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Clustering-Based Framework for Temporary Shelter Site Selection in Earthquake-Induced Landslide Risk Zones: The Case of Büyükçekmece, Istanbul

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Abstract Disaster management and emergency response are critical in building community resilience to disasters. This study specifically focuses on temporary shelter planning, an essential component of disaster management, with an emphasis on identifying safe zones in post-earthquake landslide-prone areas. The research was conducted on the European side of Istanbul, with Büyükçekmece identified as the most at-risk district due to its high post-earthquake landslide susceptibility. A systematic and transparent data collection process was employed to ensure the accuracy, reliability, and validity of the analysis. Geospatial data, topographic information, soil structure, and population density were among the key variables used to assess risk and suitability. Clustering methods, including k-means and hierarchical clustering, were applied to categorize potential gathering and shelter sites based on criteria. The clustering analysis categorized the sites into different risk levels and helped identified the most vulnerable areas, providing a basis for targeted disaster preparedness and resource allocation. Moreover, the findings support policy-makers and urban planners in prioritizing shelter infrastructure investments in critical areas. This study demonstrates a robust framework to develop temporary shelter planning in high-risk regions, offering practical insights for disaster management and improving safety outcomes in similar contexts.

Keywords Secondary Disaster · Landslides Induced by Earthquake · Temporary Shelter · Machine Learning · Clustering Analysis

Author Note This paper is an extended and full version of the study initially presented at the Conference of YAEM 2024.

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Clustering-Based Framework for Temporary Shelter Site Selection in Earthquake-Induced Landslide Risk Zones: The Case of Büyükçekmece, Istanbul

Disaster management and emergency response are critical to community capacity building in coping with natural and human-induced disasters. The domain is vast, ranging from strategies on prevention, preparedness, response, and recovery to reduce risks and ensure timely and effective action during and after the occurrence of disasters. The most important aspect of disaster management is temporary shelter provision to meet the immediate needs of the affected populations. Such shelters ensure disaster victims' safety, health, and dignity, especially in situations where permanent dwellings have been destroyed or rendered unsafe.

This is critical during the post-earthquake phase when secondary hazards such as landslides are very dangerous. The siting and location of temporary shelters should be done in areas of least landslide risk to help protect disaster victims and avoid possible secondary disasters. Recent works, in this regard have highlighted the incorporation of advanced technologies such as GIS, remote sensing, and AI into risk assessment and site selection. These tools would contribute to the identification of safe zones based on a variety of parameters, such as slope stability, slope conditions, and the integrity of the soil following earthquakes.

The main goal of this study is to propose a site selection framework for temporary shelters in a region prone to post-earthquake landslides, focusing on the primary reduction of risks from secondary disasters. The other aim is to embed advanced technological methods and an interdisciplinary approach into disaster management planning with a view to enhance safety and effectiveness during emergency responses.

This article adds value to disaster management studies because it addresses one very critical but less explored area of post-disaster recovery: the interface of temporary shelter planning and the mitigation of secondary hazards. With AI for risk assessment and site selection, the study introduces a new technology-driven approach that complements the existing methodologies. This framework also provides useful insights for policymakers and practitioners in making more effective, evidence-based decisions in disaster recovery.

Literature Review

Temporary shelter site selection is critical to disaster management, particularly in post-earthquake scenarios where secondary hazards such as landslides intensify the risks. Existing studies in the field have predominantly focused on single hazards, utilizing methodologies such as multi-criteria decision-making (MCDM), Geographic Information Systems (GIS), and clustering techniques to address the complexity of shelter planning. In this section, a literature review has been conducted for the shelter selection after the disasters and the articles are shown in Table 1.

Table 1

Literature review of the secondary disaster and study areas

Author (Year)	Topic	Methods	# of Criteria
(Chen et al., 2013)	Post-Earthquake Temporary Shelter Site Selection	Optimization	9
(Kılcı et al., 2015)	Temporary Shelter Site Selection (Kartal)	Optimization	-
(Kınay et al., 2018)	Temporary Shelter Site Selection (Kartal)	Optimization	-

Author (Year)	Topic	Methods	# of Criteria
(Shafapourtehrany et al., 2022)	Vulnerability Mapping for Istanbul	k-means	12
(Nappi & Souza, 2015)	Temporary Shelter Site Selection	MDCM	10
(Nappi et al., 2019)	Temporary Shelter Site Selection	MCDM	9
(Şenik & Uzun, 2021)	Temporary Shelter Site Selection (Düzce)	MCDM	7
(Celik, 2024)	Temporary Shelter Site Selection	MCDM	6
(Mabahwi & Nakamura, 2024)	Flood Temporary Shelter Site Selection	MCDM	4
(Gharib et al., 2022)	Temporary Shelter Site Selection	ANFIS	10

Chen et al. (2013) proposed a hierarchical location model for earthquake-shelter planning, emphasizing temporal shelter hierarchies and the importance of accessibility. Similarly, Nappi and Souza (2015) and Nappi et al. (2019) developed MCDM frameworks to optimize shelter location, integrating criteria such as proximity to infrastructure and population density. Their works underline the importance of a systematic approach to address the dynamic nature of post-disaster requirements.

The integration of the clustering methods has also been explored. Shafapourtehrany et al. (2022) applied k-means clustering to map earthquake vulnerability in Istanbul, demonstrating its efficacy in identifying high-risk zones for shelter placement. Gharib et al. (2022) used ANFIS (Adaptive Neuro-Fuzzy Inference Systems) to enhance decision-making accuracy in shelter distribution after large-scale disasters. These studies highlight the potential of combining traditional and advanced computational techniques for temporary shelter site selection. Studies addressing landslide risks after an earthquake are relatively scarce. However, Garcia-Rodriguez and Malpica (2010) employed artificial neural networks to assess earthquake-induced landslide susceptibility, providing insights into terrain stability factors. Gautam et al. (2021) and Wang et al. (2014) evaluated the factors for earthquake-triggered landslides, emphasizing different parameters. These studies serve as foundational references for incorporating secondary hazard assessments into shelter site planning. Advanced technologies like GIS have been pivotal in facilitating risk analysis and site selection. Othman et al. (2012) demonstrated the utility of GIS-based MCDM in landslide hazard zonation, which can be adapted for temporary shelter planning. Additionally, Xu et al. (2013) and Xie et al. (2018) highlighted the application of logistic regression and neural network models in susceptibility mapping. Mabahwi and Nakamura applies the AHP and WOA within ArcGIS to evaluate flood shelter locations in Kuantan, Malaysia, revealing that 21% of existing shelters are unsuitable, emphasizing the need for continuous reassessment to enhance safety and effectiveness (Mabahwi & Nakamura, 2024). Şenik and Uzun study examines emergency assembly points and temporary shelter areas in Düzce, Turkey, using GIS-based suitability analysis, highlighting significant deficiencies in site selection, size, and accessibility, and calling for better integration of urban planning and disaster management (Şenik & Uzun, 2021). Lastly, Celik utilizes the Best-Worst Method (BWM) with interval type-2 fuzzy sets to identify key criteria for temporary shelter site selection, determining proximity, distribution center capacity, and access to essential services as the most critical factors for improving disaster preparedness and response (Celik, 2024). Notably, a gap exists in integrating multi-hazard assessment into real-time decision tools on the selection of temporary shelter sites, despite significant progress on both components. Most previous methodologies fail to adapt adequately to changing post-disaster situations in a quick and iterative manner. Thus, the current research puts a thrust on combining clustering algorithms with the consideration of second-order hazards to present an appropriate, robust framework for earthquake-induced landslide regions.

