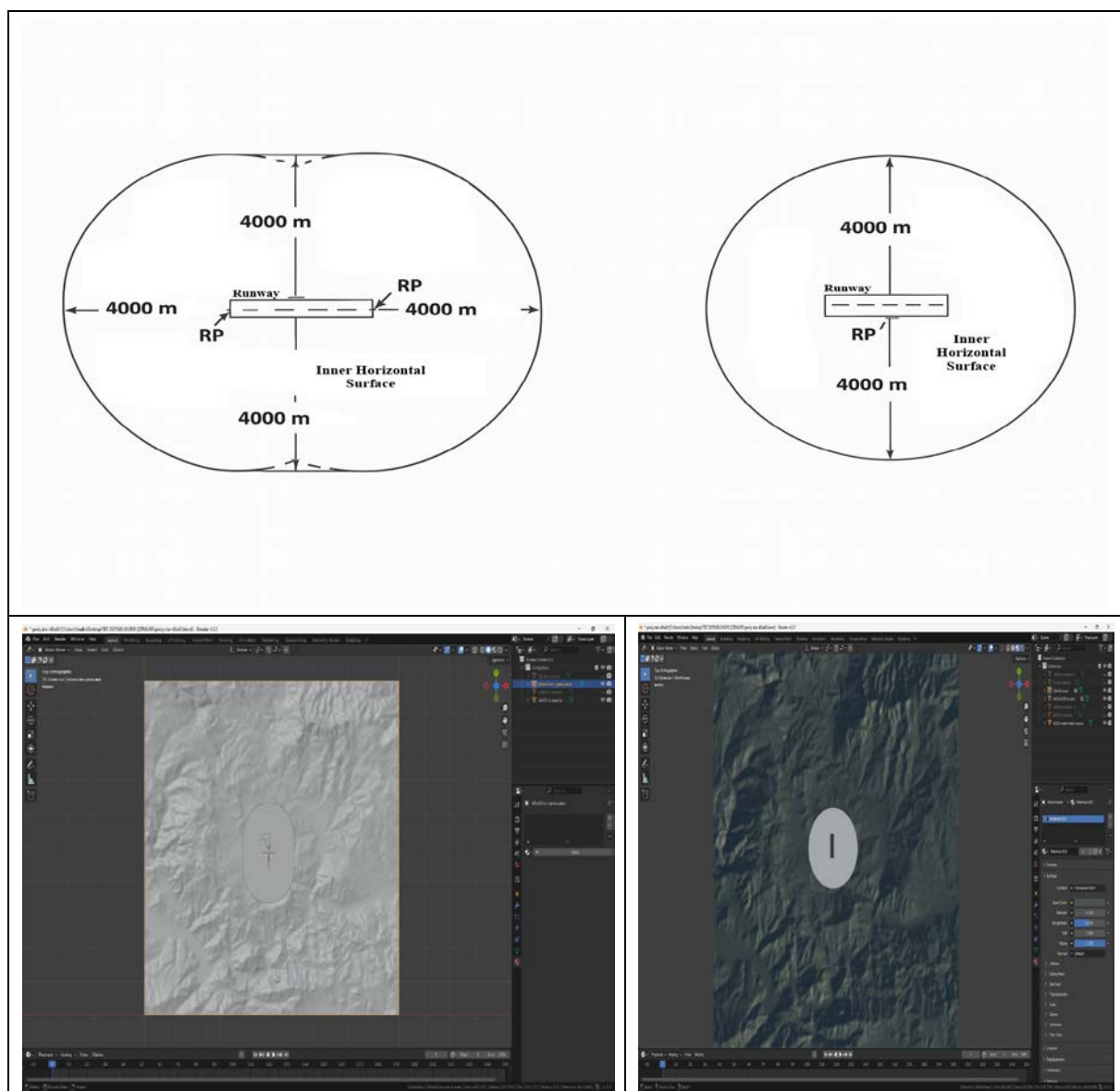


**Figure 6.** Take-off Climb Surface Model [1], [3], [9]

### 3.5.3.3. Preventive Obstacle Control (4000 m Circular Analysis)

Although obstacle limitation surfaces (OLS) are primarily defined to ensure operational safety, extended versions of these surfaces can also be used for preventive engineering control in long-term infrastructure planning.

