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LANDSCAPE MANAGEMENT FOR DISASTER-PRONE CITIES: DISASTER RESILIENT PARK PROPOSAL

Ömer Faruk BAŞGÜN ✉, Yahya BULUT

Department of Landscape Architecture, Atatürk University, Erzurum, Türkiye

Highlights:

- Elazığ is a city with high disaster intensity and is vulnerable to disasters;
- in Elazığ, disasters can trigger each other and create "secondary disasters";
- disaster parks adapted to the specific risks of a region against disasters are very important;
- a prototype has been developed for cities where disasters are intense;
- urban furniture has been developed to increase the resilience of green areas.

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Abstract. Elazığ is a disaster-prone city due to its geological structure, proximity to fault lines, and similar reasons. As part of the study, a disaster-resilient green space model applicable to the city has been developed. The study examines how green spaces should be planned and designed to be used in disaster situations. The methodology of the study consists of three phases. (1) The city of Elazığ was analyzed in terms of disasters. (2) UAV and GPS CORS devices were used to collect data in the area designated as the disaster park and three-dimensional spatial analysis was performed. (3) The disaster park was designed according to the data obtained. The results show that Elazığ is frequently affected by disasters. Therefore, it is understood that the city needs a disaster-resistant green system. Suggestions for the design of disaster parks and their inclusion in the landscape management of disaster-prone cities have been developed.

Keywords: disasters, landscape management, environmental monitoring, landscape, environmental, earthquake, urban green spaces.

✉Corresponding author. E-mail: ***farukbasgun@gmail.com***

1. Introduction

Disasters cause many deaths, injuries, and billions of dollars in damage worldwide each year. Türkiye is located in a geography with a high risk of natural disasters such as earthquakes, floods, avalanches, and landslides. Elazığ is one of the cities with the highest disaster density in Türkiye. Elazığ has suffered many losses due to major earthquakes and other natural disasters in recent years. This situation has brought to the forefront the need for a more resilient and disaster-prepared urban structure (Allan et al., 2013; Sheet et al., 2024). In this context, the development of disaster-resilient urban design is important in terms of creating a socially, economically, and environmentally sustainable living space. Particular attention should be paid to this issue when planning green spaces in the city. Disaster-resilient landscape management can increase the capacity of cities to adapt to climate, seismic, and other natural factors. This can make cities more liveable, safer, and more sustainable (Fei et al., 2019; Yıldırım et al., 2021; Yi & Pei, 2024).

Disasters have a much more devastating impact than in the past due to the rapid growth of cities. Unplanned urbanization, high-rise buildings, lack of green spaces, and poor urban management policies exacerbate this situation. Inadequate green spaces in such cities make people vulnerable to disasters (Xiu-Mei & Zhen-Lin, 2006; Park & Jang, 2018; Pan et al., 2022). Urban green spaces serve many important functions during and after disasters. Public green spaces, parks, and wooded areas provide natural shelter for people. These areas allow people to be protected from hazards in open spaces away from surrounding buildings (Timms, 2011). In addition, urban green spaces provide areas where people can meet their basic needs with amenities such as fountains, toilets, and benches (Nappi & Souza, 2015; Conzatti et al., 2022). In the aftermath of a disaster, green spaces also aid in recovery and reconstruction processes (Yıldırım et al., 2021). These spaces mitigate the trauma of disasters by providing relaxation and stress reduction in a natural environment (Rung et al., 2011; Yi & Pei, 2024). In addition, green spaces provide a platform to bring communities together and increase their solidarity. These spaces promote mental and emotional well-being during post-disaster recovery (Shrestha et al., 2018; Walz et al., 2021). These open green spaces within the city accelerate the post-disaster recovery process (Xiu-Mei & Zhen-Lin, 2006; Li et al., 2016). They play an important role in strengthening green infrastructure and protecting natural resources (Miller, 2020). Therefore, urban green spaces are in a critical position to cope with the impacts of disasters. The creation of temporary settlements in such areas is important for people to maintain their lives (Xu et al., 2016; Uddin et al., 2018).

Due to the beneficial functions of green areas in disasters, disaster-oriented green areas have been created in recent years. Such green areas are generally called disaster parks or disaster prevention parks. These parks, examples of which are quite rare, are generally located in countries with high disaster intensity such as Japan. Major disasters have shown people the importance of green spaces (Huang & Lee, 2020). In Japan, the great Kanto earthquake occurred in 1923 (Yu, 2007; Borland, 2019). Due to the risk of fire in the city center, survivors took refuge in forests and agricultural areas (Shen & Saito, 2007). After this disaster, the need for open and green spaces in urban areas became imperative (Lei, 2007). In Japan, especially in recent years, it is considered important to plan parks that can meet the need for shelter and refuge after disasters (Yu, 2007; Park & Jang, 2018). Japan's disaster parks are cleverly designed survival areas (Su & Liu, 2004). One of Japan's best-known disaster parks is the Rinkai disaster park in Tokyo. This park, where emergency services can be directed, is a disaster epicenter for Tokyo. Covering 33000 m^2, it is a large park with power points and internet connections, mobile toilets and heating facilities. This disaster park is a leading center for disaster response activities (Park & Jang, 2018; Pan et al., 2022). A park that can be used in disasters is also planned in the Hyogo region of Japan. This park is named "Miki Disaster Prevention Park". The park can be an emergency center in disasters (Sarıçam, 2019). In addition to all these criteria, disaster parks also adapt to the ordinary lives of people (Zeng et al., 2022). Park Hikarigaoka, which was completed in 1940, is a park that fulfills the recreation needs of people. When disasters occur, it is designed as a disaster park with a capacity to support 270.000 people (Lei, 2007; Sarıçam, 2019; Huang & Lee, 2020).

Disaster parks are created to prepare communities for the potential effects of natural disasters. These parks are usually designed to prepare for events such as earthquakes, tsunamis, floods, storms, and other natural disasters. These parks also aim to raise people's awareness through various activities such as emergency simulations and community preparedness meetings (Allan et al., 2013; Alawi et al., 2023; Sheet et al., 2024). These parks also address issues such as post-disaster relief and rescue operations (Park & Blake, 2020; Pourghasemi et al., 2023). After disasters such as earthquakes, mass movements, and floods, such parks have been very useful for disaster victims (Nikolov et al., 2014; Ogawa, 2014; Bhandari et al., 2021). In addition, disaster parks often provide first aid training. These parks provide visitors with hands-on training in basic medical interventions. Such activities are important for keeping people calm and minimizing panic in disaster situations (Jayakody et al., 2018).

Nowadays, with the growth of cities and the increasing destructive effects of disasters, disaster parks and similar open green space applications are gaining importance (Fei et al., 2019, 2020). Such parks are increasingly seen as an important part of urban planning. In Türkiye, there is no urban plan or practice for the use of open green spaces after a disaster. Only some parks are designated as "earthquake parks". These parks are mainly for educational purposes and focus only on earthquakes. However, it is necessary to identify the priority types of disasters that threaten cities and plan for these disasters. Although Türkiye is one of the countries facing disasters, it is not a rich country in terms of disaster parks. Only a few parks have been built for training purposes and for a single type of disaster. Elazığ is a city that is often affected by disasters in Türkiye.

Elazığ has been exposed to various disasters throughout its history. Due to its geographical location, the city is located in a region that is prone to natural disasters. Elazığ, located in the Eastern Anatolian region of Türkiye, is known for its active tectonic structure. Due to this feature, it is frequently faced with the risk of earthquakes. The city center is located in a valley. This makes it vulnerable to disasters such as flooding and erosion. It is known that some parts of the city had river beds in the past. This geographical location makes Elazığ very vulnerable to natural disasters (IRAP [İl Afet Risk Azaltma Planı], 2021).

In the literature, the definition and characteristics of disaster parks are generally evaluated under different headings. Similar issues are discussed under definitions such as earthquake parks, earthquake education parks, temporary settlement areas, and assembly areas. Some studies mention the concept of disaster park but do not provide comprehensive information on its application. In addition, the studies on the subject generally suggest the creation of temporary shelters in green areas. However, the number of studies that put ideas into practice with field studies is limited. In line with these findings, this study aims to develop disaster risk management strategies for Elazığ. In addition, the study aims to realize a pilot disaster park and equipment design to make the city more resilient. This study is unique in that it includes proposals for disaster park solutions that can be reflected in practice. The study also analyzes the priority disaster types and disaster intensities of Elazığ Province and brings a different perspective to disaster park design. A method has been applied that deals with the design and planning of disaster parks from the macro level to field studies from the beginning to the end. It is also unique in that it is the first academic study to present a disaster park design based on real field data.

2. Materials and methods

2.1. Material

The study material consists of the city of Elazığ and the project area of the Disaster Park (Figure 1). Elazığ is located in the Upper Euphrates region of Eastern Anatolia, 1067 meters above sea level. The territory of Elazığ is covered with meadows and pastures (50%), agricultural lands (28%), forests (12%), and water surfaces (reservoirs and lakes) (10%). In addition, there are 123,043 ha of forests (Elazığ Municipality, 2023). The province has 11 districts and a total population of 604,414. Approximately 75% of the province's population lives in the urban center (Turkish Statistical Institute, 2024). The impact and severity of disasters are analyzed according to the affected population. Therefore, this study focuses on the city center, the region with the highest population density. Elazığ has shown many times that it has a fragile structure in terms of disasters. It can be seen that the city has been exposed to major disasters many times throughout history. Many lives and properties have been lost in different types of disasters in the city.

There are three main reasons for choosing Elazığ as the study area.