Applied Methodology and Criteria Framework

This section focuses on the methodological approach adopted in the study and the process of determining the selection criteria. Specifically, it outlines the clustering techniques used to group potential shelter sites and explains how the selection criteria were identified based on an extensive literature review concerning post-earthquake landslide risks and temporary shelter planning. Study focuses on determining and analyzing temporary shelter sites in post-earthquake landslide risk regions, specifically targeting Büyükçekmece, a high-risk district identified in prior research. The methodology involves data collection, factor determination, and clustering analysis to classify the potential shelter areas.

Clustering Method

Generating appropriate training datasets is a priority in natural hazard analysis (Tshering et al., 2020). Since there are not enough regional databases in Istanbul, the k-means clustering algorithm is proposed in this study (Sinaga & Yang, 2020). This method can be effective in mapping seismic vulnerabilities and improving the model performance. Clustering is a powerful tool for identifying similarities and differences in datasets (Jain & Dubes, 1988).

In this study, k-means and hierarchical clustering methods were used to cluster the temporary shelter areas according to the determined criteria. The k-means algorithm clusters the data according to the closest centers (Khan & Ahmad, 2004). First, k centers are calculated, and data points are assigned to these centers. Then, the centers are re-calculated and the process continues iteratively. This method, which works with metrics such as the Euclidean distance, depends on the initial centers and the number of iterations (Milligan, 1980). Because these clustering methods serve different purposes, the choice between them is made based on the dataset characteristics and study objectives. K-Means is ideal for fixed, well-defined cluster groupings, while Hierarchical Clustering is more suitable for understanding the relationships between different shelter zones. The selection ensures that the analysis aligns with the research goals while maintaining computational efficiency and interpretability.

Factors Related to the Establishment of Temporary Shelter Areas in Post-Earthquake Landslide Risk Areas

In this part of the study, the factors to be used for the selection of the regions where temporary shelter areas will be established and how these factors are determined are explained. In the literature review, there are not many studies on secondary disasters and temporary shelter areas. For this reason, only the studies on the selection of temporary shelter areas and the selection of temporary shelter areas after earthquakes or landslides are focused. The details of the conducted literature review and the MCDM method used can be found in Yalcin Kavus & Taskin, (2025). When these studies are analyzed, the factors related to the selection of a temporary shelter area in a region with landslide risk after an earthquake are determined as follows:

Elevation/Altitude: This criterion refers to the height or altitude of a point above sea level. Geographically, it is used to indicate the elevation of an area. It is closely related to the height of the slopes, their gradients and the intensity of water runoff. Higher altitude areas can often have steeper slopes, which can increase the risk of landslides after earthquakes. It also influences landslide formation by determining the soil moisture and the rate of water flow. Flooding and runoff can be more intense at high altitudes, which can increase soil erosion and landslide risk. For these reasons, it is an important topographic criterion to be considered in post-earthquake landslide risk analyses (García-Rodríguez & Malpica, 2010; Gautam et al., 2021; Othman et al., 2012; Pham et al., 2023; Polykretis et al., 2019; Shao et al., 2019; Tao et al., 2009; M. Wang et al., 2014; Xi et al., 2019; Xie et al., 2018; Xu et al., 2013; Yamusa et al., 2022).

Distance to landslide boundary: Refers to the distance of temporary shelters from landslide-prone areas to protect them from landslide risk. After an earthquake, the stability of the ground may deteriorate and the risk of landslides may increase, especially in sloping areas. This is a critical factor for the safety of disaster victims and the sustainability of shelter areas. In landslide-prone areas, the proximity of shelters to the landslide boundary may create serious hazards due to possible landslides and mudflows. Establishing shelters at distances away from the landslide boundary reduces the risk of loss of life and injury from such secondary disasters. Road closures or damage in landslide-prone areas can complicate emergency response and the delivery of relief supplies. Shelters located far from the landslide boundary enable logistical support and emergency response to be carried out more effectively and without interruption. This is important for the rapid mobilization of emergency response teams and the timely delivery of necessary supplies. The distance to the landslide boundary is a vital criterion in determining temporary shelter areas after an earthquake. Therefore, in disaster management and emergency planning, safe and strategic shelter areas should be selected by considering the distance to the landslide boundary (Shafapourtehrany et al., 2022)

Distance to Fault Line: Fault lines represent areas where earthquakes commonly occur and landslide risk may be higher close to these areas. This distance is an important criterion for understanding landslide occurrence by determining the potential earthquake effects, soil movements, ground damage, and soil liquefaction risk. Therefore, the distance to the fault line should be considered in post-earthquake landslide risk assessments (Gautam et al., 2021; Hoseinzade et al., 2021; Othman et al., 2012; Pham et al, 2023; Polykretis et al., 2019; Salehpour Jam et al., 2021; Salleh et al., 2018; Shao et al., 2019; Tao et al., 2009; X. Wang et al., 2023; Xi et al., 2019; Xie et al., 2018; Xu et al., 2013, 2016; Yamusa et al., 2022)

Soil Class: This criterion is used to determine the possible behavior, strength, and water absorption capacity of the soil. Different soil types can cause variations in factors such as erosion resistance, liquefaction risk, vegetation cover and building foundations. Some soils may absorb more water and be more resistant to erosion, while others may liquefy. This affects the post-earthquake behavior of the soils and possible landslide formation. Therefore, it is an important indicator for understanding soil movements and landslide formation and a factor to be considered in post-earthquake risk analyses (Gautam et al., 2021; Hoseinzade et al., 2021; Othman et al., 2012; Salleh et al., 2018; Umar et al., 2014).

Peak Ground Acceleration (PGA): This represents the maximum speed of motion of the earth's surface during an earthquake. This measurement is used to assess the impact of an earthquake at a specific point and to understand the resistance of structures, buildings, or infrastructure to this acceleration. This value is considered an important parameter for predicting the effects of an earthquake and potential damages. High PGA can reduce soil movement and stability and increase the likelihood of landslides. It can also affect the earthquake resilience of the structures and infrastructure. Therefore, PGA values are used to predict landslide occurrence and assess potential damages. Therefore, it is important to study PGA in post-earthquake landslide risk analyses (Gautam et al., 2021; Polykretis et al., 2019; Shao et al., 2019; Tao et al., 2009; Umar et al., 2014; Xi et al., 2019; Xie et al., 2018; Xu et al., 2013, 2016).

