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ORIGINAL PAPER

A GIS-RANCOM integrated methodology for post-disaster debris waste storage site selection problem

M. F. Uzun[1] · Ö. N. Bilişik[1] · H. Baraçlı[1]

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Abstract
In the context of disaster management systems, effective waste management processes represent a critical component in terms of environmental sustainability, public health, occupational health, and safety. The objective of the present study is to ascertain the most suitable locations for the provisional storage of debris waste that will be generated following a severe and destructive earthquake for the city of Istanbul, which is highly susceptible to seismic activity, to minimize the financial costs of waste management and the harmful effects of waste. This study integrates geographic information systems (GIS) with the RANking Comparison Method (RANCOM), a multi-criteria decision-making (MCDM) method. The most suitable candidate sites for temporary storage areas (TSAs) for debris waste were determined based on criteria established in accordance with expert opinions, literature studies, and guidelines prepared by international organizations such as the United Nations (UN), the United States Federal Emergency Management Agency (FEMA), and the Environmental Protection Agency (EPA). 15 potential TSAs were identified for the entire Istanbul Province based on expert opinions regarding the specified criteria. In the accuracy assessment of the GIS-based maps obtained, the overall accuracy was calculated as 92%, with a kappa value of 0.94. It is assumed that the developed hybrid methodology can be applied to all other disaster scenarios.

Keywords Disaster waste management · Temporary storage sites · Earthquake waste · Debris waste · The expected Istanbul earthquake · Multi criteria decision method

Introduction

Waste management is a critical component of disaster management, particularly in ensuring environmental sustainability, public health, and occupational safety. Effective disaster waste management requires a comprehensive and integrated approach covering all stages from waste generation to final disposal (Tabata et al. 2019).

Such an approach should include waste planning and control, estimation of waste quantity and composition under disaster conditions based on expert judgment (Sakai et al. 2013), collection and transportation logistics, and selection of appropriate treatment and disposal methods in accordance with environmental and public health legislation.

Preparedness and pre-disaster planning play a key role in enabling effective disaster waste management (Boonmee et al. 2018; Tajima et al. 2014). In this context, recycling and reuse constitute fundamental components of debris management, offering significant environmental, economic, and social benefits (Jalloul et al. 2022).

Hazardous waste generated after disasters must be rapidly removed from residential areas and transported to TSAs for sorting, pre-treatment, recycling, reuse, or final disposal (Ministry of the Environment Japan 2018). International best practices demonstrate the importance of such systems; for example, following the 2016 Kumamoto earthquake in Japan, disaster waste was managed through temporary and secondary storage sites integrated with recycling processes (Saffarzadeh et al. 2016; Sakai et al. 2019).

Figure 1 illustrates the disaster waste management process schematically.

Debris management strategies begin with forecasting debris volume using historical data and prediction models. Following this process, a two-phase collection plan is implemented:

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✉ Ö. N. Bilişik
oznalan@yildiz.edu.tr

[1] Department of Industrial Engineering, Yildiz Technical University, 34349 Besiktas-Istanbul, Turkey

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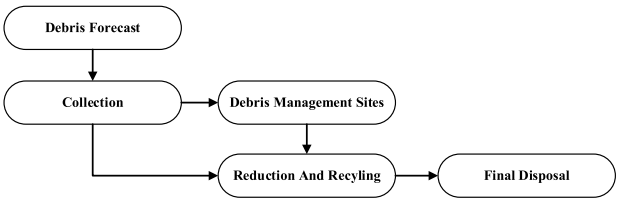

Fig. 1 Components of a debris waste management system (FEMA 2007)

- During the response phase, emergency access routes are opened immediately after the disaster.
- During the recovery phase, once transportation routes are opened, individuals return to their homes and debris is moved to public areas.

When direct transportation to disposal facilities is not feasible, TSAs provide essential operational flexibility through temporary storage, volume reduction, separation, and processing of debris, particularly when disposal facilities are distant or insufficient (FEMA 2007). An effective debris management plan should therefore incorporate systematic transportation of waste to TSAs and on-site volume reduction processes (Hahashi and Katsumi 1996). The separation of recyclable materials such as wood, metal, glass, plastics, and electronic waste reduces hazardous waste volumes and minimizes the amount of waste requiring final disposal (Söder and Müller 2011). Pre-identifying TSAs significantly accelerates emergency response and recovery efforts while offering cost, logistical, and environmental advantages (Kim et al. 2014; Gabrielli et al. 2018).