Within this scope, two circular analysis surfaces with a radius of 4000 m were generated, each centered at one end of the runway. All potential natural obstacles in the surrounding area were evaluated volumetrically within these circular zones (see Figure 7) [4,7].



**Figure 7.** 4000 m Radius Obstacle Zone for Inner Horizontal Surface [4], [7]

The analyses were conducted on a  $40 \times 40$  km<sup>2</sup> SRTM-based model, and no intersection was identified between the terrain and the defined surfaces [7]. This result demonstrates that the runway

surroundings are suitable not only under current operational conditions, but also for potential future expansions.

Although these extended surfaces are not officially defined by ICAO as part of the standard obstacle limitation surfaces, they are considered strategic engineering references within the framework of the SHGM SHT-Mania Plan (2020) for long-term airport planning [4]. Similarly, the European Union Aviation Safety Agency (EASA), in its CS-ADR-DSN guidance, recommends the extended obstacle surface concept as a supportive method for future airport development and safety assessments [11].

#### **3.5.3.4. Inner Horizontal Surface Modelling and Analysis**

The inner horizontal surface is a horizontal reference plane established to provide obstacle control over a wide area surrounding the airport [1,3]. According to ICAO, this surface is defined by adding 45 m to the average runway elevation [1]. In this study, the average runway elevation was taken as 1380 m, and the inner horizontal surface was modelled at 1425 m elevation. In the Blender environment, this surface was positioned at the center of the runway and integrated into the site as a circular plane with a radius of 4000 m (see Figure 7) [9]. Analyses revealed no penetration (intersection) between the surface and the terrain.

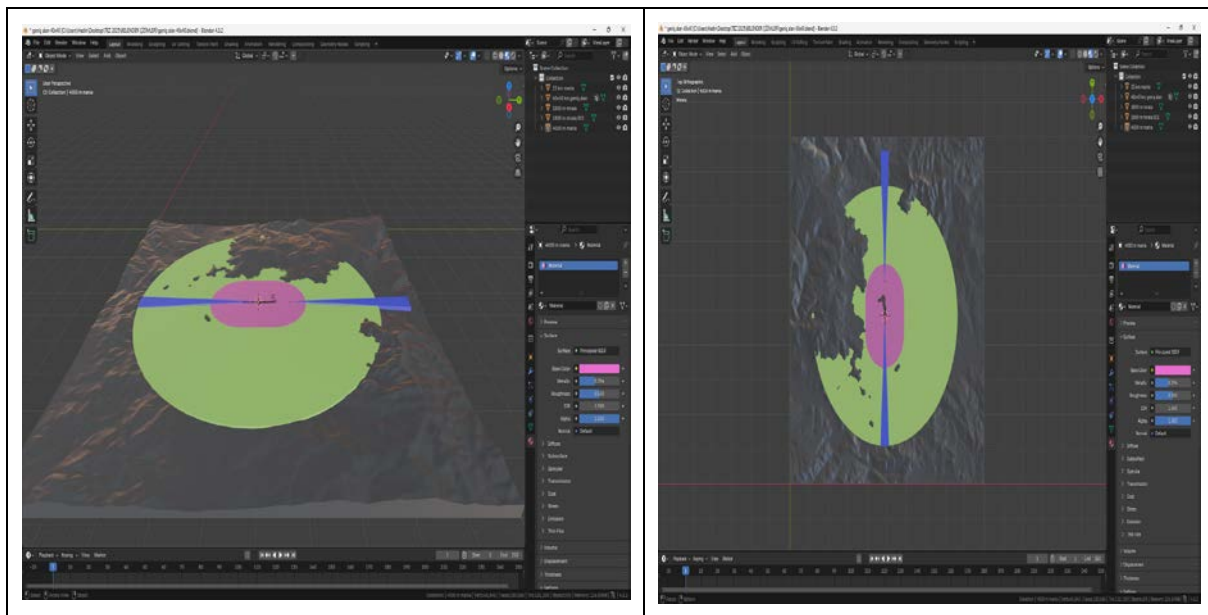
This finding indicates that the runway surroundings are not only suitable in terms of approach and take-off directions, but also ensure overall airspace safety for airport operations.