- *The city has been exposed to many different types of disasters throughout its history:* The disasters that have occurred in Elazığ in the past have caused many negative effects. People who survived a big disaster faced other dangers. For example, after the earthquake, there were many problems in the green areas that were chosen as temporary settlements without considering other disasters. Disaster victims were exposed to secondary disasters such as floods, storms, or fires. Türkiye and the province of Elazığ, which is the subject of this study, have experienced such negative examples in the past.
- *75% of the urban population resides in the city center:* There is a very large population difference between the central district and other districts in Elazığ. For example, the Sivrice district, which experienced the disasters intensively, has a very low population of 8,149. However, the Central District, which has a greater impact on the people affected, is included in this study.
- *Although there are many open and green spaces in the city, there are no disaster parks:* There are more than 300 urban parks of different sizes in the city center. The amount of green space per capita in Elazığ is 8.74 m^2 (Demircan & Başgün, 2022). However, none of these parks are designed for post-disaster use. After the earthquake in 2020, Kültür Park (180,000 m^2) was used as a disaster assembly area. However, only 38,000 m^2 of the park area could be used. Of this area, 20,000 m^2 was reserved for temporary shelters. The reason why a large part of the area could not be used is that the park is not suitable for temporary settlement after a disaster. About 1900 people took shelter in Kültür Park. A total of 484 tents were set up in the park. It is also stated that Kültür Park suffered a loss between 2.6 million USD and 3.5 million USD after being used as a temporary settlement area (Elazığ Municipality, 2023). Disaster victims stayed in Kültür Park for 45 days. Therefore, the city needs an area suitable for pre- and post-disaster use.

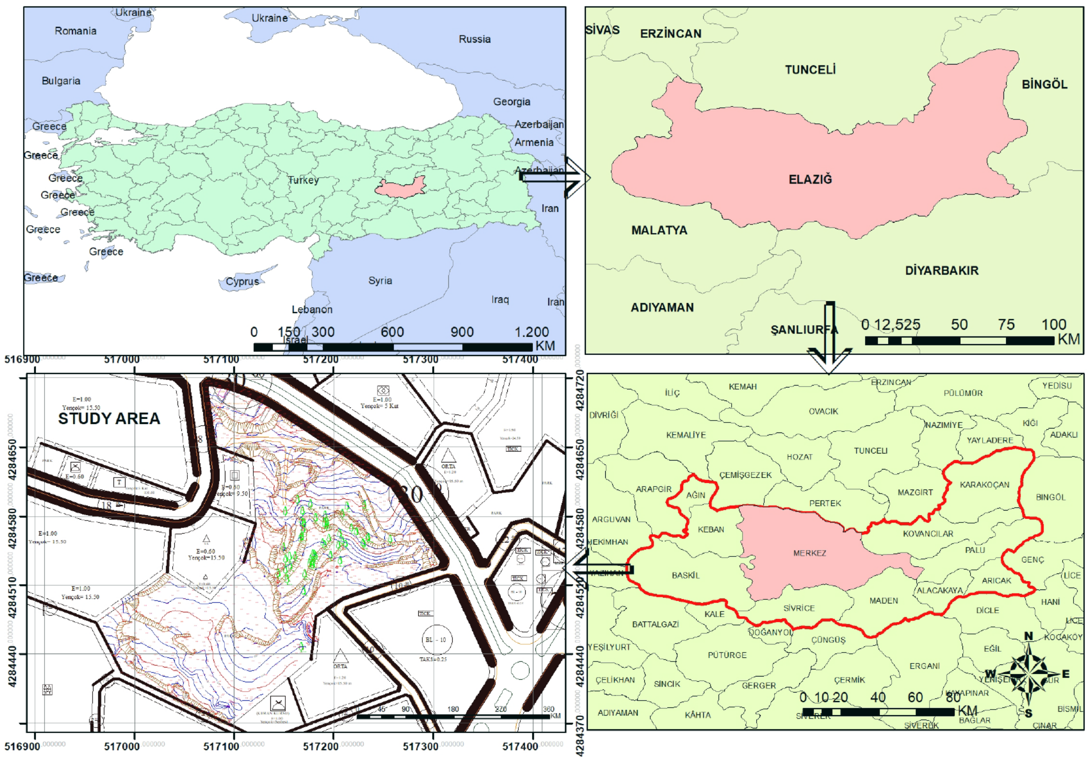


Figure 1. Study area location map

2.2. Methods

The methodology of this study consists of three main phases:

1. Analysis of the current situation of Elazığ and its vulnerability to possible disasters.
2. Scanning the area identified for the disaster park using an unmanned aerial vehicle (UAV). Data collection with GPS Continuously Operating Reference Station (GPS CORS) devices. Detailed three-dimensional analysis of the area.
3. Design of a model disaster park project and park equipment according to the findings.

2.2.1. Analysis of the natural disaster situation of the city

The first phase of the study analyzed the types and intensities of natural disasters to which the city is exposed. These disasters were analyzed and mapped through a literature review and current data. Document-based research techniques were used in this study. Dissertations, books, articles, and internet sources on the subject were collected using the document based research method. These sources were also collected visually. In the empirical analysis, objectively collected data were analyzed using measurement tools. Data was also collected from secondary sources and a literature review technique was used. University libraries, publications and internet sources were used in the literature review. In addition, photographs and documents on the use of green spaces and urban parks in Elazığ province before and after the disaster were collected and analyzed.

2.2.2. Obtaining the data

In the second phase of the study, data on the hazard exposure of Elazığ were analyzed using ArcGIS 10.7.1. In this context, different maps such as earthquake intensity, fault lines, flood risk, precipitation, and hydrology were created. These maps were analyzed according to the frequency of occurrence of disasters. Silverman's rule of thumb was applied for bandwidth estimation in-intensity analysis. This rule was applied using ArcGIS software and earthquake epicenter data. Kernel density analysis in ArcGIS is a geographic method used to analyze the density distribution of points or lines in a region (Harpole et al., 2014).

- Stages of applying the method to software

a. Data Preparation

For manual kernel density analysis, it is first necessary to have a correct data set.

Data type: It can be a point or line data set. In this study, since the earthquake epicenter data is used, the data type is point data.

Coordinate system: It is necessary to make sure that the data is in a correct projection when it is transferred to the program. Otherwise, even if the analysis is performed, the results may be incorrect. Since kernel density analysis is a distance-based process, a metric coordinate system should be used (Moss & Tveten, 2019). In this study, the WGS84 coordinate system was used.

b. Kernel Bandwidth (Search Radius) Calculation

For kernel density analysis, a search radius must be determined (Harpole et al., 2014). In this study, it was manually calculated using Silverman's (1986) rule of thumb.

Equation (1) was used to calculate the kernel density for the points (each (x, y)) and to determine the default search radius in the kernel density formula.

$$Density = \frac{1}{(radius)^2}\sum_{i=1}^{n}\left[\frac{3}{\pi}.pop_i\left(1-\left(\frac{dist_i}{radius}\right)^2\right)^2\right],$$

$$\text{for } dist_i < radius. \qquad (1)$$

For a set of input points $i = 1, ..., n$ with population area values pop_i (optional) and distances *dist* from a given location (x, y), the density at that location is calculated. This density is scaled by the total number of points or the sum of the population areas to ensure that the spatial integral is equal to the number of points (Silverman, 1986). This calculation is repeated for each location that requires a density estimate, such as the earthquake analysis in Elazığ. The algorithm also determines the default search radius (bandwidth) for grid generation by first calculating the weighted average center of the input points. Subsequent calculations are weighted accordingly, leading to the calculation of the bandwidth using formulae such as weighted median distance and weighted standard distance (*SD*). Equation (2) was used to calculate the bandwidth:

$$SearchRadius = 0.9\times\min\left(SD, \sqrt{\frac{1}{\ln(2)}}\times D_m\right)\times n^{-0.2}. \qquad (2)$$

D_m represents the weighted median distance from the weighted mean center, where n signifies the total number of points if cluster space is not employed. However, for this research, point data were utilized due to the specific locations of disaster occurrences in Elazığ. *SD* denotes the standard distance. The crucial part of the equation yielding *SD* or a smaller value is $\sqrt{\frac{1}{\ln(2)}}\times D_m$. It's noteworthy that the utilization of weighted distance is vital for accurate results (Equation (3)).

$$SD_w = \sqrt{\frac{\sum_{i=1}^{n} w_i(x_i-\bar{X}_w)^2}{\sum_{i=1}^{n} w_i}+\frac{\sum_{i=1}^{n} w_i(y_i-\bar{Y}_w)^2}{\sum_{i=1}^{n} w_i}+\frac{\sum_{i=1}^{n} w_i(z_i-\bar{Z}_w)^2}{\sum_{i=1}^{n} w_i}}. \qquad (3)$$

w_i is the weight of feature i and {xw, yw, zw} represents the centre of the weighted average. This method of selecting the search radius is based on Silverman's rule of thumb for estimating bandwidth but adapted for two dimensions. This approach to calculating the default radius avoids the ring-around-the-point phenomenon that often occurs in sparse datasets, and is robust to spatial outliers (a few points that are too far away from the rest). This makes the method more reliable (Silverman, 1986). A workflow diagram of the study methodology is shown in (Figure 2).

In addition, the Schreiber method was used in rainfall calculations to determine flood risk. The Schreiber formula is one of the most commonly used formulas to measure differences in precipitation based on topographic factors. According to this formula, precipitation increases by 54 mm for every 100 m increase in elevation. The formula is based on the assumption that precipitation increases with altitude. In the calculation based on the Schreiber formula, calculations were made according to topographic variables of 100 m in a range of ±54 mm according to altitude (Doğru & Güngöroğlu, 2022). The Schreiber formula is as follows

$$Ph = P0 + (54h). \quad (4)$$

In the formula, Ph is the precipitation (mm) of a point whose elevation is known, and h is the height variable (hectometer) between Ph and $P0$. $P0$ is the value of precipitation (Equation (4)). Ph is the precipitation value (mm) of the comparison value for which elevation information is available for $P0$. For this calculation, 250 points were created throughout the study area using ArcGIS. After the precipitation map, a hydrology analysis of Elazığ Province was prepared. After the analysis, a flood risk map of Elazığ Province was prepared.