The main criteria to be considered in determining TSAs are as follows:

- The area should be of sufficient size and have suitable topography and soil structure.
- This area should be located at a safe distance from drinking water sources and water bodies such as lakes, rivers, and streams.
- Areas with high flood risk or wetlands should be avoided.
- It should be located away from ecologically sensitive areas.
- It should not damage areas of historical or cultural significance.
- It should have preventive systems against erosion, surface runoff, dust formation, and fire risk.
- It should be free of infrastructure obstacles such as power lines and pipelines.
- Heavy machinery should have easy access to these areas.
- They should be located at a sufficient distance from residential areas and should not cause noise, odor, or traffic problems (EPA 2019).
- Public land should be preferred where possible; if suitable public land is not available, private property should be considered (MSP/EMHSD 2008).

Based on the literature review, the studies examined have been classified into three methodological groups. The grouping is as follows: GIS-based, MCDM-based, and optimization/hybrid approaches.

While GIS-based models emphasize spatial suitability and mapping efficiency, MCDM studies focus on weighting various environmental, social, and logistical suitability criteria and decision consistency; other hybrid optimization approaches aim to increase operational efficiency.

Table 1 summarizes literature review on the location selection of temporary storage areas for disaster waste according to the defined methodological classification.

Studies in the first group use GIS-based methodologies. Following the Great East Japan Earthquake on March 11, 2011, Kishimoto et al. (2017) developed a GIS-supported site selection model for Shizuoka Prefecture that identified suitable candidate sites based on land suitability, secondary disaster risks, and site conditions. In another GIS-based study, the pre-determination of potential disaster areas (PDAs) in Hamilton County, Indiana, was carried out for multiple disaster scenarios using Binomial Cluster Analysis (Grzeda et al. 2014). The studies in this group were conducted using spatial analysis tools.

TSA selection is a MCDM problem requiring consideration of numerous constraints and variables (Habib and Sarkar 2017). In such spatial decision problems, GIS and MCDM offer significant advantages to decision-makers (Bilgilioglu and Gezgin 2022). The second group examines studies conducted using hybrid methodologies based on MCDM methods. For example, Lontoc et al. (2023) combined GIS and MCDM methods (Boolean Logic) to determine TSAs for a flood scenario in the Cavite region of the Philippines based on defined criteria. Similarly, Cheng and Thompson (2016) identified 45 candidate TSAs using GIS and standardized the criteria layers using Boolean logic. Lee et al. (2022) developed a multi-criteria GIS-based decision support model for selecting temporary disaster waste management sites under post-flood conditions in Seoul, South Korea, proposing a framework that enhances site suitability and strengthens resilience in urban planning. The framework focuses on post-flood conditions and also considers potential constraints on vehicle access and transportation based on flood depths and road widths. As seen in the studies in this group, multiple MCDM methods are used together.

Another group consists of optimization-based hybrid models. Nickdoost et al. (2022) determined the most suitable TSAs after Hurricane Michael in Florida using GIS-supported analyses with the AnyLogic Optimization engine. This study developed an integrated planning