Number of Households in Need of Temporary Shelter at Night: This refers to the number of households in need of temporary shelter after a disaster. This criterion is important for the capacity planning of shelter areas and resource allocation. The number of households in need of temporary shelter at night is necessary for accurate planning of the capacity of shelter areas. In order for disaster victims to be able to shelter safely and comfortably, the areas should be of sufficient size and equipped. This criterion ensures the effective management of capacity planning, resource allocation, security and risk management, social and psychosocial support, and health and hygiene conditions. Therefore, taking this criterion into account in disaster management and emergency planning plays a critical role in meeting the shelter needs of disaster victims in a safe, healthy, and organized manner (Gharib et al., 2022; Shafapourtehrany et al., 2022).

Night Population Density: Refers to the population density of a given area at night. High population density requires shelter areas to be larger and better planned. In landslide-prone areas, the designation of shelter areas in areas with high night-time population density should be carefully considered in terms of safety. A high population density means that more people will be at risk in the event of a landslide. Therefore, areas with low landslide risk and balanced night population density should be preferred when selecting shelter areas. This approach is vital to ensure the life safety of disaster victims and minimize secondary disaster risks. The night population density criterion is a vital factor in determining temporary shelter areas in landslide-prone areas after an earthquake. This criterion ensures the effective management of security and risk management, resource and infrastructure planning, social order and psychosocial support, logistics and access, and health and hygiene conditions. Consideration of night population density in disaster management and emergency planning plays a critical role in meeting the shelter needs of disaster victims in a safe, healthy, and organized manner (Gharib et al., 2022; Shafapourtehrany et al., 2022).

Distance to Drinking Water: Refers to the distance of temporary shelters from drinking water sources. Proximity to water improves hygiene and health conditions and facilitates water supply. Without proper planning, it can lead to serious health and hygiene problems. Drinking water is a basic human need, and the provision of adequate, clean water is critical for protecting the health of disaster victims. Locating temporary shelters close to drinking water sources ensures that the water is fresh and clean. Problems in water supply in areas far from water sources may lead to deterioration of hygiene conditions, spread of infectious diseases and worsen the overall health status of disaster victims. An easy and continuous water supply is essential for the effective functioning of temporary shelters. . This criterion is of great importance in terms of health and hygiene, logistics and ease of access, psychosocial well-being, meeting basic needs and the effectiveness of disaster response operations. In disaster management and emergency planning, the distance to drinking water should be taken into account to ensure that the safe, healthy and sustainable shelter needs of disaster victims are met (Chen vd., 2013; Gharib vd., 2022; Nappi vd., 2019; Nappi & Souza, 2015).

Distance to the Main Road: Refers to the distance of the temporary shelters from the main road networks. Proximity to the main road increases the effectiveness of logistical support, material supply, and emergency response. The “Distance to Main Road” criterion is critical in terms of logistics and ease of access in determining temporary shelter areas in landslide-prone areas after earthquakes. Shelter areas close to main roads ensure the rapid access of emergency response teams, efficient distribution of relief supplies, and safe evacuation of disaster victims. The proximity to transportation networks also enables the uninterrupted provision of health services, food, water, and other basic needs. In areas far from main roads, however, transportation and logistical difficulties can disrupt relief operations and severely affect the living conditions of disaster victims. Therefore, locating temporary shelters close to main roads plays a crucial role in the efficiency and acceleration of post-disaster response and recovery processes (Chen et al., 2013; Gharib et al., 2022; Nappi et al., 2019; Nappi & Souza, 2015).

Distance to the main depot: This refers to the distance of the temporary shelter areas from the main material and resource depots. This distance is important for the rapid and efficient delivery of essential supplies and assistance. It is crucial for the rapid and efficient distribution of vital supplies and resources. Shelter areas close to main warehouses ensure uninterrupted and timely supply of food, water, medical supplies, and other basic needs. This proximity facilitates logistics operations, speeds up relief activities, and allows disaster victims' basic needs to be met faster. Shelters far from warehouses, on the other hand, may cause delays in the transportation of supplies and logistical difficulties, which may negatively affect the living conditions of disaster victims. Therefore, locating temporary shelters close to main warehouses plays a critical role in the effectiveness of post-disaster response and recovery processes (Chen et al., 2013; Gharib et al., 2022; Nappi et al., 2019; Nappi & Souza, 2015).

Case Study and Clustering Results for Temporary Shelter Site Selection

This study focuses on post-earthquake landslide risk in districts on Istanbul's European side, specifically identifying Büyükçekmece as the most at-risk area due to its status as an active landslide region with high risk. A total of 134 gathering sites across all neighborhoods in Büyükçekmece were initially considered. Data are sourced from the Büyükçekmece Municipality's Urban Automation Systems (KEOS). Following preliminary filtering based on the February 17, 2023 "Standards for Temporary Shelter Areas" by the Turkish Chamber of Engineers and Architects, which requires sites to be larger than 500 m², 132 gathering sites remained for further analysis (Geçici Barınma Alanlarına İlişkin Standartlar, 2023). The first five rows of the sites are shown in Table 2. For all remaining entries, refer to Appendix A.

Table 2

Literature review of the secondary disaster and study areas

No	Neighboorhood	Location Name	Area (m²)
1	19 Mayıs	Çanakkale Şehitleri Anafartalar Parkı	3300
2	19 Mayıs	Atatürk Spor Kompleksi	101106
3	19 Mayıs	Nineteen Mayıs Mahallesi Parkı (Avcılar Kulübü)	4966
4	19 Mayıs	19 Mayıs Ortaokulu Bahçesi	13015.5
5	19 Mayıs	Demet Caddesi ve Tabya Caddesi Kesişimi Yeşil Alan	4272

The identified areas were then labeled in Google Earth Pro (7.3) (Figure 1). Factor data are collected with the help of this program.

Figure 1

Post-disaster assembly areas in the Büyükçekmece district

Obtaining the Data Set

In this section, it is explained in detail how the factor data for 132 assembly areas are collected and which sources are used. Of the total 10 factors used, 5 (Height / Altitude, Distance to landslide boundary, Distance to Fault Line, Peak Ground Acceleration (PGA), Soil Class) are factors related to post-earthquake landslide risk. The other 5 factors (Number of Households Needing Temporary Shelter at Night, Population Density at Night, Distance to Drinking Water, Distance to Main Road, Distance to Main Warehouse) are the factors required for the establishment of temporary shelter (Chen et al., 2013; Gharib et al., 2022; Nappi et al., 2019; Nappi & Souza, 2015).