2.2.3. Sample disaster park project and equipment design

In the final stage of the study, a model disaster park design was implemented. First, since the project should be planned by taking measurements in a real field to be a feasible study, a request was made to the Elazığ Municipality and information meetings about the disaster park were held. In the interviews with the municipality, an area among the park areas in Elazığ Province was allocated as the project area by considering the criteria in the literature and examples of existing disaster parks. As a result of the interviews, the field studies were started with the permission of the municipality.

During the field studies, the point heights of the area were determined using an RTK/CORS compatible GNSS receiver, and an up-to-date map of the area was created. Unmanned aerial vehicle (UAV) flights were then conducted over the area. From these flights, aerial photographs were taken by scanning an area of approximately 0.270 km^2, including the study area and its immediate surroundings. The data was then transferred to Pix4D Mapper and the area was analyzed. After analysis, 3D images of the area were generated. After the area analysis was completed, the disaster park project was designed using AutoCAD 2021, SketchUp 2022, and Lumion 10 Pro.

3. Results

3.1. Results on the natural disaster situation of the city

As a result of available resources, documents and literature review, the most frequent disasters in Elazığ province were identified. The current situation of the city was analyzed according to these disasters. It may not be possible to take measures against all types of disasters that may occur in

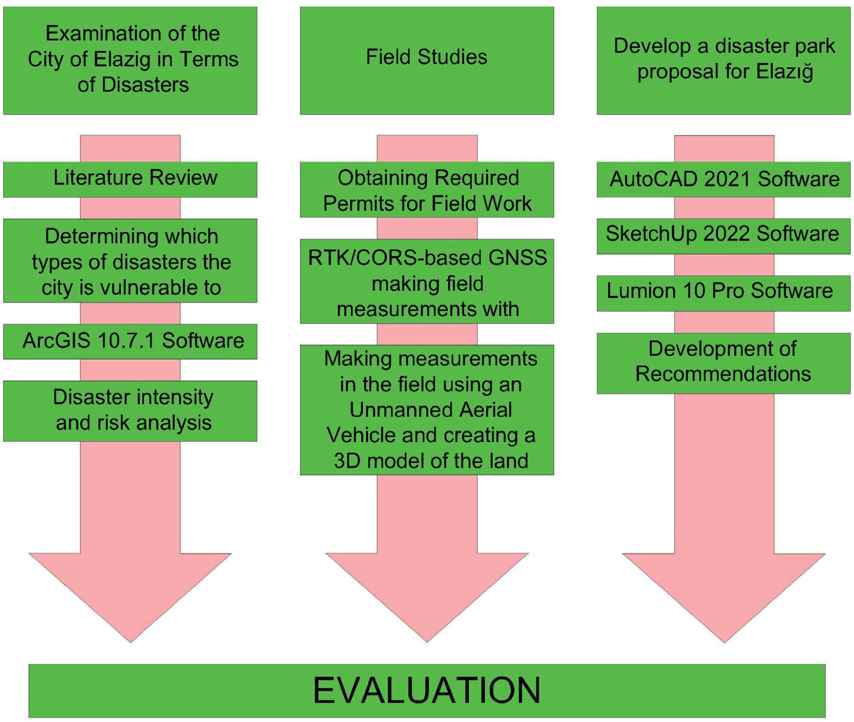
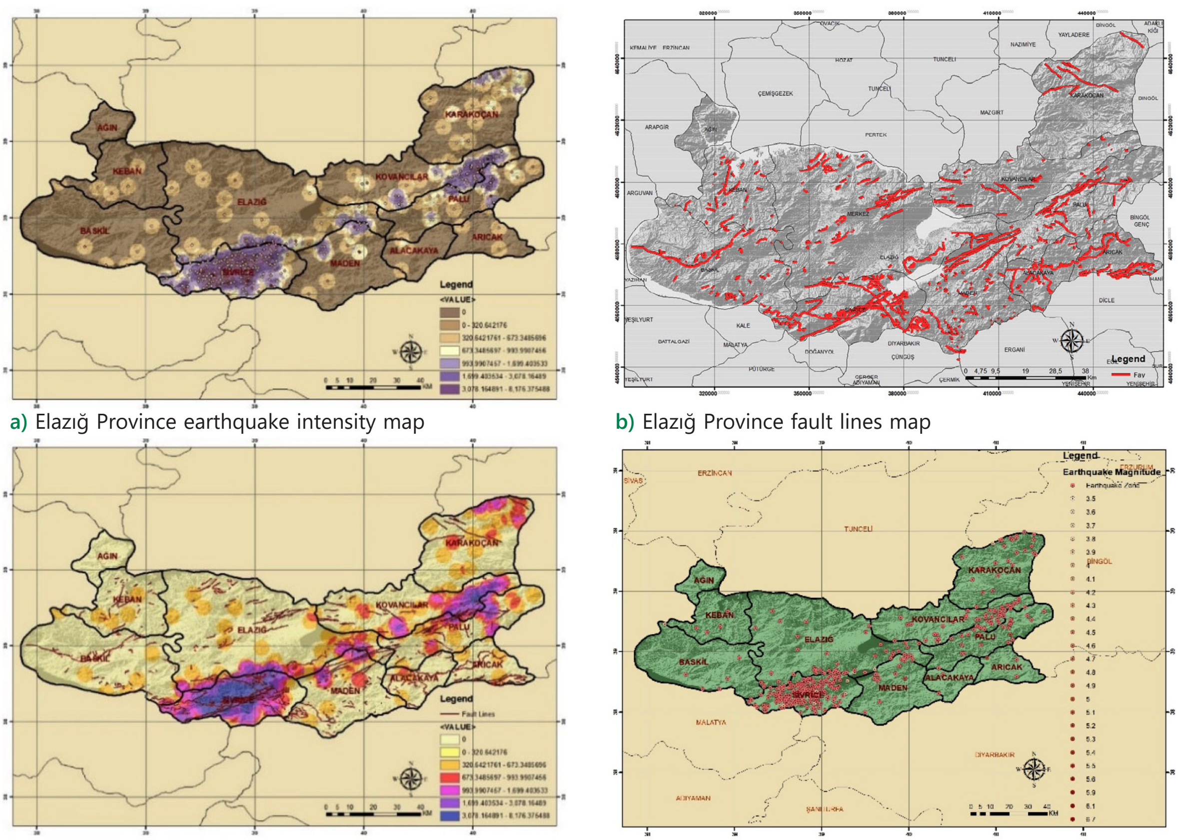


Figure 2. Workflow of the study methodology

a disaster park at the same time. However, measures for some of the most common types of disasters can be taken simultaneously. To do this, priority disaster types should be determined. Then a strategy should be followed accordingly. In Elazığ Province, the priority disaster types are earthquakes, mass movements and floods (AFAD [Afet ve Acil Durum Yönetimi Başkanlığı], 2020; IRAP, 2021). It is noteworthy that the literature is mostly based on natural disasters. Disasters such as fires are not included in the ranking because they are not considered natural disasters (Elazığ Fire Department, 2023).

3.1.1. Analyzing Elazığ in terms of earthquakes

Türkiye lies on the Alpine-Himalayan earthquake belt (European-Mediterranean Seismological Centre, 2021). Especially in places with high population density, the effects of earthquakes can be significantly increased (Li & Tao, 2009). Earthquakes are the most common type of disaster in Elazığ. Earthquakes in the Elazığ region are generally caused by the East Anatolian Fault. Therefore, the intensity of earthquakes in the region is high (U.S. Geological Survey [USGS], 2021). Earthquakes in Elazığ generally have magnitudes between 5.0 and 6.5. However, large earthquakes with magnitudes close to 7.0 sometimes occur. More important than the magnitude of the earthquakes is the preparedness of the region they affect. For example, the magnitude 6.0 earthquake that occurred in Elazığ in 2010 caused severe damage in the region (Peker & Şanlı, 2022). Even a moderate earthquake can cause loss of life and property if disaster preparedness is lacking. Elazığ Province is one of the most densely populated regions, which increases the collective impact of disasters on people. According to historical records, many earthquakes have occurred in and around Elazığ. For example, thousands of people lost their lives in the 1875 earthquake (Kandilli Observatory..., 2020). The most recent major earthquake with its epicenter in Elazığ was a 6.8 magnitude earthquake in 2020. In this earthquake, 41 people lost their lives and 1,631 people were injured (AFAD, 2020). Analyzing the depths of earthquakes in the region, it can be seen that they are generally between 1 km and 18 km. These depths have a significant impact on the damage caused by earthquakes (Özcan et al., 2013; Oyguç, 2022). The first earthquake data used in the analyses date back to 1909. It was found that some of the faults shown on the maps did not experience earthquakes. This indicates that these faults have not been active for at least 115 years (Figure 3). A direct relationship between earthquakes and fault lines, rivers and lakes could not be established. However, Lake Hazar is an exception. Tectonic lakes such as Lake Hazar are known to be associated with earthquakes. It is seen that there are many fault lines around Lake Hazar. Lake Hazar is a region where earthquakes are concentrated and the probability of a catastrophe is high (Figure 3).



a) Elazığ Province earthquake intensity map

b) Elazığ Province fault lines map

c) Comparative analysis of earthquake intensity and fault lines in Elazığ Province

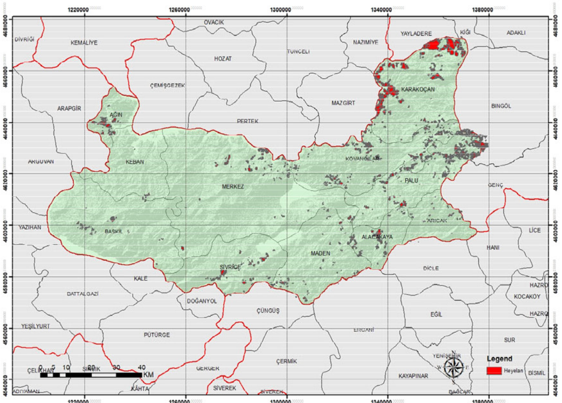
d) Elazığ Province earthquake magnitude and location map