Table 1 Grouped literature on TSA site selection methodologies

Methodological Group	References	Study focus	Disaster type	Main methodology / Tool
1-GIS-based Approaches	Kishimoto et al. (2017)	Modelling site selection of temporary yards for disaster waste treatment in Japan	Earthquake	GIS
	Grzeda et al. (2014)	Identifying temporary debris sites using binomial cluster analysis and GIS	Tornado, flood, wildfire	GIS + Cluster analysis
2-MCDM-based Approaches (Hybrid)	Lontoc et al. (2023)	Multi-criteria evaluation of suitable TSA locations in the Philippines	Flooding	GIS + Boolean logic
	Cheng and Thompson (2016)	Determining suitable TSA locations using GIS and Boolean logic	Bushfire	GIS + Boolean logic
	Habib and Sarkar (2017)	Integrated model for temporary debris management under uncertainty	Hurricane	ANP + Fuzzy TOPSIS
	Lee et al. (2022)	Framework for post-flood recovery site selection in South Korea	Flooding	Multi-criteria GIS analysis
	Demir and Dinçer (2023)	To determine optimal TSA using a GIS-integrated emission-based approach	Earthquake	GIS + MCDM (AHP-TOPSIS)
3-Optimization and Hybrid Approaches	Nickdoost et al. (2022)	Integrated framework for debris management and logistics planning	Hurricane	GIS + AnyLogic optimization
	Wang et al. (2019)	Optimization of temporary debris site selection for removal efficiency	–	Multiple-Objective Debris Removal Optimization Model
	Onan et al. (2015)	Multi-objective optimization for disaster waste management (Istanbul)	Earthquake	NSGA-II algorithm
	Kim et al. (2014)	Selecting effective debris management sites using dynamic simulation	Hurricane	HAZUS-MH + PDNA + GIS
	Montoya et al. (2021)	Location of temporary site for earthquake waste separation	Earthquake	Transportation Model (MILP)

framework that minimizes debris collection time and negative impacts on the community. In another study, a multi-objective mixed-integer linear model (Multiple-Objective Debris Removal Optimization Model) was developed to optimize TSA selection, minimizing debris removal costs, time, and environmental impact while maximizing recycling gains (Wang et al. 2019).

Kim et al. (2014) propose an original method for determining the optimal locations of TSAs to accelerate the post-disaster debris removal process using a dynamic simulation model that integrates HAZUS-MH, PDNA, and GIS data.

Following the 2017 Mexico earthquake, Montoya et al. (2021) optimized TSA selection using a transportation model based on Mixed Integer Linear Programming.

Looking at studies conducted in Turkey, following the Kahramanmaraş earthquakes, an integrated GIS-MCDM (AHP-TOPSIS) algorithm was developed using an emission-sensitive approach to determine TSAs (Demir and Dinçer 2023).

For Istanbul's European Side, Onan (2013) developed a GIS-supported multi-purpose optimization model due to the area's high earthquake risk and dense population. The model plans TSA selection using the NSGA-II algorithm.

According to the "Updating of Potential Earthquake Loss Estimates" study conducted in 2019 by the Istanbul Metropolitan Municipality in collaboration with the Kandilli Observatory, a large portion of the approximately 1,166,000 buildings in Istanbul are at high risk from seismic hazards. In a scenario involving a 7.5 magnitude earthquake,

approximately 194,000 buildings are expected to suffer moderate to severe damage, while 48,000 buildings are expected to suffer heavy or very heavy damage. This scenario would result in serious loss of life as well as a large amount of debris. According to estimates, approximately 25 million tons of debris are expected to be generated. It is anticipated that removing this volume of waste will take at least two years and that transporting it outside the city will cause significant logistical and environmental problems. Therefore, comprehensive planning is essential regarding how, when, and by what methods the debris will be managed (Istanbul Metropolitan Municipality 2019).

This study explores current debris management practices in Istanbul and proposes a comprehensive framework for the systematic, environmentally friendly, and economically sustainable management of waste in the event of a potential disaster. The developed model envisions the establishment of TSAs at suitable locations throughout Istanbul and the sorting of mixed waste at these sites. A portion of the separated waste will be directed to recycling facilities, while another portion will be processed on-site using mobile recycling units. The aim is to reuse materials such as sand, gravel, and stone obtained from recycling in the construction sector and to create economic value by separating materials such as plastic and metal. Furthermore, it is planned to reduce the volume of waste before it is sent to storage areas.

The rapid and uninterrupted establishment of TSA following a major earthquake is of vital importance for effective waste management. Accessibility, environmental sensitivity, and logistical efficiency should be considered as key criteria in the selection of these areas. However, currently, there are no TSAs ready for use after a disaster in Istanbul. This situation necessitates that the study focus on the problem of determining a common temporary storage area covering the entire city of Istanbul.