#### **3.5.4. General Evaluation of the Obstacle Control for the Second Runway**

The north-south orientation of the proposed runway at the Tunceli-Munzur site has been comprehensively evaluated not only in terms of topographic compatibility, but also with respect to flight safety.

For this purpose, the geometric obstacle limitation surfaces (OLS) defined in ICAO Annex 14 and SHGM Airport Design Criteria were analyzed on a three-dimensional SRTM-based digital terrain model (see Figure 8) [1,3,7,9]. In the study, approach surfaces, take-off climb surfaces, 4000 m radius preventive control zones, and the inner horizontal surface were applied to the site. Each surface was tested for possible terrain penetrations, and the modelling was conducted within a  $40 \times 40$  km<sup>2</sup> area in the Blender environment, confirming that no intersection occurred between the terrain and any of the surfaces [9].

The north-south runway alignment, which effectively avoids the mountainous formations along the east-west axis, has provided a significant operational advantage. Furthermore, modelling the inner horizontal surface at +45 m ( $\approx 1425$  m) relative to the assumed runway elevation of 1380 m indicates the presence of adequate clearance, supporting not only current safety conditions but also future expansion possibilities.



**Figure 8.** Obstacle Analysis Model in Blender Environment

As a result, the volumetric modelling and visual validation processes have demonstrated that the proposed runway alignment fully complies with ICAO/SHGM standards, offers a high safety margin, and provides a solid foundation for future expansion and planning.

### 3.6. Geometry and Dimensional Design Criteria of the Second Runway

The runway geometry was determined based on ICAO Annex 14, SHGM Airport Design Criteria, and FAA AC 150/5300-13A standards [1-3]. The design aircraft is the Boeing 737-800, classified as ICAO Code 4C; this classification serves as the basis for defining dimensional parameters such as runway width, shoulders, strips, and safety areas. In the final design, the runway centerline was aligned in the north-south direction with an approximately 0.5% constant longitudinal slope. This value remains below the ICAO upper limit of 1.25%, ensuring adequate surface drainage and topographic conformity [1,2].

#### 3.6.1. Runway Length and Width

The runway length, considering altitude, temperature, and slope factors, was determined to be approximately 3200 m. This exceeds the minimum ICAO Code 4C standard of 1800 m. The runway width is 45 m, providing a safe operational area for the B737-800, which has a 35.8 m wingspan and a 6.2 m main gear track width [1-3].

#### 3.6.2. Runway Shoulders

A 7.5 m shoulder is provided on each side of the runway, giving a total paved width of:  $45 \text{ m (runway)} + 2 \times 7.5 \text{ m (shoulders)} = 60 \text{ m}$ . The shoulders are non-load-bearing; they allow the aircraft's wheels to re-enter the runway without structural damage and help maintain surface integrity [1-3].

### 3.6.3. Runway Strips (Graded Areas)

Beyond the shoulders, 2.5 m graded strips (bankets) are planned on both sides. These areas act as transition zones, reducing structural damage risk in runway excursion events and allowing controlled transition to the safety strip [1,3].

### 3.6.4. Runway Strip Width

For Code 4C runways, the strip width is 75 m on each side (total 150 m). Within this area lie the 45 m runway, 7.5 m shoulders, and 2.5 m graded strips; the remaining portion is compacted soil/grass, leveled with low cross slopes [1-3].

### 3.6.5. Longitudinal and Transverse Slopes

The longitudinal slope is fixed at 0.5% (limit: 1.25%). The transverse slope, designed to ensure surface water drainage, is 1.5%, corresponding to the upper limit of ICAO's recommended range (1.0-1.5%) [1-3].