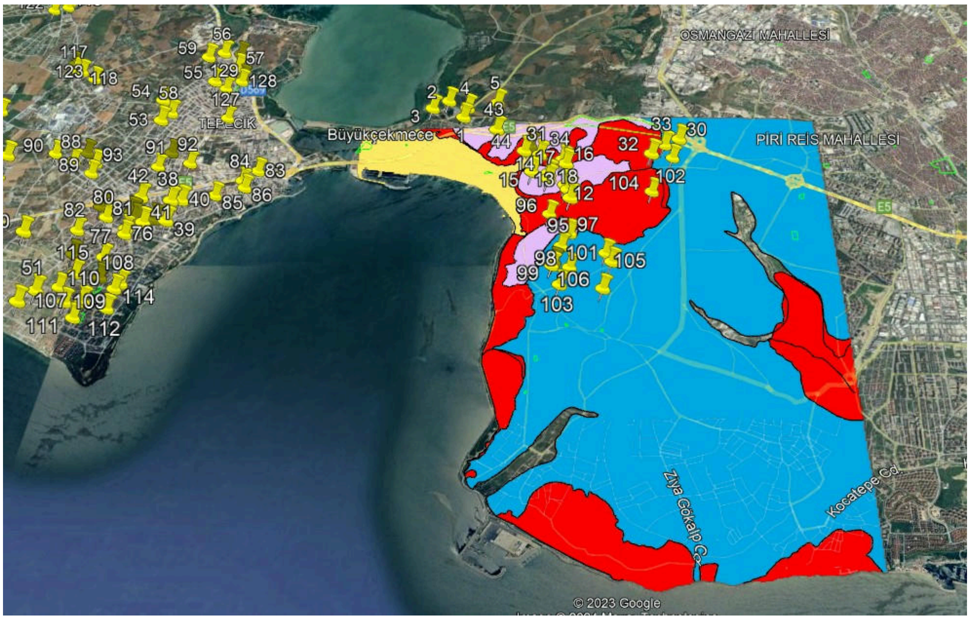
Elevation/Altitude: The Height/Altitude values of each collection point are calculated in meters using Google Earth Pro, considering the values determined in the application.

Distance to the landslide boundary: The Google Earth Pro application was used to calculate the values for this criterion. The values of the pre-existing landslide areas and landslide area boundaries in the Büyükçekmece district are provided by the Istanbul Metropolitan Municipality (IBB). The landslide area and boundaries are shown in Figure 2. The IMM divided the landslide risk areas into 4 groups in its study in the neighborhoods located east of Büyükçekmece.

The areas shown in red are indicated as dangerous landslide areas. The distance from the assembly areas to the ones inside these areas is determined as 0 km. Those outside the area are determined by their distance from the borders of this region. The areas shown in pink are indicated as medium-risk landslide areas. The areas shown in yellow are designated as stable landslide areas. Areas shown in blue are indicated as non-hazardous landslide areas. The distance to the landslide boundary criterion for all assembly areas is obtained by measuring the distance to these areas in meters.

Figure 2

Landslide areas and their boundaries in the Büyükçekmece district

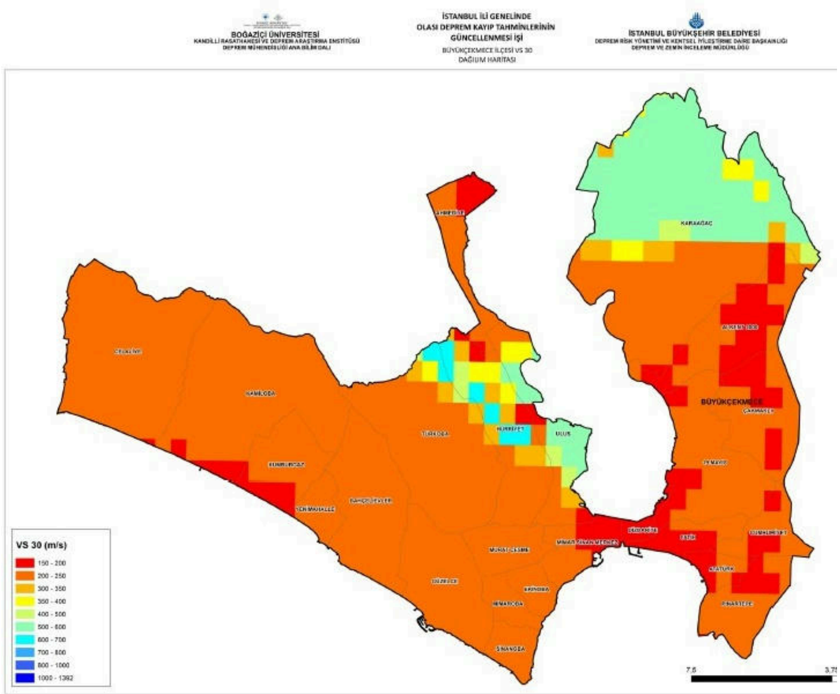


Distance to Fault Line: For the distances to the fault line passing through the south of the Büyükçekmece district, the "List of 1/25.000 Scale Digital Fault Maps" was obtained from the General Directorate of Mineral Research and Exploration (MTA General Directorate, n.d.). The file obtained from here is placed on Google Earth Pro, and the distance to each gathering point is measured in kilometers.

Soil Class: For the soil class of the designated assembly areas, the district "Possible Earthquake Loss Estimates Booklet" prepared by IMM and Kandilli Observatory is utilized (Earthquake and Soil Investigation Directorate, n.d.). The map shown in Figure 3 illustrates the ground conditions of the Büyükçekmece district.

Figure 3

Büyükçekmece district ground conditions



It is looked at according to the values in the range corresponding to the VS30 value determined on the map. For each of these ranges, there is a Ground Class equivalent. Soil class equivalents were evaluated according to their equivalents in the supplementary document "Principles for the Design of Buildings Under Earthquake Effects" published in the Official Gazette. Table 3 shows the soil classes and their equivalents.

Table 3

Local Soil classes

Local Soil Class	Soil Class	VS 30 [m/s]	Color Codes
ZA	Solid, hard rocks	>1500	Navy Blue
ZB	Slightly weathered, moderately intact rocks	760-1500	Blue, Dark Blue
ZC	Very tight layers of sand, gravel and hard clay or weathered, weak rocks with many cracks	360-760	Orange, Yellow, Light Green, Turquoise, Blue
ZD	Medium dense-dense layers of sand, gravel or very solid clay	180-360	Dark orange
ZE	Loose sand, gravel, or soft to solid clay layers	<180	Red

PGA: After the soil class values are determined, the peak ground acceleration of each gathering point is calculated with the help of these values. The latitude and longitude coordinates of each point are entered into the AFAD-Turkey Earthquake Hazard Maps Interactive Web Application. Here, the earthquake ground motion level is determined as DD-2 for Büyükçekmece. The values of each point were calculated by entering the soil class, and the PGA values of the gathering points were obtained.