Current disaster management plans (Turkey Disaster Response Plan and Provincial Disaster Reduction Plan) address disasters broadly but lack specific strategies for managing post-disaster waste (Presidency of Disaster and Emergency Management 2022; Istanbul Governorship Provincial Directorate of Disaster and Emergency 2023). Similarly, the "Destructive Istanbul Earthquake Potential Debris Management Plan" (Istanbul Metropolitan Municipality 2021) analyses the distribution of debris by district and the capacity and efficiency of disposal facilities; however, it does not provide any information regarding the locations of TSAs.

Therefore, the lack of a comprehensive disaster waste management plan, including TSAs, points to a critical gap that needs to be addressed in Istanbul's disaster preparedness processes. The GIS–RANCOM-based approach model developed in this context will significantly contribute to the planned, environmentally sustainable, and operationally efficient implementation of post-disaster waste management.

Ultimately, this study seeks to answer the following key research questions:

- Which environmental, social, economic, and logistical criteria are critical in the TSA selection process?
- Based on these criteria, which areas of Istanbul constitute the most suitable TSA candidate sites?
- How can GIS and RANCOM methods be integrated in the selection of post-disaster waste storage areas?
- Can the developed GIS–RANCOM methodology be adapted to different types of disasters (e.g., floods, landslides, hurricanes, etc.)?

Materials and methods

Methodology

Figure 2 shows the subsequent sections of the study methodology, which were designed to integrate GIS and MCDM for the post-earthquake debris waste TSAs site selection problem.

Firstly, the evaluation and exclusion criteria that are considered to be effective for site selection are identified. The data sets employed for site selection encompass various geographical and environmental considerations. These include the distance from wetlands, forests, agricultural lands, settlements, natural protected areas, and settlement areas. In addition, connection roads, topographic slope and elevation, ground permeability, underground water level, and rivers, hydrological and geomorphological features, etc., are considered in the selection process. In determining these suitability criteria and other constraints, the relevant legislation, literature and the opinions of experts working in this field and the region were utilized.

The accuracy and reliability of results in GIS-based decision-making studies depend on the detail, timeliness, and accuracy of spatial data. Data collection, updating, and verification processes must be executed systematically. The utilization of the most contemporary and substantiated data sets in planning and analysis processes directly influences the quality of the decisions made.

The next step is to obtain geographic data for the specified criteria. To ensure the reliability and validity of the spatial analyses conducted in this study, particular attention was paid to the quality attributes of the GIS data sets used. The geographic database was created using vector and raster data sets obtained from authorized national institutions and internationally recognized data providers. Data accuracy, spatial resolution, and temporal currency were considered as key parameters during data selection.

Detailed information regarding the geographic datasets used in the study is presented in Table 2.