Figure 3. Comparative analysis of earthquake epicenters and magnitudes with fault lines and earthquake intensity

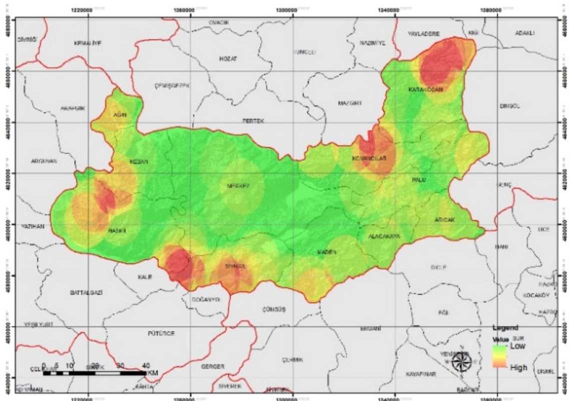
3.1.2. Analyzing Elazığ in terms of mass movements

When the city of Elazığ is analyzed in terms of mass movements, the most frequent disasters are landslides, erosion, and avalanches, respectively. Landslides occurred in Karakoçan, Maden, and Sivrice districts in the eastern part of the city (Figure 4). In addition, the Sivrice district, located to the southeast of the city center, tops the list of 10 "disaster-prone" decisions in terms of landslide disasters. Natural factors, such as the frequency of earthquakes, precipitation, topography, geological features, and water status, play an important role in the occurrence of landslides in Sivrice (USGS, 2024). Sivrice is followed by Karakoçan and Maden districts. The number of regions in Elazığ that are subject to disasters under Law No. 7269 is 90 (IRAP, 2021).

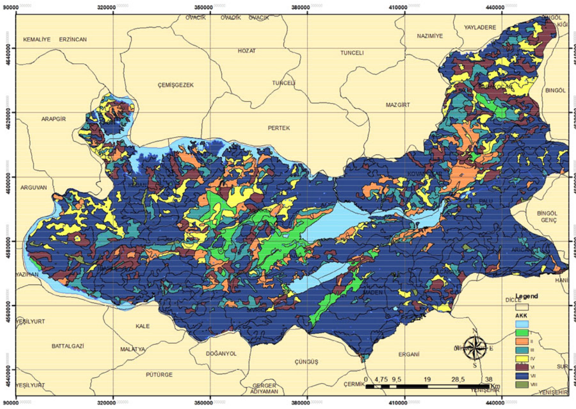
Considering the climatic characteristics of Elazığ, it is stated that precipitation and earthquake factors are particularly effective in triggering landslides. Another important mass movement affecting Elazığ is erosion. Elazığ is one of the cities negatively affected by erosion because it is a city with fertile soils and sloping land (Sunkar & Avcı, 2015). The classes and groups of soils in Elazığ were determined within the scope of this analysis (Figure 5). The



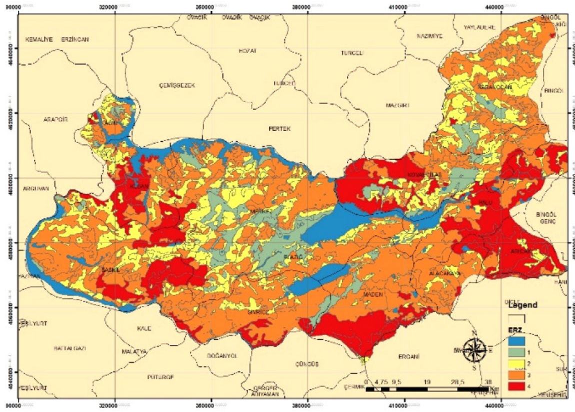
a) Elazığ Province landslide areas map



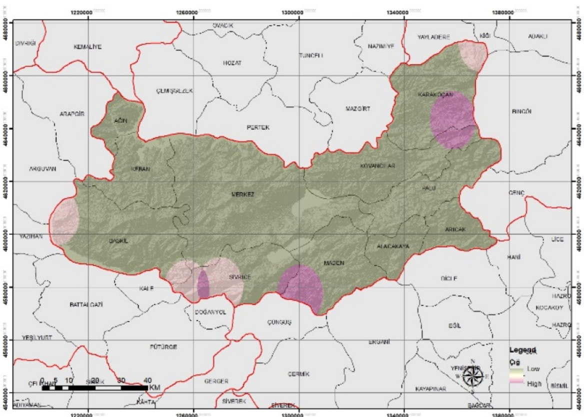
b) Elazığ Province landslide density map



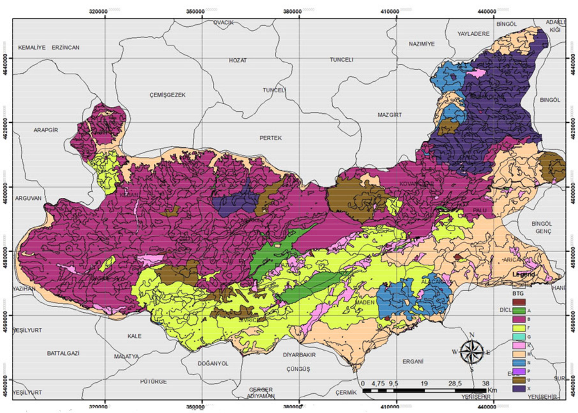
c) Elazığ Province land use capability map



d) Erosion risk map of Elazığ Province



e) Elazığ Province avalanche density map



f) Map of major soil groups in Elazığ Province

Figure 4. Analyzing Elazığ in terms of mass movements

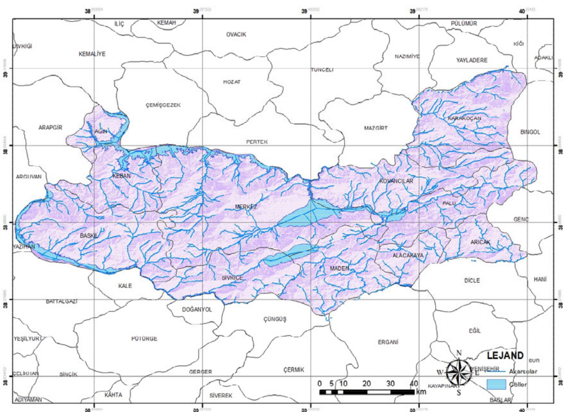
fact that Elazığ is in good condition in terms of arable soils causes erosion, leading to bigger problems in the city. Erosion is another important factor that prepares the ground for the accumulation of population in urban centers. For this reason, although erosion generally does not directly injure or kill people, it is a disaster that negatively affects society in terms of its long-term consequences.

The mountainous rocky regions of Elazığ city and the continental climate that dominates the city generally trigger avalanches, another mass movement. In Türkiye, avalanches, including Elazığ (IRAP, 2021), are generally concentrated in eastern Anatolia. In Elazığ province, there are a total of 22 disaster-prone area decisions against avalanche disasters (Sunkar, 2011; IRAP, 2021).

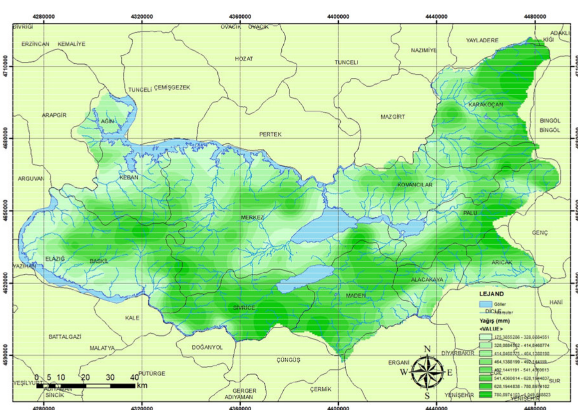
3.1.3. Analyzing of Elazığ in terms of floods and inundations

The geographical location and climatic characteristics of Elazığ province are important factors in terms of water floods. The city is located on the northeast bank of the Euphrates River in a valley surrounded by high mountains. This geographical structure increases the frequency of floods and flood disasters (Karakas et al., 2023). Throughout history, Elazığ province has experienced many flood disasters and water floods. These disasters have caused human casualties, economic loss, and infrastructure damage (Gurusamy & Vasudeo, 2023).

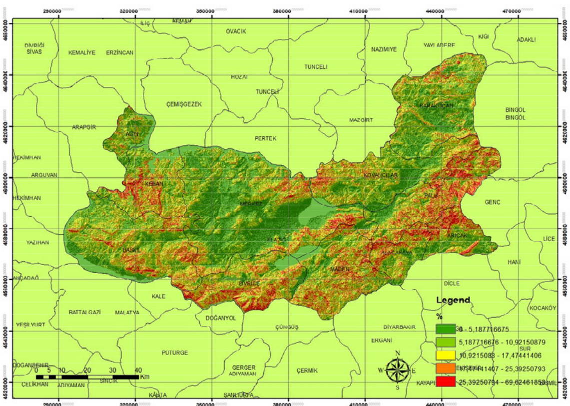
The climatic conditions of Elazığ are also important factors that affect floods. Under the influence of the continental climate, the city experiences hot and dry summers and cold and snowy winters. This climate can cause flooding, especially when combined with heavy rainfall in the spring and fall. In addition, sudden temperature increases in spring with snowmelt increase the risk of flooding (Sertel & Sanyürek, 2017; IRAP, 2021). The hydrological conditions of Elazığ province are also important factors affecting the frequency of floods. The Murat River, a tributary of the Euphrates River, is one of the important water resources of the city and has a high flow rate, which increases flood risk. In addition, underground water sources can also contribute to flooding. Floods and flood disasters are not limited to environmental impacts but also have social and economic impacts. They can force people to evacuate from their homes, damage agricultural land and infrastructure, and lead to economic loss (Karakas et al., 2023). Some incorrect policies by local governments in the city also increase the risk of flooding. For example, covering flood channels with small pipes to reduce their capacity, covering them with asphalt, and turning them into roads or recreational areas can make cities vulnerable to floods.