Number of Households in Need of Temporary Shelter at Night: When estimating the loss of life and injuries that may occur in a major earthquake that may affect Istanbul, it is necessary to utilize data from earthquakes that have caused damage and losses in metropolitan areas. The closest example in Turkey is the 1999 Kocaeli earthquake. It is appropriate to develop a model similar to the 1999 Kocaeli earthquake to estimate the loss of life and different injury levels that may occur because of a scenario earthquake for Istanbul. Since the 1999 Kocaeli earthquake occurred at 03.02 a.m. local time, the model will primarily be suitable for the night earthquake scenario (Earthquake and Soil Investigation Directorate, n.d.). For the data on the number of households needing shelter at night, the district "Possible Earthquake Loss Estimations Booklet" prepared by IBB and Kandilli Observatory was used (Earthquake and Soil Investigation Directorate, n.d.). Based on the values given in Table 4, the gathering areas in the neighborhoods are divided among the gathering areas according to the square meter area.

Table 4

Number of Neighborhood-Based Values of Temporary Shelter Needs in the Büyükçekmece District for Mw=7.5 Scenario Earthquake

Neighborhood Name	Number of Households in Need of Temporary Shelter
19 MAYIS	818
AHMEDIYE	117
ALKENT 2000	406
ATATÜRK	1933
BAHÇELIEVLER	579
CELALIYE	471
CUMHURIYET	631
ÇAKMAKLI	430
DIZDARIYE	818
EKINOBA	1061
FATIH	1920
GÜZELCE	1076
HÜRRIYET	1902
KAMILOBA	549
KARAAGAÇ	227
KUMBURGAZ	801
MIMAR SINAN MERKEZ	967
MIMAROBA	1453
MURAT ÇESME	1423
PINARTEPE	1849
SINANOBA	1681
TÜRKOBA	1216
ULUS	1732
YENIMAHALLE	238
TOPLAM	**24298**

Night Population Density: For the Night Population Density of the designated assembly areas, the district "Possible Earthquake Loss Estimates Booklet" prepared by IMM and Kandilli Observatory is utilized (Earthquake and Soil Investigation Directorate, n.d.). The map in Figure 4 shows the night population density distribution of the Büyükçekmece district. The variables are expressed categorically here.

Category 1: 0-2000

Category 2: 2001-5000

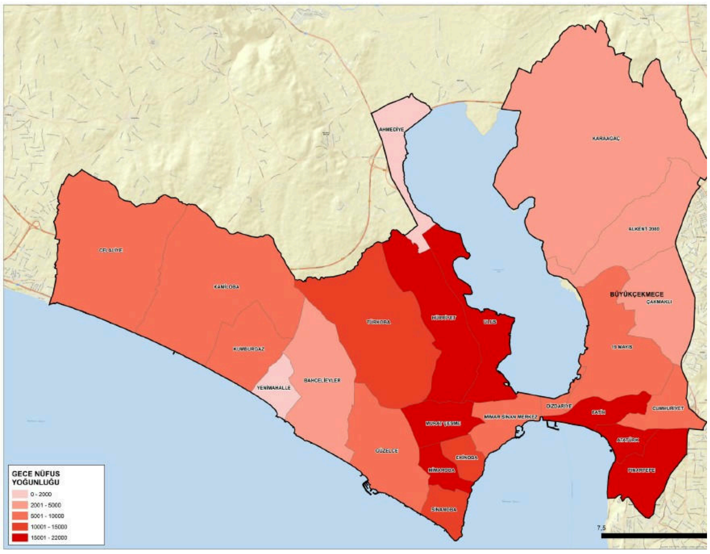
Category 3: 5001-10000

Category 4: 10001-15000

Category 5: 15001-22000

Figure 4

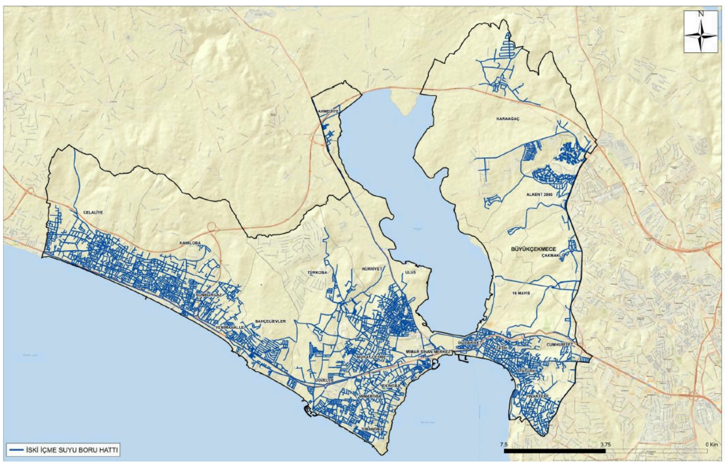
Büyükçekmece district Night Population Density Distribution



Distance to Drinking Water: For the calculation of the Distance to Drinking Water of the designated assembly areas, the district "Possible Earthquake Loss Estimates Booklet" prepared by IMM and Kandilli Observatory is utilized (Earthquake and Ground Investigation Directorate, n.d.). The map shown in Figure 5 shows the distribution of the ISKI drinking water pipelines in the Büyükçekmece district.

Figure 5

Büyükçekmece District ISKI Drinking Water Pipeline Distribution



This map is projected on Google Earth Pro and the Night Population Density classes of the 132 marked gathering areas are determined. The distance to the drinking water pipeline passing closest to the points identified here is calculated in meters using the measurement feature of the application.

Distance to Main Roads: The main roads considered for the Büyükçekmece municipality are the E-80, E-5, and D100 highways located to the north and south. The distance from each point to the nearest highway was measured with the help of Google Earth Pro.

Distance to the main depot: A predefined main depot is used for the distribution of aid, food, and other essential supplies in temporary shelter areas. For this study, the Büyükçekmece Port was selected as the main depot. Distances to the depot were measured using Google Earth Pro.

Table 5

Factor Characteristics of Gathering Sites in Büyükçekmece Municipality

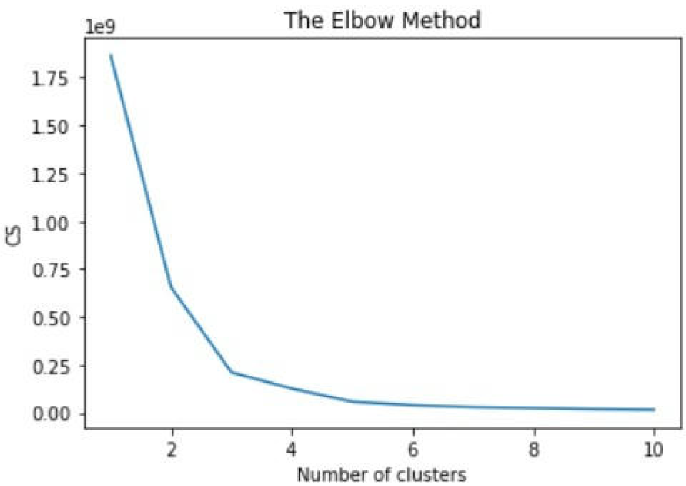
Neighborhood Name	Number of Households in Need of Temporary Shelter
19 MAYIS	818
AHMEDIYE	117
ALKENT 2000	406
ATATÜRK	1933
BAHÇELIEVLER	579
CELALIYE	471
CUMHURIYET	631
ÇAKMAKLI	430
DIZDARIYE	818
EKINOBA	1061
FATIH	1920
GÜZELCE	1076
HÜRRIYET	1902
KAMILOBA	549
KARAAGAÇ	227
KUMBURGAZ	801
MIMAR SINAN MERKEZ	967
MIMAROBA	1453
MURAT ÇESME	1423
PINARTEPE	1849
SINANOBA	1681
TÜRKOBA	1216
ULUS	1732
YENIMAHALLE	238
TOPLAM	