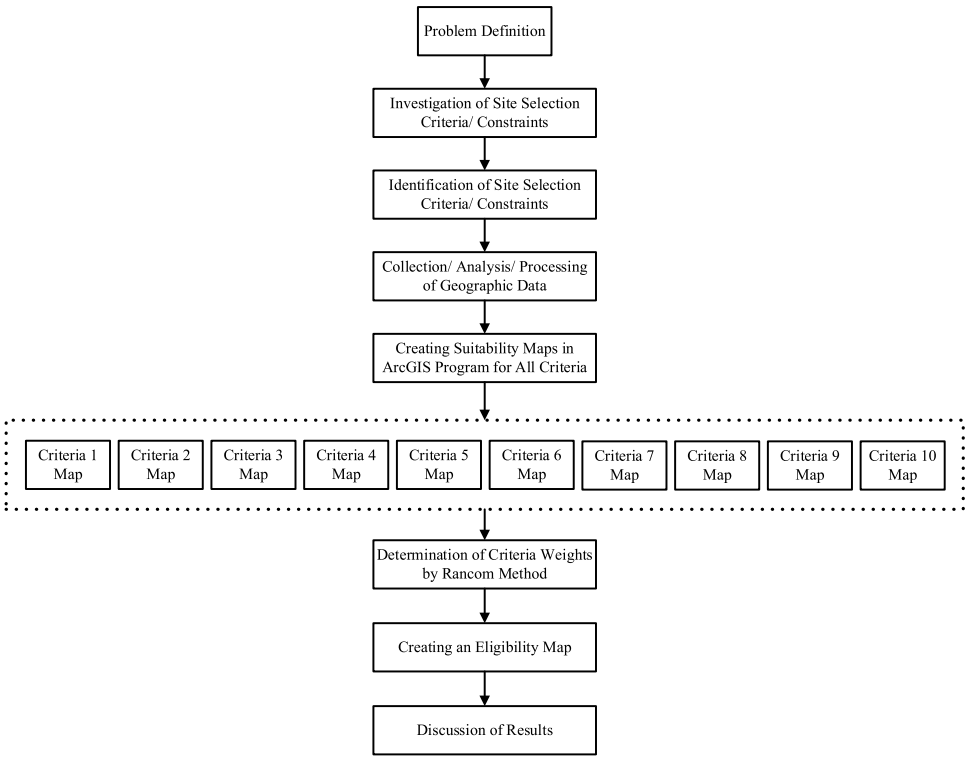

Fig. 2 Thesis methodology (GIS-MCDM Integration)

Table 2 Geospatial datasets used in the study and their characteristics

Data	Data type	Year	Resolution
Surface water sources	Vector, Polyline	2025	1/10.000
Protected areas	Vector, Polyline	2025	1/10.000
Environmentally sensitive areas	Vector, Polyline	2025	1/10.000
Fault lines	Vector, Polyline	2022	1/100.000
Flood zones	Vector, Polyline	2025	1/100.000 (web map service)
Slope	Raster	2014	27 m
Roads	Vector, Polyline	2025	1/10.000
Nearest settlement	Vector, Polyline	2025	1/10.000
Land use	Vector, Polyline	2018	1/100.000
Elevation	Raster	2014	27 m

Surface water resources, protected areas, roads, and settlements are vector data provided at scales of 1:10.000 and 1:100.000, offering sufficient detail for regional planning and decision-making. Raster data such as elevation and slope have been used at a spatial resolution of 27 m; this resolution is sufficient for determining topographic constraints, which are important in debris transport and site suitability analyses. In terms of temporal timeliness, the most recent data (2018–2025) has been preferred, especially for dynamic elements such as settlements, transportation networks, and environmental protection areas. Data on fault lines and land use has been obtained from the relevant authorities and represents the most current versions available.

All datasets were preprocessed, standardized, and analyzed using ArcGIS 10.8 software. Raster data was used in GeoTIFF (.tif) format, while vector data was used in Shapefile (.shp) format to ensure consistency and data compatibility throughout the workflow. Where necessary, data was digitized; suitability maps were produced for each criterion using spatial analysis techniques such as overlay, Euclidean distance analysis, or raster-vector integration.

In the subsequent phase, criterion weights were determined using the RANCOM, a MCDM method.

The determination of criterion weights constitutes a pivotal stage within the MCDM process. Past experiences and expert opinions are utilized; however, since expert opinions usually produce subjective results, it is essential to verify the decisions taken with multiple decision-making analysis methods (Senturk and Erener 2017).

In MCDM problems, evaluating criterion conformity by experts becomes more arduous, particularly when the number of criteria increases and the margin of error in the decision process is amplified. In this context, the necessity for methodologies that reflect expert knowledge straightforwardly and intuitively becomes evident. While standard subjective weighting methods such as AHP, SMART, SWARA and BWM generally produce consistent results without expert indecision, their ability to effectively manage

expert hesitation may be limited. The preferred method in this study addresses this need by determining the weight vector based on the criteria ranking.