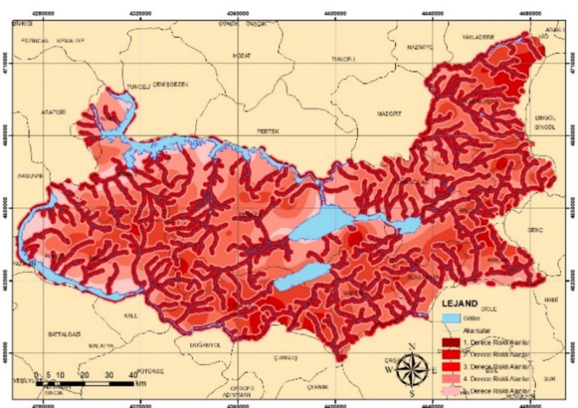
a) Elazığ Province hydrology analysis



b) Elazığ Province precipitation analysis (according to Schreiber method)



c) Elazığ Province slope analysis



d) Elazığ Province flood risk analysis

Figure 5. Analyzing of Elazığ in terms of floods and inundations

3.2. Obtaining data on the disaster parking area

3.2.1. Determination of criteria for Disaster Park Project area

The natural occurrence of disasters is inevitable; however, the damage and losses caused by them can be significantly reduced. The proper selection of disaster park sites is a critical factor in minimizing damage and protecting human lives. Therefore, the selection of disaster park sites requires a multifaceted approach. Proper site selection is essential for parks to provide maximum benefits and be used quickly and effectively in disaster situations (Masuda, 2014; Masoumi, 2017). In addition to natural factors such as climate and geography, population density, infrastructure status, risk analysis results, and the needs of the local community should also be considered. According to the research and literature, the characteristics of disaster parks are listed in Table 1.

Criteria for project site selection are based on both the scientific rationale for disaster risk reduction and meeting societal needs. Based on the findings and literature, the primary rationale for site selection can be explained as follows:

a. Minimizing disaster risk:

- One of the main objectives is to ensure that the selected area is protected as much as possible from the adverse effects of natural disasters. The key parameters in this regard are listed below:
- Distance from fault lines: Locating the site away from active fault lines is critical to minimize the risk of direct damage from earthquakes.
- Flooding and flood risk: The site has been selected away from flood-prone riverbeds or low-lying areas, supported by hydrological analysis.
- Topographic advantages: The site was selected with appropriate slopes (2–10%) to support the stability of the structure while allowing for natural drainage.

b. Accessibility and logistics:

- The area offers easy access for rapid response and evacuation in the event of a disaster. The key parameters in this regard are
- Central location: Proximity to the city center and densely populated neighborhoods is a strategic advantage to expedite emergency response.
- Transportation network: The area is well connected by wide roads and perimeter connections, allowing emergency vehicles and logistics equipment to reach the site quickly.

c. Multipurpose use and social benefit:

- Disaster parks must serve the community not only in times of crisis but also in normal times. In this context, the selected site will meet the following needs
- Recreation and education: In normal times, the green space can be used for social activities such as sports facilities and training centers. This increases the social acceptance of the area.
- Gathering and shelter area: The area provides ample physical capacity for people to gather safely and set up temporary shelters during a disaster.

d. Environmental compliance and sustainability:

- Long-term resilience depends on the compatibility of the chosen site with environmental conditions.
- Existing green space potential: The site is already located within an urban green space, which reduces infrastructure costs and supports environmentally sensitive design.
- Ecological adaptation: The natural vegetation and soil characteristics of the site have been assessed to support ecological sustainability and biodiversity.

e. Scientific and technological support:

- Modern analytical methods and technologies were used in the site selection process.
- Use of unmanned aerial vehicles (UAVs): Three-dimensional mapping of the area and detailed topographic analysis were performed using UAVs, increasing the accuracy of decisions.
- GIS-based density analysis: Density and risk analyses conducted with ArcGIS provided a scientific basis for determining the suitability of the area for disaster resilience.

The rationale behind the selection of the project site is based on minimizing disaster risk, enhancing social resilience, and ensuring environmental sustainability. The site is planned to function not only as an emergency shelter but also as a valuable green space and social activity center for the community. These approaches make the site a strategic choice from a scientific, logistical, and social perspective. Based on these criteria, Elazığ Municipality selected a site for the pilot design of the Disaster Park. After the project area was determined, field work began.

3.2.2. Conducting field studies

The field studies were started after obtaining the necessary permits from Elazığ Municipality. The field studies were completed within one month by visiting the study area with the project team and performing ground and airborne measurements in the field. In the field studies, ground measurements were first made with an RTK/CORS-based GNSS receiver (Figure 6).

In the following sections of the study, after the ground measurements were completed, the area was scanned with an unmanned aerial vehicle (UAV). An area of 0.270 km^2 was analyzed with 4K resolution imagery along with its immediate surroundings. Prior to the UAV measurements, four polygons were drawn to serve as reference points (Figure 6). This resulted in more realistic and accurate measurements.

Table 1. Disaster park planning and design criteria

Requirements	Explanation
Positioning	Disaster parks need strategic locations, close to city centers but away from danger zones like floodplains or coastal areas susceptible to tsunamis. Accessibility to diverse segments of society should also be ensured for equitable access (Ogawa, 2014; Masoumi, 2017).
Education and Awareness	These parks should offer educational resources, interactive displays, and programs to increase public awareness about disaster preparedness (Yıldırım et al., 2021).
Secure Infrastructure and Architecture	Park structures must withstand earthquakes, floods, and other disasters, meeting modern engineering standards for safety (Masuda, 2014; Coutaz, 2018; Sarıçam, 2019).
Emergency Preparations	Including emergency equipment, first aid stations, and trained staff is crucial for effective disaster response within the park (Yıldırım et al., 2021).
Green Spaces and Social Connections	Incorporating green spaces for stress reduction, along with areas for community events, fosters social cohesion and support (Sarıçam, 2019; Mabon, 2021).
Suitable for expansion	Parks should be sized adequately, with room for future expansion, ensuring they can accommodate evolving needs. (Masoumi, 2017).
Security Measures	Proximity to security resources, such as emergency services, and designs resistant to external threats are essential for park safety (Masuda, 2014).
Accessibility	Access to and within the park should be suitable for people with special needs such as the elderly, disabled, pregnant women, and children.
Infrastructure	Basic infrastructure like electricity, water, and sewage systems should be available within the park.
Social Facilities	In compliance with zoning regulations, specific types of buildings can be erected in designated areas such as recreation areas, park zones, and green spaces, with allowable construction determined by the area's size. For instance, in a recreation area, constructions like multi-purpose halls, mosques, restaurants, coffee shops, tea gardens, and kiosks are permitted, provided they do not exceed 5% of the total building area, including basements. This limit was reduced to 3% in park areas (Planned Areas Zoning Regulation, 2017). Furthermore, larger parks designated as post-disaster living spaces must incorporate facilities like schools, kindergartens, places of worship, health institutions, children's playgrounds, and sports facilities as per relevant laws and regulations (Masuda, 2014; Ogawa, 2014).
Flood Risk Management	Parks should be elevated to mitigate flood risks, with proper drainage systems in place (Singh, 2010; Chung, 2015; Feng & Yamamoto, 2020; Pan et al., 2022).
Suitability for drainage	The slope should not fall below 2% for the topographic structure of the land to be suitable for drainage (Singh, 2010; Masoumi, 2017).
Erosion Prevention	Slopes should be controlled to minimize erosion risks and associated costs (Ogawa, 2014; Masoumi, 2017; Sarıçam, 2019).
Wind Considerations	Consideration of prevailing wind direction is crucial in designing disaster parks to prevent tent fires, epidemics, and negative effects like smoke, odor, and dust on temporary settlements (Masuda, 2014; Ogawa, 2014; Cerrahoğlu & Maden, 2024).
Renewable energy sources	Renewable energy sources are crucial in disaster parks for bolstering environmental sustainability, energy security, and disaster response capabilities. These sources, like solar, wind, hydroelectric, and geothermal energy, are safer for human health and pose minimal harm to the environment. Integrating technologies such as solar panels, wind turbines, and hydroelectric systems in disaster parks not only fulfills their electricity needs but also enhances functionality during emergencies, reducing the impact of power outages and enabling more effective post-disaster rescue operations (Nikolov et al., 2014; Ogawa, 2014; Bhandari et al., 2021). This approach ensures disaster parks maintain an eco-friendly and sustainable structure, thus mitigating the adverse environmental effects of natural disasters.

Figure 6. Field studies

Figure 7. Images from unmanned aerial vehicle flights in the study area

UAV flight parameters are optimized for field conditions. Accurate data collection is critical for 3D modeling and analysis. The basic UAV flight parameters used in this study are detailed below:

a. Altitude: Designated altitude of 100 meters.

Rationale: This altitude is ideal for maintaining a sufficient level of detail (Ground Sampling Distance – GSD) while providing a wide perspective of the area. Higher altitudes may result in a loss of image detail (Eker et al., 2021).

b. Flight speed: Determined to be an average of 5 m/s.

Rationale: Keeping the speed low allows the UAV to capture more detail and increase image clarity. As the speed increases, there is a risk of image blurring and a decrease in overlap rates (Li et al., 2022).

c. Flight path planning: Flight paths are grid patterns. UAV flight paths are planned in a grid pattern to ensure complete coverage of the area. Paths are organized parallel to each other, with 60% longitudinal and 40% lateral image overlap between adjacent lines.

d. Camera settings and data acquisition: The camera model is a high-resolution RGB camera.

Ground Sampling Distance (GSD): 2.94 cm/pixel. This GSD provides an ideal resolution for detailed topographic analysis and 3D modeling. The image format is 4K resolution still images. The high resolution allows us to visualize fine details of the area (soil structure, slopes, etc.).

e. Flight conditions

Weather conditions: Flights were conducted in clear and cloudless conditions (Figure 7).

Windless or lightly windy conditions were preferred; early morning or late evening flights were avoided.