Cluster Analysis

In this section, after preparing the relevant dataset, analyses are conducted using the selected clustering methods. The input for these methods consisted of the defined factors, and the output provided cluster classifications for each gathering site. The analyses included k-means clustering with 3, 4, and 5 clusters, as well as hierarchical clustering with the same cluster numbers. For k-means clustering, the potential cluster values were first determined using the Elbow method, as shown in Figure 6, identifying 3, 4, and 5 as the optimal values for k.

Figure 6

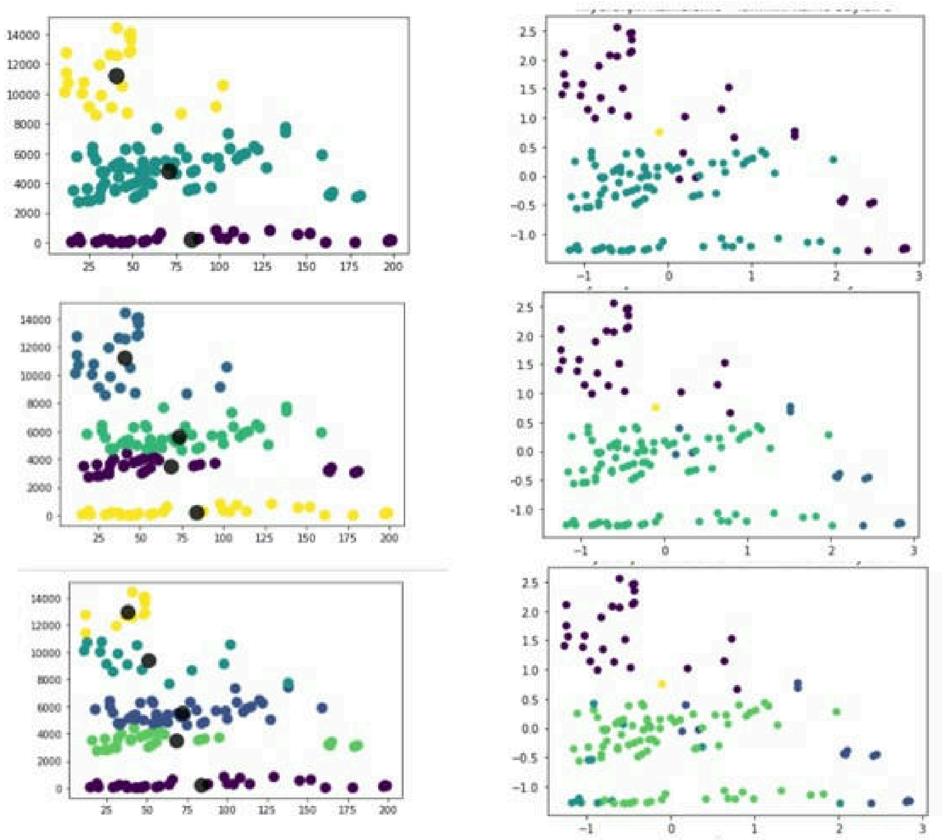
Elbow Method for Determining Potential Number of Clusters



Clustering analyses were conducted using 3, 4, and 5 clusters for both methods to facilitate easier comparison. The clustering results are shown in Figure 7. In the first column, the clusters calculated using k-means for k=3, k=4, and k=5 are displayed, while the second column presents the corresponding results for hierarchical clustering.

Figure 7

Clustering Visualization for K-Means with 3, 4, and 5 Clusters and Hierarchical Clustering



When analyzing all clusters collectively, only 3 of the 132 gathering sites were assigned to different clusters. As shown in Table 6, the Silhouette validity index is calculated for both algorithms, and the clustering method with the highest Silhouette index is selected. The Silhouette index, widely used in the literature as an internal clustering validation criterion (Cheng et al., 2018), evaluates clustering results by averaging the validity of individual samples while disregarding shared characteristics across all elements.

Table 6

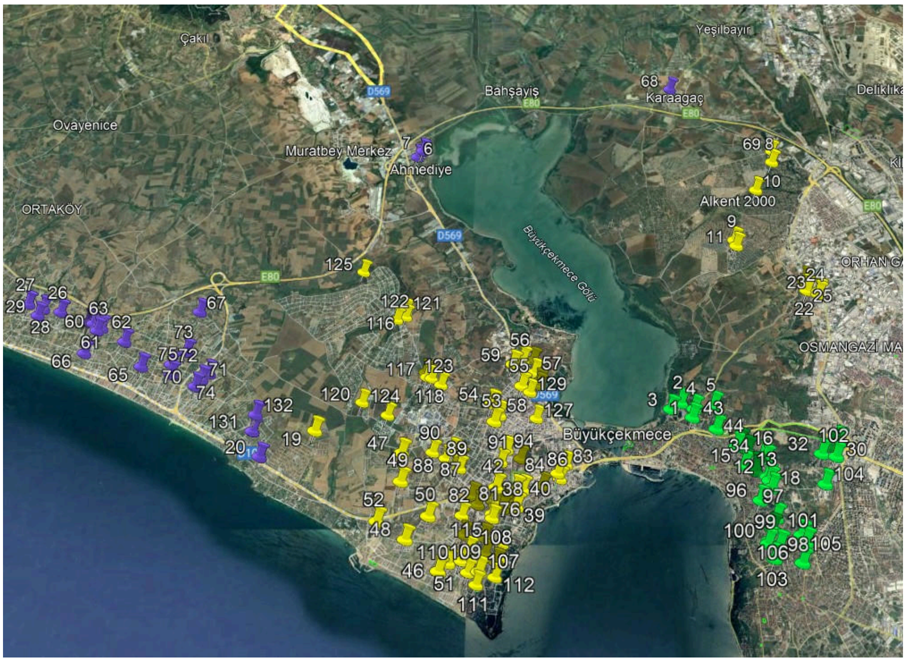
Silhouette Validity Index Values

Silhouette Validity Index Values			
No. of the Cluster	**k=3**	**k=4**	**k=5**
k-means	**0.68**	0.65	0.66
Hierarchical Clustering	0.11	0.01	-0.02

Based on these results, the most suitable method is the k-means clustering with k=3. All neighborhoods within the clusters are displayed on the Büyükçekmece district map in Figure 8.