The RANCOM method was selected in this study due to its superior performance in handling expert evaluations involving multiple criteria with high reliability, consistency, and reproducibility. Unlike commonly used subjective weighting approaches such as AHP, BWM, SWARA, or SMART, which require extensive pairwise comparisons and thus increase the risk of inconsistency, expert fatigue, and subjectivity, RANCOM employs a direct ranking-based approach that enables experts to express their judgments more intuitively and simply. This characteristic significantly reduces cognitive load and potential biases during the decision-making process. Comparative analyses in the literature (Więckowski et al. 2023) have demonstrated that RANCOM ensures lower error rates, higher reliability, and repeatability, particularly in problems involving five or more criteria. Such methodological strengths make it particularly advantageous in complex multidimensional domains, such as disaster waste management, where environmental, logistical, spatial, and social factors must be considered simultaneously. Moreover, the integration of RANCOM with GIS in this study enhanced methodological robustness by unifying qualitative expert assessment and quantitative spatial analysis within a transparent and objective decision-support framework. This hybrid GIS–RANCOM approach strengthens the scientific rigor of the study, provides a sounder basis for weighting processes based on expert judgment, and reinforces the applicability and reproducibility of the results within decision support systems.

During the study, three experts and academicians in environment, waste management, and local government were invited to rank the criteria according to their perceived importance using an evaluation form. According to these rankings, the weight values indicating the importance of the requirements in solving the decision problem were calculated using the RANCOM method, and the criteria were then ranked according to their importance.

The final suitability map was created using overlay analysis in the ArcGIS program, using the pre-determined criteria weights.

While the proposed approach has certain limitations, it offers a balanced and efficient framework suitable for large-scale spatial decision problems.

Validation of GIS maps

Accuracy assessment in GIS data is critical for determining the reliability of classification and the information value that the data carries for the user. The overall accuracy of the classified image indicates how well each pixel matches the actual land cover. Producer accuracy measures the level of correct capture of land cover classes (omission errors), while user accuracy measures the probability that a classified pixel matches the actual land cover (Congalton 1991; Campbell 2007; Jensen 2005). The error matrix and kappa coefficient are fundamental tools commonly used to evaluate these accuracies. Rwanga and Ndambuki (2017) conducted accuracy assessment using a high-resolution satellite image-based method. The validation of the maps obtained in the study was performed using this method.

Ranking comparison method (RANCOM)

As outlined in Więckowski et al. (2023), the RANCOM entails the direct ranking of criteria by assigning lower values to more significant parameters, permitting ties. Decision-makers can establish rankings through various methods, including scoring systems, sorting algorithms, and tournaments. This structured approach facilitates the simplification of ranking, even in cases involving numerous criteria. The subsequent steps delineate the method (Więckowski et al. 2024). The following section will illustrate the application process of the method, as demonstrated in Fig. 3.

Tournament method

In this method, the expert manually compares pairs of criteria to determine their importance, filling the *MAC* matrix accordingly. There are three possible comparisons between criteria (C_i, C_j): (1) C_i is more critical than C_j, (2) equally important, or (3) less important. The significance function (C) defines the comparison result. The tournament method helps streamline this process by comparing all criteria combinations. However, inconsistencies may arise if the expert hesitates during comparisons, which can be mitigated using the triads consistency coefficient (Sałabun et al. 2021; Więckowski et al. 2023).

Step 1: *Establishing the ranking of criteria*

The expert determines the relative position of each criterion concerning other factors. Lower numerical values are assigned to more significant criteria in the ranking process. Furthermore, it is conceivable for criteria to be assigned the same rank, thus enabling the occurrence of ties during the expert evaluation process.

The ranking of criteria may be represented by consecutive numbers (for instance, [1, 2, 3, 4, 5] for five criteria) or with more varied numbers (such as [1, 5, 9, 12, 18] for five criteria). However, it is essential to note that differences in the ranking vector will not affect the calculated weights unless they reflect distinct hierarchical levels among the criteria.