Calibration and reference points: 4 reference polygons were established around the site and these points were fixed during the flight to improve the quality of the measurements.

f. Flight area and coverage: The area covered is approximately 0.27 km^2 (27 hectares).

Number of images: 200 high-resolution images, 100% processed and calibrated.

g. Data processing: The software used is Pix4D Mapper. The resulting images were processed to produce an enhanced digital surface model (DSM) and 3D maps.

Accuracy control: RTK/GPS control points were used to verify data quality. Positional accuracy was measured to ±0.02 meters.

In addition, UAVs with image stabilization were preferred to prevent image blurring during flight. General technical information about the flight is given below (Table 2).

Table 2. General information about the UAV flight

Project	Disaster Park
Processed	2023-10-27 15:06:16
Camera Model Name(s)	FC6310R_8.8_5472x3648 (RGB)
Average Ground Sampling Distance (GSD)	2,94 cm / 1,16 inç
Area Covered	0.270 km^2 / 27.0378 ha / 0.10 sq. mi. / 66.8464 acres
Images	Median of 39019 key points per image
Data Set	200 out of 200 images calibrated (100%), all images activated
Camera Optimization	1.09% relative difference between initial and optimized internal camera parameters
Matching	Median of 20708.5 matches per calibrated image

A DSM is a data model that digitally represents the landforms and features of a region. A DSM contains elevation information on the Earth's surface and usually shows the heights and positions of all objects (buildings, trees, hills, valleys, etc.) on the terrain. DSM is created by processing data from sources, such as aircraft, UAVs, and light reflectance and ranging (LIDAR).

For detailed and precise studies, densified and corrected DSM or ortho mosaics are usually preferred (Figure 8). This type of data is more processed, error-free, and has a higher resolution, which makes it more suitable for precise and detailed analyses. Therefore, these steps were used in this study to perform precise and detailed analyses.

Image artifacts are anomalies caused by errors or uncertainties during image recording or rendering. These can affect the image quality and are influenced by factors such as optical aberrations, camera vibrations, motion blur, focusing errors, lighting changes, and sensor inaccuracies. Table 3 demonstrates that the image axis maintains a straight line without shift or distortion, which is crucial for the accurate processing of topographic data, terrain mapping, and three-dimensional terrain modeling.

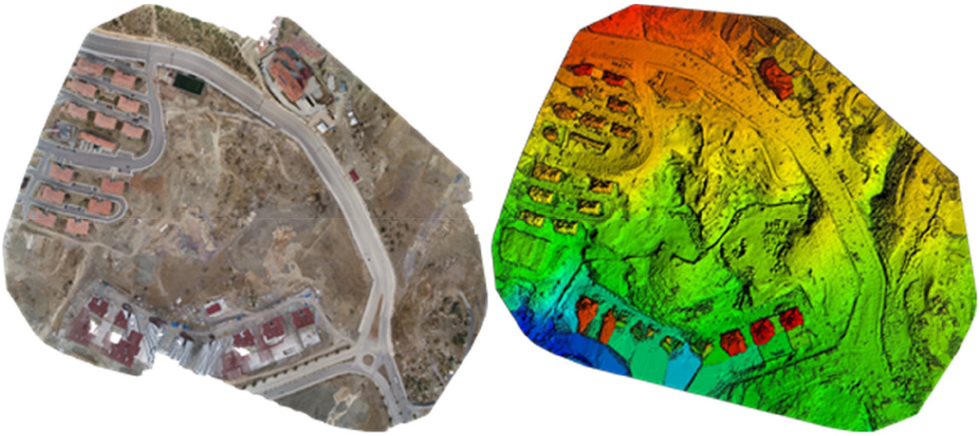
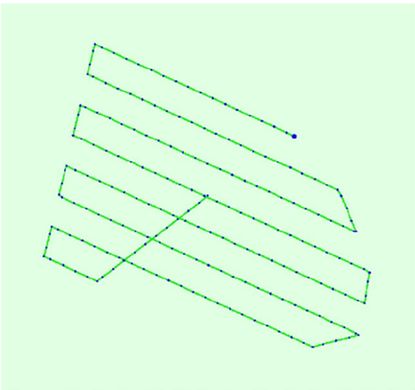
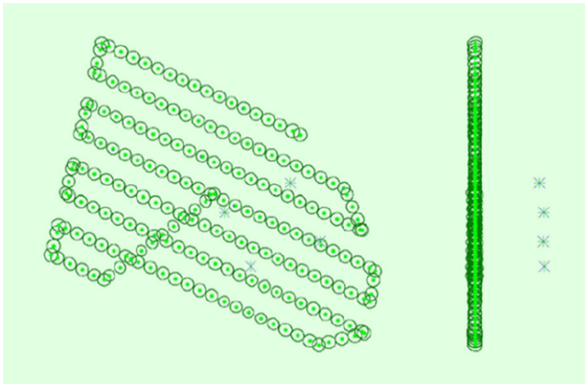


Figure 8. Ortho mosaic and corresponding sparse DSM before densification

Table 3. Image axis and uncertainties

	 Uncertainty ellipses 5000x magnified
The initial image position is depicted in a top view, with a green line indicating the image's trajectory over time from a starting blue dot.	The offset between initial (blue dots) and calculated (green dots) image positions, as well as the offset between initial positions (blue crosses) and calculated positions (green crosses) of Ground Control Points (GCPs), is shown in top, front, and side views. The dark green ellipses illustrate the absolute position uncertainty resulting from bundle block adjustment.

The number of overlapping images captured by a UAV directly affects the data resolution and quality of the resulting 3D model. In a recent study, it was observed that UAVs typically captured five or more overlapping images in the study area and its surroundings (Figure 9) to enhance data accuracy.

The correlation of imagery from UAVs often involves a variety of techniques and algorithms used for applications, such as image similarity measurement, template matching, motion tracking, and object recognition (Table 4). These techniques identify similarities or relationships by processing and analyzing image data from cameras. Thus, tasks such as object recognition, motion tracking, and three-dimensional (3D) reconstruction can be performed in various applications. In this way, a more detailed analysis and three-dimensional models were produced from the data obtained within the scope of the study.

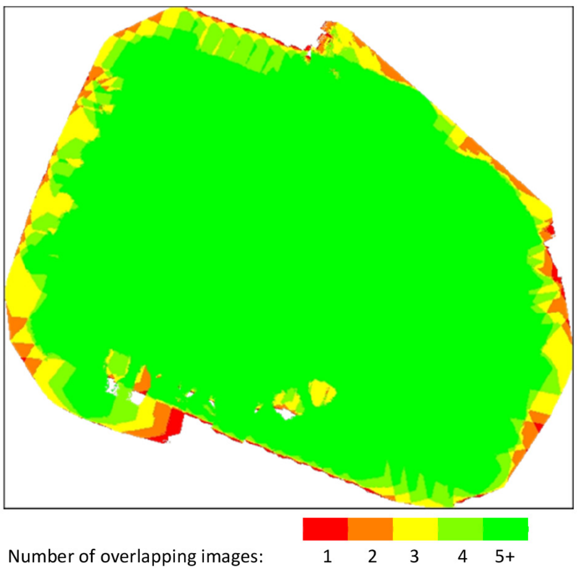
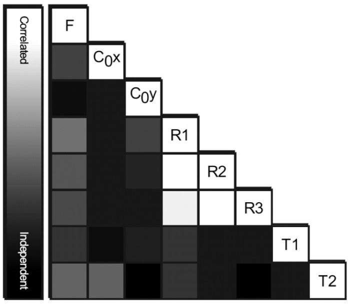


Figure 9. Overlap analysis of images

Table 4. Correlation

	Focal distance	Focal distance	Focal distance	R1	R2	R3	T1	T2
Initial Values	3658.300 [piksel]	3658.300 [piksel]	3658.300 [piksel]	–0.269	0.112	–0.033	0.000	–0.001
Optimized Values	8.580 [mm]	8.580 [mm]	8.580 [mm]	–0.285	0.128	–0.037	0.000	–0.000
Uncertainties (Sigma)	3698.222 [piksel]	3698.222 [piksel]	3698.222 [piksel]	0.000	0.000	0.000	0.000	0.000
				The correlation between internal camera parameters is crucial for data accuracy. A white color in the correlation map signifies a complete correlation between parameters, indicating that changes in one parameter can be compensated by another. Conversely, black indicates independence from other parameters, meaning changes in one parameter do not affect others.				
				Automatic Ports Per Pixel (ATP) is crucial for image analysis. A color scale ranging from black to white represents the ATPs extracted per pixel, with white indicating over 16 ATPs on average and black indicating none. Examining the image reveals the average direction and magnitude of reprojection errors per pixel, aiding in error analysis with scaled vectors for clarity (the scale bar represents a 1-pixel error magnitude).				

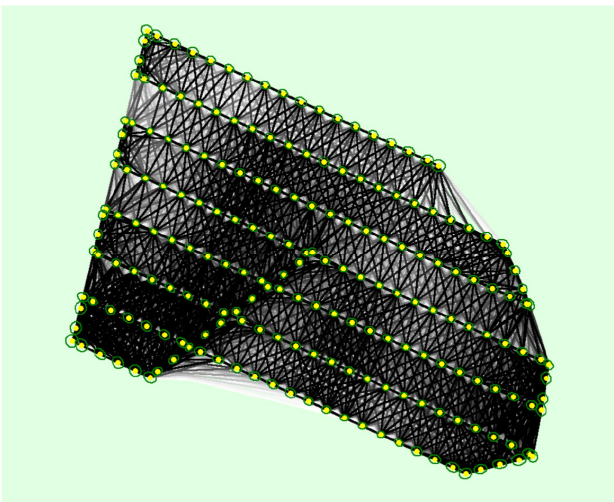


Figure 10. Uncertainty ellipses 1000x magnified

Image positions were computed alongside the connections among matching images, with the darkness of links reflecting the quantity of matching 2D key points between images. Bright links denote weaker connections that necessitate manual anchor points or additional images. Dark green ellipses indicate the relative camera position uncertainty in the bundle-block adjustment result. When analyzing the images, we extracted the median, minimum, maximum, and average number of 2D and 'B' key points per image. Table 5 presents the key point counts based on these criteria (Figure 10).