Figure 8

Clustered gathering sites for the Büyükçekmece District



Conclusion and Discussion

This study proposed a clustering-based framework for identifying suitable temporary shelter sites in post-earthquake landslide-prone regions, with a case study focused on the Büyükçekmece district of Istanbul. By integrating multiple spatial and risk-related factors, the research aimed to support data-driven decision-making in disaster preparedness and emergency planning.

The analysis employed both k-means and hierarchical clustering methods to group 132 potential gathering sites based on ten critical criteria related to landslide risk and shelter suitability. Among the tested methods, the k-means clustering algorithm with $k = 3$ yielded the highest Silhouette index and was identified as the most appropriate technique. The resulting clusters were categorized as high, moderate, and low landslide risk areas, offering valuable insights into the spatial distribution of shelter suitability across the district.

The factors used in this study are primarily sourced from literature and include subjective elements, which can be considered a limitation. While these factors strengthen the theoretical foundation and maintain consistency with previous research, they may restrict the study's applicability. The data limitations of this study primarily stem from the availability and accuracy of spatial data, as the precision of site selection depends on up-to-date information regarding topography, land use, infrastructure, and disaster risk zones. Additionally, uncertainty in disaster risk predictions, particularly for secondary hazards like landslides after earthquakes, poses a challenge because historical records may not fully reflect future scenarios influenced by climate change or urban expansion. Furthermore, the use of MCDM techniques introduces subjectivity in the weighting of criteria, as expert opinions may influence priority rankings rather than relying solely on data-driven methods. To mitigate these limitations, a broader literature review and the integration of data from diverse sources are recommended. This approach would enhance the study's scope and generalizability of the factors. Additionally, employing systematic and transparent methods for factor selection could minimize subjective influences and improve reliability. Being aware of these limitations and addressing them with appropriate measures can significantly enhance the study's scientific contribution and practical applications.

Future research should aim to improve the objectivity of factor selection by incorporating data-driven methods and real-time datasets such as satellite imagery, sensor networks, and GIS-based monitoring tools. Furthermore, expanding the study to include other districts or hazard types (e.g., flooding, fire) would enhance the generalizability of the proposed framework. Lastly, scenario-based simulations for shelter routing and resource allocation within the most at-risk cluster could significantly strengthen operational disaster planning and response efficiency.

In conclusion, this study contributes a replicable and adaptable methodology for temporary shelter planning in regions facing compound disaster risks and offers strategic guidance for policymakers and disaster management professionals working in similar urban contexts.

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Appendix

appendix 1

Table 2 Büyükçekmece district post-disaster gathering area information

No	Neighboorhood	Location Name	Area (m²)
1	19 Mayıs	Çanakkale Şehitleri Anafartalar Parkı	3300
2	19 Mayıs	Atatürk Spor Kompleksi	101106
3	19 Mayıs	Nineteen Mayıs Mahallesi Parkı (Avcılar Kulübü)	4966
4	19 Mayıs	19 Mayıs Ortaokulu Bahçesi	13015.5
5	19 Mayıs	Demet Caddesi ve Tabya Caddesi Kesişimi Yeşil Alan	4272
6	AHMEDİYE	Ahmediye Meydan	699.5
7	AHMEDİYE	Ahmediye Parkı	1406
8	ALKENT 2000	Alkent 2000 Yeşil Alan	61290
9	ALKENT 2000	Alkev Özel Okulları Bahçesi	22702
10	ALKENT 2000	Alkent 2000 Yüzme Havuzu Parkı	15490
11	ALKENT 2000	MEV Koleji Özel Büyükçekmece İlkokulu Bahçesi	32079
12	ATATÜRK	60lıklar Parkı	2091
13	ATATÜRK	Atatürk İlkokulu Bahçesi	3948
14	ATATÜRK	Hayriye Duruk Kız Meslek Lisesi Bahçesi	4638
15	ATATÜRK	Pembe Panter Parkı	3262
16	ATATÜRK	Yeşiltepe Cami Bahçesi	3571.5
17	ATATÜRK	Alev Sokak Parkı	2394.5
18	ATATÜRK	Serinpınar Parkı Üstü Yeşil Alan	2403.5
19	BAHÇELİEVLER	Ahmet Yesevi Cad. Yeşil Alan	10981
20	BAHÇELİEVLER	Bülbül 4 Sk. Parkı	2379
21	ÇAKMAKLI	Alkent 2000 Anaokulu Bahçesi	1491.5
22	ÇAKMAKLI	Hastürk Caddesi Parkı	5162.5
23	ÇAKMAKLI	(172/1 VE 172/2 Parsel) Sağlık Ocağı Bahçesi	2748
24	ÇAKMAKLI	Çakmaklı Cumhuriyet Ortaokulu Bahçesi	4656.5
25	ÇAKMAKLI	Çakmaklı Cami Bahçesi	2261
26	CELALİYE	Celaliye Halk Akademisi Bahçesi (TRANSFER ALANDIRI.)	8538
27	CELALİYE	Lodos Sokak Parkı	1119.5
28	CELALİYE	Celaliye İstasyon Caddesi Parkı	1009.5
29	CELALİYE	Yahya Kemal Sosyal Tesisleri (Eski İsmi Baki Sk. Parkı)	14156

No	Neighboorhood	Location Name	Area (m²)
30	CUMHURİYET	Recep Güngör Anadolu Lisesi Bahçesi	3504.5
31	CUMHURİYET	Bülent Sokak Çocuk Bahçesi	701
32	CUMHURİYET	Büyükçekmece Belediyesi Beykent Garaj Alanı	3256.5
33	CUMHURİYET	Çoruh Sokak Parkı	869
34	CUMHURİYET	Mesut Sokak Parkı	936.5
35	EKİNOBA	Ekinoba Pazar Yeri	4540
36	EKİNOBA	19 Mayıs Gençlik Parkı	3627
37	EKİNOBA	Efeler Sokak Yeşil Alan	3670
38	EKİNOBA	Hazar Sokak Parkı	888.5
39	EKİNOBA	Kahraman Orkun Kaya Spor Tesisleri Bahçesi	8238
40	EKİNOBA	Münir Özkul Park	1529
41	EKİNOBA	Salih Bozok Parkı	8297.5
42	EKİNOBA	Turan Sokak Parkı	4289
43	FATİH	Ali Efendi Sk. Parkı	1742.5
44	FATİH	75.Yıl Parkı	3337.5
45	FATİH	Sedir Sokak Parkı	2015.5
46	GÜZELCE	Vatan 1 Sokak Parkı	576
47	GÜZELCE	Güzelce Türkoba Cad. Parkı	1702.5
48	GÜZELCE	İfakat Genç Parkı	3570
49	GÜZELCE	Hacıbektaş-ı Veli Parkı	2989
50	GÜZELCE	Orhan Kotan Parkı	1945.5
51	GÜZELCE	Medeni Sokak Parkı	1291
52	GÜZELCE	Güzelce Kapalı Pazar Yeri (TRANSFER ALANIDIR.)	25621
53	HÜRRİYET	İSKİ Hizmet Alanı	13205
54	HÜRRİYET	Tepecik Tozkoparan Parkı	1008
55	HÜRRİYET	Ayazma Parkı	3773.5
56	HÜRRİYET	Ahmet Mithat Caddesi Parkı	3692.5
57	HÜRRİYET	Tepecik TEİAŞ Parkı	5464.5
58	HÜRRİYET	Reyhan Parkı	1186
59	HÜRRİYET	Osmanbaşı Cami Bahçesi	2426.5
60	KAMİLOBA	Fethi Alpay Parkı	2262
61	KAMİLOBA	Fırın Sokak Parkı	1163.5
62	KAMİLOBA	Gökhan Kurtulmuş Parkı	1100.5
63	KAMİLOBA	Kamiloba Stadı	8903.5
64	KAMİLOBA	Köyiçi Parkı	1073
65	KAMİLOBA	Kümeevler Parkı	952.5
66	KAMİLOBA	Nebil Eşen Parkı	1517
67	KAMİLOBA	Zeytinsuyu Parkı	4320
68	KARAAĞAÇ	Karaağaç Şenlik Parkı	2749.5