Step 2: *Formulate the ranking comparison matrix*

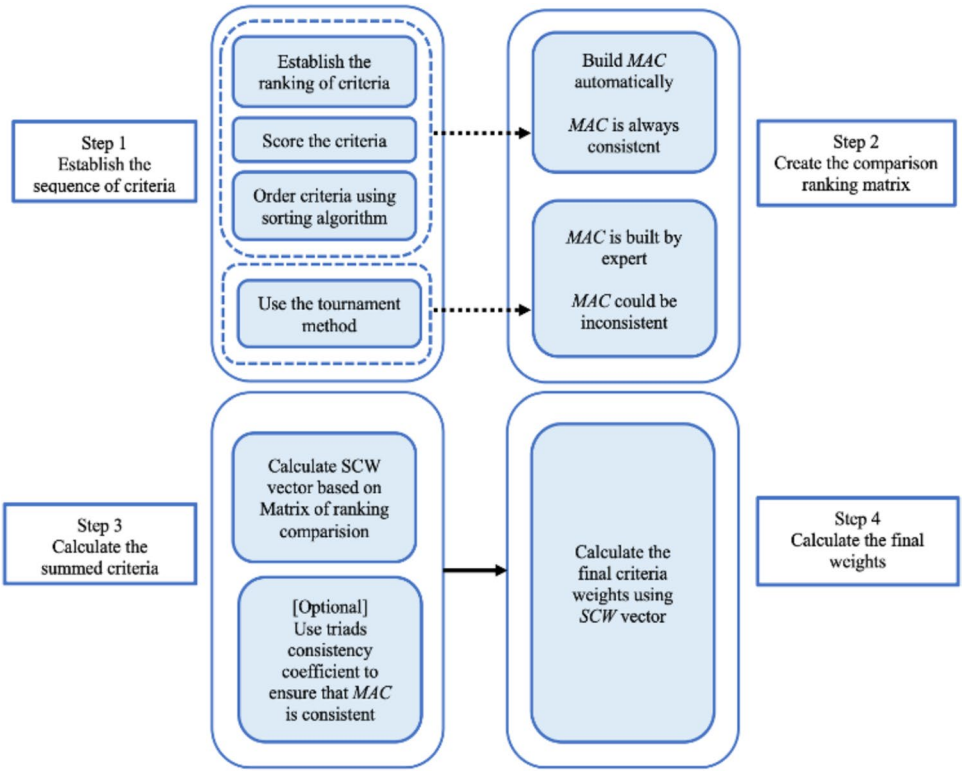

Fig. 3 Flowchart depicting the next steps of the RANCOM method (Więckowski et al. 2024)

The Matrix of Ranking Comparison (MAC) is formulated through pairwise comparisons of the ranks determined by the expert. The outcome of each comparison is represented as.

α_{ij} Consequently, the MAC matrix can be expressed as follows:

$$MAC = \begin{matrix} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} \begin{bmatrix} C_1 & C_2 & \dots & C_n \\ \alpha_{11} & \alpha_{12} & \dots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \dots & \alpha_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{n1} & \alpha_{n2} & \dots & \alpha_{nn} \end{bmatrix} \quad (1)$$

Given that n represents the total number of criteria considered in the problem, the value of α_{ij} is calculated as follows:

$$\alpha_{ij} = \begin{cases} IF\ f(C_i) < f(C_j)\ THEN\ 1 \\ IF\ f(C_i) = f(C_j)\ THEN\ 0.5 \\ IF\ f(C_i) > f(C_j)\ THEN\ 0 \end{cases} \quad (2)$$

Here, f(C) denotes the critical function associated with criterion C.

Step 3: *Calculate the summed criteria weights*

Based on the obtained MAC, the horizontal vector of the summed criteria weights.

(SCW) is formulated as follows.

$$SCW_i = \sum_{j=1}^{n} \alpha_{ij} \quad (3)$$

Step 4: *Determine the final weights of the criteriaStep*

In the final step, preference values are estimated for each criterion. Consequently, the horizontal vector W is established, where the i-th element corresponds to the estimated preference value forC_i. The computed weights for the entire set of criteria are expressed as follows:

$$w_i = \frac{(SCW_i)}{\left(\sum_{(i=1)}^{n} SCW_i\right)} \quad (4)$$

In the subsequent analysis stage, the arithmetic mean of the final weightings of each criterion for the three experts was calculated.

Subsequently, maps were generated using the ArcGIS program, and these maps were overlaid and merged to reveal suitable alternative debris waste collection areas. This process was undertaken with due consideration for ranking the criteria weights, as determined by the RANCOM method. Consequently, a suitability map delineating the candidate points was developed.