Table 5. Number of 2D and 2D keypoints per image

	Number of 2D keypoints per image	Number of matching 2D keypoints per image
Median	39019	20709
Minimum	27944	14503
Maximum	54814	32343
Average	38994	20991

The margin of error and verification are very important concepts in assessing reliability. The margin of error indicates the degree to which a measurement or estimate deviates from its true value. It is usually expressed as a percentage. For example, a margin of error of 5% indicates that the actual measurement may differ from the estimated value by up to 5%. In this study, the margin of error is approximately 0.006. That is, it is less than 1%. This result indicates high reliability (Table 6).

3.2.3. Creating a three-dimensional model and triangle model of the terrain

After the field analysis, measurements, and UAV images were taken, data processing was started. The photographs obtained by the UAV from each point in the point cloud were matched and optimized.

At the same time, the data from the RTK/CORS GNSS receiver measurements were processed and a triangulation model of the area was created. The UAV data and the GNSS receiver data were processed to minimize the

Table 6. Margin of error and verification status

GCP name	Accuracy XY / Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection error [pixels]	Verified / Marked
s.1 (3D)	0.020 / 0.020	–0.006	–0.008	0.001	0.232	21 / 21
s.2 (3D)	0.020 / 0.020	–0.002	–0.002	0.005	0.223	25 / 25
s.3 (3D)	0.020 / 0.020	0.012	0.011	–0.012	0.300	21 / 21
s.4 (3D)	0.020 / 0.020	–0.004	–0.000	0.005	0.373	18 / 18
Average [m]		0.000036	–0.000036	–0.000383		
Sigma [m]		0.007270	0.006711	0.006802		
RMS Error [m]		0.007270	0.006711	0.006812		

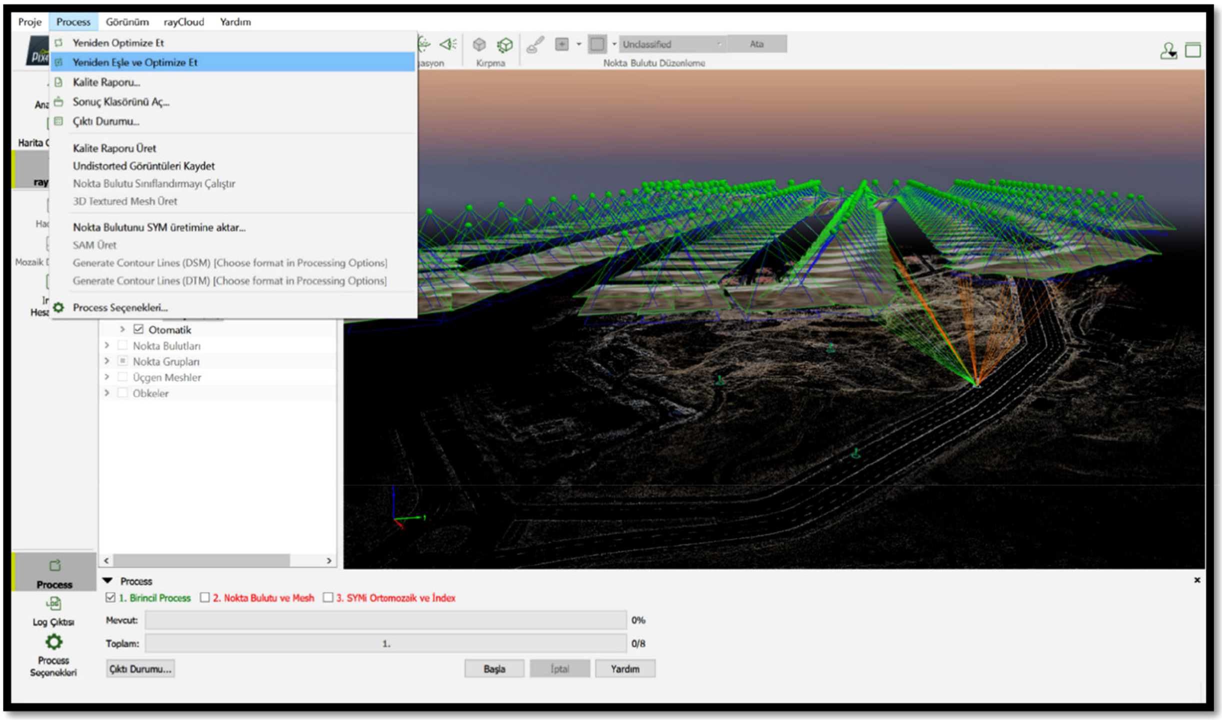


Figure 11. Remapping and optimization of UAV images

margin of error. In addition, the obtained land measurements were placed on a 1:1000 scale land use plan obtained from Elazığ Municipality. Thus, a modern land map was created.

UAV technologies are very important in terms of obtaining faster and more reliable results in terrain analysis than other methods (Dönmez et al., 2021). Analyses performed using images obtained with the help of UAVs provide more accurate and faster results than ground measurements (Figure 11).

After processing the terrain map triangular model and aerial photographs obtained with the UAV, a three-dimensional model of the land was created using the Pix4Dmapper program (Figures 12 and 13). The Pix4Dmapper program is used to process images obtained by UAVs and allows various analyses to be performed on the images (Çilek et al., 2020).

3.3. Development of a disaster park proposal

The Elazığ Disaster Park proposal has undergone a development process that included obtaining official permits and conducting site analyses. The proposal aims to serve as a center for disaster coordination, temporary shelter and other functions. The main features of the park include pergolas that can be converted into temporary shelters. These pergolas are designed to meet people's primary shelter needs. There is also a disaster museum, environmentally friendly facilities powered by solar and wind energy, shelters and children's playgrounds. The park is designed to be energy self-sufficient with systems such as solar power and wind turbines. The park also includes a helipad, bio-filtered water fountains, sports fields, cafeterias, restaurants, green areas with flood mitigation systems, permeable soil, and retaining walls against mass movements.

There are ninety pergolas throughout the park, each seating four people. The park can accommodate up to

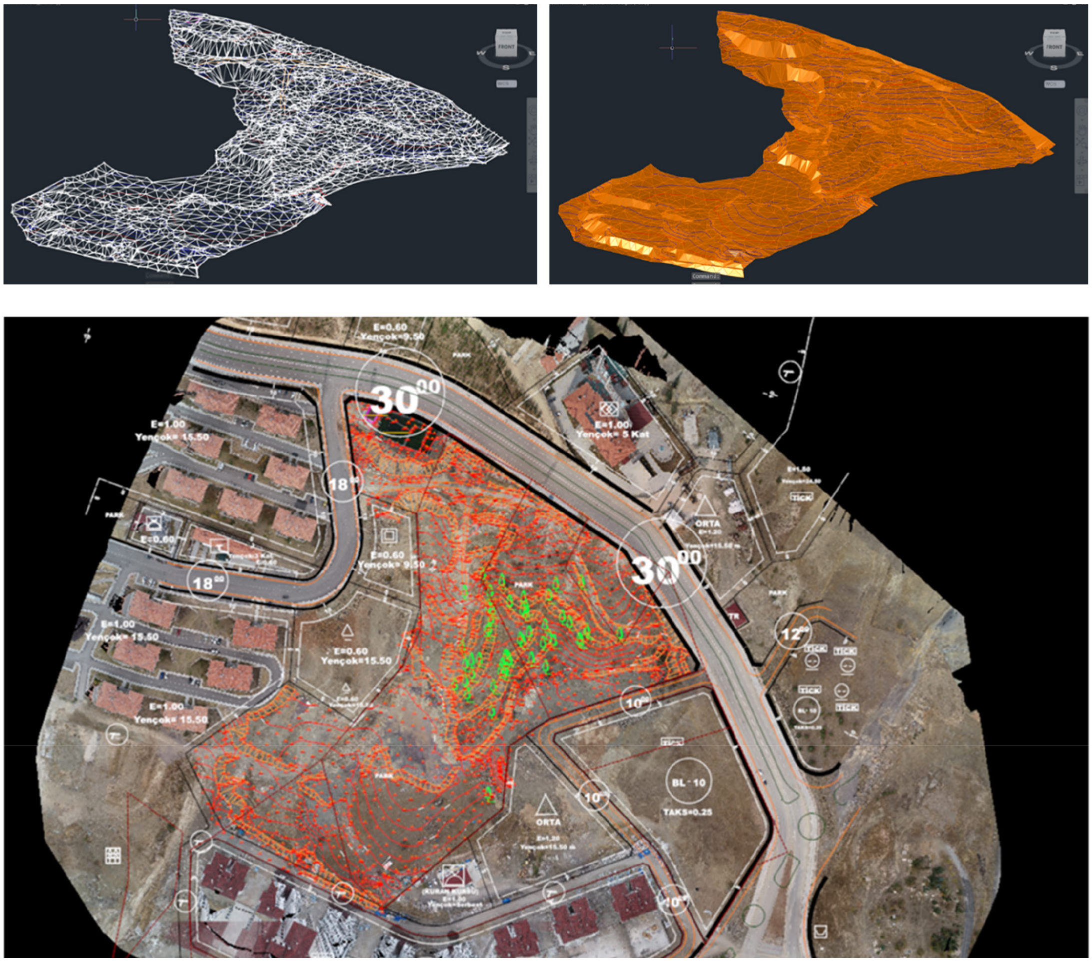


Figure 12. The creation of the current map and triangular model as a result of field studies