No	Neighboorhood	Location Name	Area (m²)
69	KARAAĞAÇ	İstanbul Üniversitesi Kampüs Altı Yeşil Alan-Otopark	34578
70	KUMBURGAZ	Karakol Caddesi Parkı	3689.5
71	KUMBURGAZ	Kadir Topbaş Parkı	4760
72	KUMBURGAZ	Yasa Sokak Parkı	2829.5
73	KUMBURGAZ	Kuvayi Milliye Okul Bahçesi	7409
74	KUMBURGAZ	Kumburgaz Turizm Otelcilik Meslek Lisesi Yan Bahçesi	15228.5
75	KUMBURGAZ	Sağlıklı Yaşam Parkı	1605.5
76	MİMAROBA	Barış Sokak Parkı	4993.47
77	MİMAROBA	Büyük Atatürk Parkı (TRANSFER ALANIDIR.)	83594.5
78	MİMAROBA	Füsun Sokak Parkı	1704.5
79	MİMAROBA	Mehtap Sokak 1 Parkı	6913
80	MİMAROBA	Orçelik Parkı	3916
81	MİMAROBA	Papatya Sokak Parkı.	1734.5
82	MİMAROBA	Halide Edip Adıvar Parkı	3947
83	MİMARSİNAN	Mimarsinan Stadyumu	7104
84	MİMARSİNAN	Dilara Sokak Parkı	1065.5
85	MİMARSİNAN	Halide Edip Adıvar Parkı	991.5
86	MİMARSİNAN	Mimar Sinan İlkokulu Ve Ortaokulu Bahçesi	9702.5
87	MURAT ÇESME	Ahmet Yesevi Parkı (Eski Ömür Sk. Parkı)	8171
88	MURAT ÇESME	Engelliler Eğitim Merkezi Bahçesi	6275.5
89	MURAT ÇESME	Erdal Çiçek Parkı	2567
90	MURAT ÇESME	Şehit Sadık Bezer Parkı	4006.5
91	MURAT ÇESME	Gazanfer Sokak Parkı	885.5
92	MURAT ÇESME	İhramcızade Cami Bahçesi	4183.5
93	MURAT ÇESME	Çiltaş Sokak Parkı	1670.5
94	MURAT ÇESME	Nasrettin Hoca Parkı	1281
95	PINARTEPE	Ateş Sokak Parkı ve Hazreti Osman Cami Bahçesi	5104.5
96	PINARTEPE	Esin 1 Sokak Parkı	1237
97	PINARTEPE	Dr. Sadık Ahmet Parkı	8010
98	PINARTEPE	Köykent Parkı	3274
99	PINARTEPE	Pınartepe Ortaokulu Bahçesi	3780
100	PINARTEPE	Pınartepe Ortaokulu Otopark Alanı	1953
101	PINARTEPE	Prof. Dr. Ali Akyüz Parkı	1486
102	PINARTEPE	Beykent Fatih Koleji Bahçesi	12101.76
103	PINARTEPE	Belediye Parkı	11429.5

No	Neighboorhood	Location Name	Area (m²)
104	PINARTEPE	Akyurt Caddesi Sosyal Tesisler Bahçesi	43428
105	PINARTEPE	Alamara Sanat Merkezi Bahçesi	1798
106	PINARTEPE	Fırtına Sokak Parkı	1992.5
107	SİNANOBA	Lozan Parkı (TRANSFER ALANIDIR.)	43090.5
108	SİNANOBA	Tarık Akan Parkı	4493.5
109	SİNANOBA	Aktay Caddesi Parkı	8441.5
110	SİNANOBA	Akkor Sokak Parkı	3051
111	SİNANOBA	Yalçın Çiftçioğlu İlkokulu Yanı Parkı	6122
112	SİNANOBA	Güzergah Sokak Parkı	6038.5
113	SİNANOBA	Prof. Dr. Aziz Sancar Nobel Parkı (Eski İsmi Fazıl Ört Parkı)	16671.5
114	SİNANOBA	Lavinya Parkı	1460
115	SİNANOBA	Zülfü Livaneli Kültür ve Sanat Merkezi Bahçesi	4410.5
116	TÜRKOBA	Bahadır Demir Ortaokulu Bahçesi	4958
117	TÜRKOBA	Türkoaba Meydanı	617
118	TÜRKOBA	Türkoba İlkokulu Bahçesi	7386
119	TÜRKOBA	Türkoba Parkı	1324
120	TÜRKOBA	Mimar Turgut Cansever Ortaokulu Bahçesi	7736
121	TÜRKOBA	Bahardır Demir Ortaokulu Yanı Yeşil Alan	16228.5
122	TÜRKOBA	Nene Hatun Parkı (Eski Cennetin Gözü Parkı)	76760
123	TÜRKOBA	Zeynel Abidin Cami Arkası	4423.5
124	TÜRKOBA	Tepekent Borsa Anadolu Lisesi Bahçesi	6284
125	TÜRKOBA	Tepekent Çevresi Yeşil Alanlar	135283.5
126	ULUS	Nejat Uygur Kültür Merkezi Bahçesi (TRANSFER ALANIDIR.)	4572.03
127	ULUS	Ulus Parkı	3331
128	ULUS	Tepecik İmam Hatip Ortaokulu Bahçesi	9967
129	ULUS	Tepecik Meydan	1386
130	ULUS	Aşık Veysel Sosyal Tesisi	13890.5
131	YENİMAHALLE	Rüya Caddesi Parkı	704.5
132	YENİMAHALLE	Kumburgaz Mehmet Erçağ Anadolu Lisesi Bahçesi	7103