### 3.6.6. Jet Blast Area (Blast Pad)

At both runway ends, a 60 m blast pad with the same cross-section as the runway is provided. Blast pads are not used for take-off or landing; they protect the pavement from erosion or loosening caused by jet exhaust and are clearly marked according to standards [1-3].

### 3.6.7. Runway End Safety Area (RESA)

A RESA of at least 240 m in length is provided at each runway end.

The configuration is as follows:

Runway end → 60 m blast pad → 240 m RESA. The RESA is a non-load-bearing safety zone designed to protect aircraft integrity in the event of an aborted take-off (RTO) or overrun landing [1-3].

**Table 4.** Summary of Runway Geometric Design Parameters

Runway Dimensional Design Summary		
1	Design Aircraft	Boeing 737-800
2	ICAO Code Classification	Code 4C
3	Reference Runway Length (Sea Level, ISA)	2000 m
4	Altitude Correction (1380 m)	+32.2 % → 2644 m
5	Temperature Correction (27 °C)	+21.06 % → 3200 m
6	Slope Correction (0.5 %)	Not required (below ICAO/FAA limit)
7	Total Calculated Runway Length	3200 m
8	Minimum ICAO Code 4C Runway Length	1800 m
9	Runway Width	45 m
10	Runway Shoulders	15 m (2 × 7.5 m)
11	Graded Strips (Bankets)	5 m (2 × 2.5 m)

12	Runway Strip Width	150 m (2 × 75 m)
13	Jet Blast Area (Length)	120 m (2 × 60 m)
14	RESA (Length)	480 m (2 × 240 m)
15	RESA (Width)	150 m (2 × 75 m)
16	Total Field Length (Runway + Blast + RESA)	3200 + 120 + 480 = 3800 m

#### 4. Conclusion

Within the scope of this study, two alternative airport runway sites proposed within the boundaries of Tunceli Province were comparatively evaluated in terms of engineering feasibility and flight safety criteria. The first site was found unsuitable due to excessive topographic slope, obstacle (mania) violations, and construction difficulties. The conducted analyses revealed that:

- The average longitudinal slope was 3.09%, exceeding the ICAO allowable limits;
- Obstacle infringements occurred by 142.3 m in the east and 447 m in the west;
- The calculated runway length requirement of approximately 3066 m was not feasible under the existing terrain conditions.

These findings demonstrated that traditional two-dimensional (2D) analytical methods fail to provide sufficient accuracy in complex topographies and cannot effectively evaluate the volumetric relationship between terrain and obstacles.

Alternatively, the second site (Munzur site) was analyzed using a three-dimensional (3D) modelling-based approach. A digital elevation model (DEM) was employed to generate a realistic 3D terrain model within the Blender environment, allowing volumetric assessment of runway-obstacle interactions. The obtained technical results indicated that:

- The north-south runway orientation aligns well with prevailing wind directions and provides the safest configuration in terms of obstacle clearance;
- The average elevation was determined as 1380 m, and after altitude and temperature corrections, the required runway length was calculated as 3200 m;
- No surface penetrations (intersections) were identified in the obstacle clearance analyses;
- The runway geometry 45 m width, 0.5% longitudinal slope, and ICAO Code 4C compliance met all international design standards;
- Furthermore, extended analyses with 4000 m radius control zones and inner horizontal surface modelling revealed sufficient reserved area for potential future apron or terminal expansions.

All results confirmed that the 3D modelling approach provides significantly higher accuracy and decision support capability compared to conventional 2D profile-based analyses.

Consequently, a 3200 m-long north-south oriented runway design at the Munzur site has been identified as the most suitable airport solution for Tunceli in terms of topography, obstacle safety, wind conditions, and accessibility.

#### Acknowledgment

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## Conflict of Interest

The authors declare that they have no conflicts of interest. The study was written with the contributions of all authors.

## Research and Publication Ethics Statement

The authors declare that they have complied with the scientific, ethical and citation rules of the *International Journal of Pure and Applied Sciences* throughout all stages of the study.

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