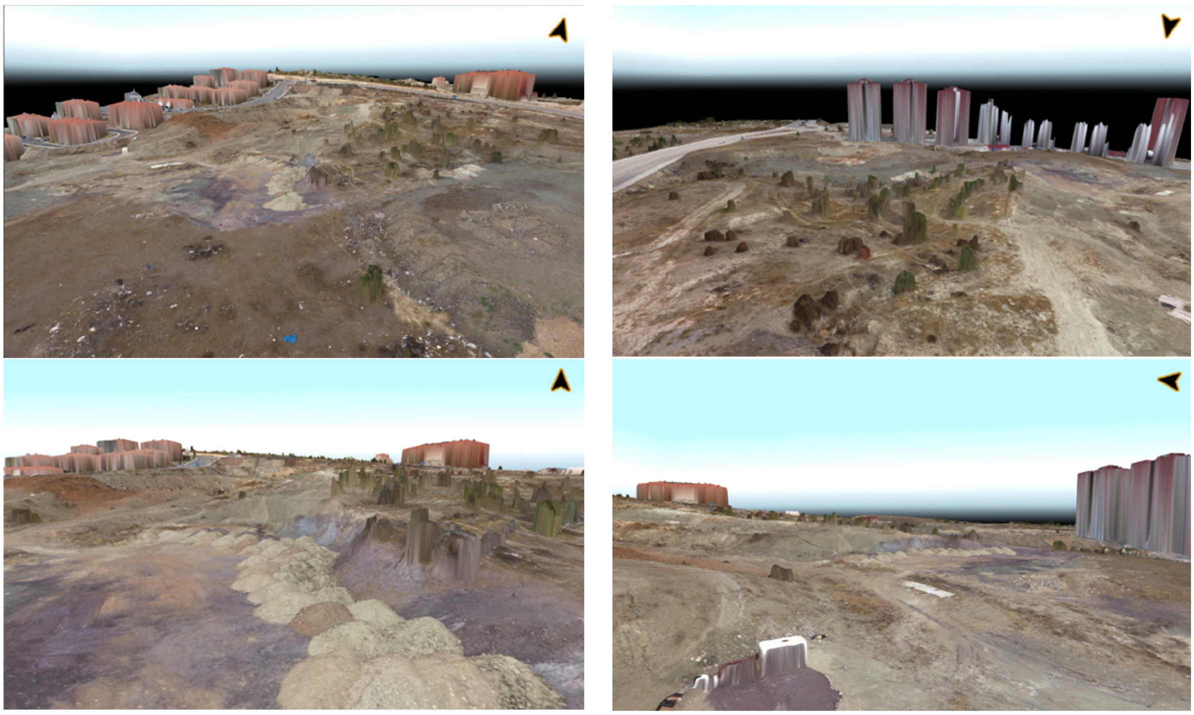


Figure 13. Creation of a three-dimensional model of the land

360 people without tents. Including open spaces, sports fields, and buildings suitable for tents, the park can accommodate 3,500 people. This exceeds the capacity of unplanned green spaces and demonstrates the benefits of purpose-built disaster parks. The 52,173 m^2 park is designed to provide safe shelter for maximum occupancy. The design also overcomes the problem of limited access for emergency vehicles in unplanned settlements during emergencies. In addition, the project addressed challenges such as the potential for secondary disasters and epidemics. The park mitigates these risks by providing a structured and sustainable environment. It minimizes post-disaster damage associated with temporary settlements. The establishment of planned disaster parks is essential to ensure public safety and well-being during crises in urban areas.

The Disaster Park project was developed based on the criteria and characteristics summarized in the Findings section. Located in the center of the city, the park benefits from 30-meter wide roads that provide easy access. The surrounding empty parking lots can be used as buffer zones in case the capacity of the park is not sufficient. Complementing this central park, smaller disaster parks will be established in neighborhoods connected by bike paths. This will create a resilient green space network for Elazığ (Figure 14). In the project proposal, the layout of the facilities is planned based on scientific analysis, disaster management strategies, and site characteristics. The factors considered in determining the layout of the facilities are described in detail below:

a. Functional use of space: The layout of the facilities in the project area is divided into different zones according to their functions. Each zone is positioned to play a critical role during and after a disaster.

- Emergency response areas: The locations of facilities such as emergency coordination centers, helipads, and logistics storage areas have been carefully selected. They are located in easily accessible areas near major transportation routes. This is important to reduce crisis response times and increase operational efficiency.
- Shelter sites: Temporary shelters are located in flat and safe areas away from disaster risks such as flooding and landslides. These areas are close to logistics centers so that basic needs can be easily met.
- Educational and social facilities: These facilities, usually used for education and awareness activities, are planned in quieter areas around the park.

b. Topographical and environmental factors: Topography and environmental conditions played an important role in the design of the facility.

- Slope and surface stability: Facility sites were selected in areas with high soil stability and favorable slope (between 2–10% slope). This is important to increase structural stability and reduce the risk of landslides from potential disasters.
- Drainage and water management: Shelter and logistics areas are located parallel to drainage lines to prevent water accumulation after rainfall. In addition, flood-prone areas have been avoided.

c. User needs and safety: User safety and ease of access were prioritized in the design of the facility.

- Main roads and ease of access: Facilities are located near the park's main transportation routes. This can

Figure 14. Development of Disaster Park Project

expedite evacuation and response in the event of a disaster. It also facilitates user access during normal times.

- Emergency exits: Adequate distances have been maintained between shelters and social areas, and evacuation corridors have been provided in the event of a crisis.
- Water surfaces: Pools have been placed in temporary settlement areas in the area. These pools provide an aesthetic appearance. However, it can be used for emergency water needs. It can also meet the need for a backup water tank in case of a possible fire.

d. Social and psychological support: The design of the facilities is planned to support social solidarity and psychological recovery after a disaster.

- Entertainment areas for children: Some measures have been taken to ensure that children who take shelter in the park after the disaster can recover from the negative effects of the disaster. For example, some facilities such as different types of playgrounds and water games that can attract children's interest are located near temporary settlements in the area.
- Green space integration: Facilities have been placed in harmony with existing green spaces. This approach aims to reduce the stress of individuals and provide psychological support after a disaster.

e. Scientific and technological basis: The layout of the facilities is based on scientific data obtained from field analysis.

- GIS analyses: Density analysis using ArcGIS determined which disasters could affect the area. Also
- UAV data: 3D models created by UAVs were used to assess the topographic suitability of the facilities and create the optimal layout plan.
- Hazard maps: Earthquake, flood, and landslide risk maps provided scientific guidance for locating facilities in safe areas.

f. Energy and resource management: Facilities are planned to optimize water management and access to sustainable energy sources.

- Solar energy and wind turbines: Renewable energy sources will be used to ensure energy independence.
- Water storage and treatment: Water storage and purification systems for emergency use will be located near shelters.

The proposed Disaster Park project has demonstrated a scientific and strategic approach to facility layout. This layout represents a holistic model that combines emergency response, safety, accessibility, and social benefits through disaster management principles. The layout logic of the facilities is based on site analysis, environmental conditions, and user needs, and aims to provide a sustainable disaster management infrastructure.

4. Conclusions and recommendations

The deterioration in the population balance between urban and rural areas has led to a rapid increase in population density in urban centers. This situation has increased the negative impact of natural disasters compared to previous years. Unplanned urbanization and insufficient green areas make urban residents vulnerable to disasters. Urban green spaces play a crucial role during and after disasters by providing natural shelter and protection. Therefore, they are vital for disaster mitigation.

Elazığ is an example of this type of city with its dense population and frequent disasters. The city has suffered loss of life and property in the 2020 Elazığ earthquake and other major disasters. After the disasters, people usually took shelter in parks and green areas in the city. However, there were problems because these areas were not suitable for shelter. Secondary disasters such as fires, floods and epidemics caused damage to people living in temporary shelters. This situation shows the urgent need for planned green spaces for disasters in Elazığ. The creation of a disaster park in Elazığ will increase the city's level of preparedness for disasters. It will also provide a valuable green space for recreation. The park will contribute to risk mitigation strategies, making Elazığ better equipped to cope with potential disasters. Therefore, the establishment of such parks is of great importance for effective disaster management and community preparedness in Elazığ. By integrating disaster parks into a comprehensive disaster risk reduction strategy, a disaster-resilient green space system can be established in Elazığ.

As a result, Elazığ has a history of frequent disasters, particularly earthquakes, mass movements, and floods. Secondary disasters such as fires and floods have exacerbated these challenges, especially in densely populated areas. To address this problem, disaster parks tailored to the specific risks of a region are of great importance. In Elazığ, a comprehensive disaster park acting as a coordination center could be a strategic solution. A feasible model for this purpose is presented in the study. A landscape management approach at the urban level is also proposed. This landscape management can be achieved through smaller disaster parks at the neighborhood level that systematically support the main park. By connecting these parks with bicycle paths, the neighborhood disaster parks can function like a network that pumps blood from the heart to the organs. This can keep transportation systems functioning even when traditional transportation systems collapse during disasters. Renewable energy sources are also an important part of this system. Renewable energy will allow life to continue in these areas even in adverse situations, such as when power lines break. This research emphasizes the need for multiple interconnected disaster parks, each serving a specific purpose in disaster response and management. For example, the main park can house coordination facilities. Neighborhood disaster parks can focus on local support and aid distribution. Seamless integration and connectivity between these parks should be ensured to provide rapid assistance to affected areas. This proposed disaster park model and landscape management system is designed for Elazığ. However, this model can also be applied to other disaster-prone cities.

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Author contribution

Conceptualization: Y. B., Ö. F. B. methodology: Ö. F. B.; software: Ö. F. B.; formal analysis: Ö. F. B.; investigation: Ö. F. B.; resources: Ö. F. B., Y. B.; data curation: Ö. F. B.; writing–original draft preparation: Y. B., Ö. F. B.; writing–review and reediting: Y. B., Ö. F. B.; supervision: Y. B., Ö. F. B.

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Data availability

The data is remote sensing data. All data in this article will be available upon request.

Declarations

Ethical approval

Ethical approval is not required for this article.

Consent to participate

No human or animal specimens were used in this work. The environment is not damaged.

Consent for publication

All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

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