Fig. 4 The case study area

Case study

The study area

The study area, Istanbul Province, is located in northwestern Turkey, at a strategic point connecting the continents of Europe and Asia. It lies between 41° N latitude and 29° E longitude, and its surface area is approximately 5461 km^2. The total population of Istanbul is approximately 15,701,602 people (Republic of Turkey Ministry of Interior Turkish Statistical Institute 2025). The climate is transitional between the Black Sea and Mediterranean climates. The average annual precipitation is approximately 850–1200 mm and the yearly temperature is around 13–15 °C. Istanbul is under the influence of the main branches of the North Anatolian Fault Zone (NAFZ) passing through the Marmara

Sea. It is located in a region with a great earthquake potential (Istanbul Governorship Provincial Directorate of Disaster and Emergency 2023). The study area map is given in Fig. 4.

Determination of eligibility criteria

First, the issue of location selection was addressed. To do so, 10 criteria were determined by experts' opinions, existing guides, and research findings on disaster waste management. These criteria are listed in Table 3.

Results and discussion

Creation of suitability maps

Suitability maps were developed for each criterion using the ArcGIS 10.8 program, conforming to the requirements delineated in Table 3.

C1-Distance from surface water sources

A certain distance must be maintained between TSAs for disaster waste and surface water sources, as the various pollutants generated in these areas have the potential to contaminate wetlands such as lakes, streams, rivers, etc. Consequently, a distance of 2000 m has been designated as a buffer zone. Regarding site selection, areas located 2000 m or further away from surface water sources will be considered suitable. (Fig. 4)

The distance map to surface water sources in Fig. 5 was created using Euclidean Distance analysis with vector formats of existing maps obtained from an open source map platform (https://www.openstreetmap.org/#map=4/38.01/-95.84).

On the map in Fig. 5, areas smaller than 2000 m are shown in gray, while areas larger than 2000 m are shown in green. Areas suitable for TSAs selection will be the areas shown in green.

C2-Distance to protected areas

TSAs should be far from protected areas such as historical, touristic, archaeological, etc., to preserve their structural and aesthetic values.

In the ArcGIS program, the distance map to protected areas in Fig. 6 was created by digitizing the Istanbul Planning Agency's protected areas, 'Synthesis Map of Important Areas in terms of Ecosystem and Biodiversity' (Istanbul Planning Agency 2024).

Regarding site selection, areas within 1000 m and more than 1000 m away from protected areas will be identified as

Table 3 Exclusion and evaluation criterias

Criteria	Description	Constraint	References
C1	Distance from surface water sources such as streams, rivers, lakes etc	= > 2000 m	Cheng and Thompson (2016), EPA (2019), FEMA (2007), Republic of Turkey Ministry of Forestry and Water Affairs (2017), Uzun (2023)
C2	Distance to protected areas (protected areas, historical, touristic, archaeological areas)	= > 1000 m	Bilgilioglu and Gezgin (2022), EPA (2019), FEMA (2007), Republic of Turkey Ministry of Environment and Forestry (1991), Republic of Turkey Ministry of Environment and Forestry (2017)
C3	Distance to environmentally sensitive areas (Nature Park, Nature Reserve, wildlife protection and development areas etc.)	= > 1000 m	EPA (2019), FEMA (2007)
C4	Distance to fault lines	> 300 m	Ayaim et al. (2019) Bilgilioglu and Gezgin (2022), EPA (2019), Kamdar et al. (2019)
C5	Flood zones	Not located in flood zones	Cheng and Thompson (2016), FEMA (2007)
C6	Slope	< 20%	Akbari et al.(2008, Bilgilioglu and Gezgin (2022), EPA (2019), Uzun (2023)
C7	Distance to roads	> 200 m	Cheng and Thompson (2016), FEMA (2007)
C8	Distance to the nearest settlement	= > 1000 m	Cheng and Thompson (2016), FEMA (2007), Republic of Turkey Ministry of Environment and Forestry (1991), Republic of Turkey Ministry of Environment and Forestry (2017), Sengun et al. (2018)
C9	Land use (Forests, agricultural areas, urban areas)	_	Cheng and Thompson (2016), Dogdu and Alkan (2023), Uzun 2023)
C10	Elevation	= < 1100 m	Sengun et al. (2018), Uzun (2023)

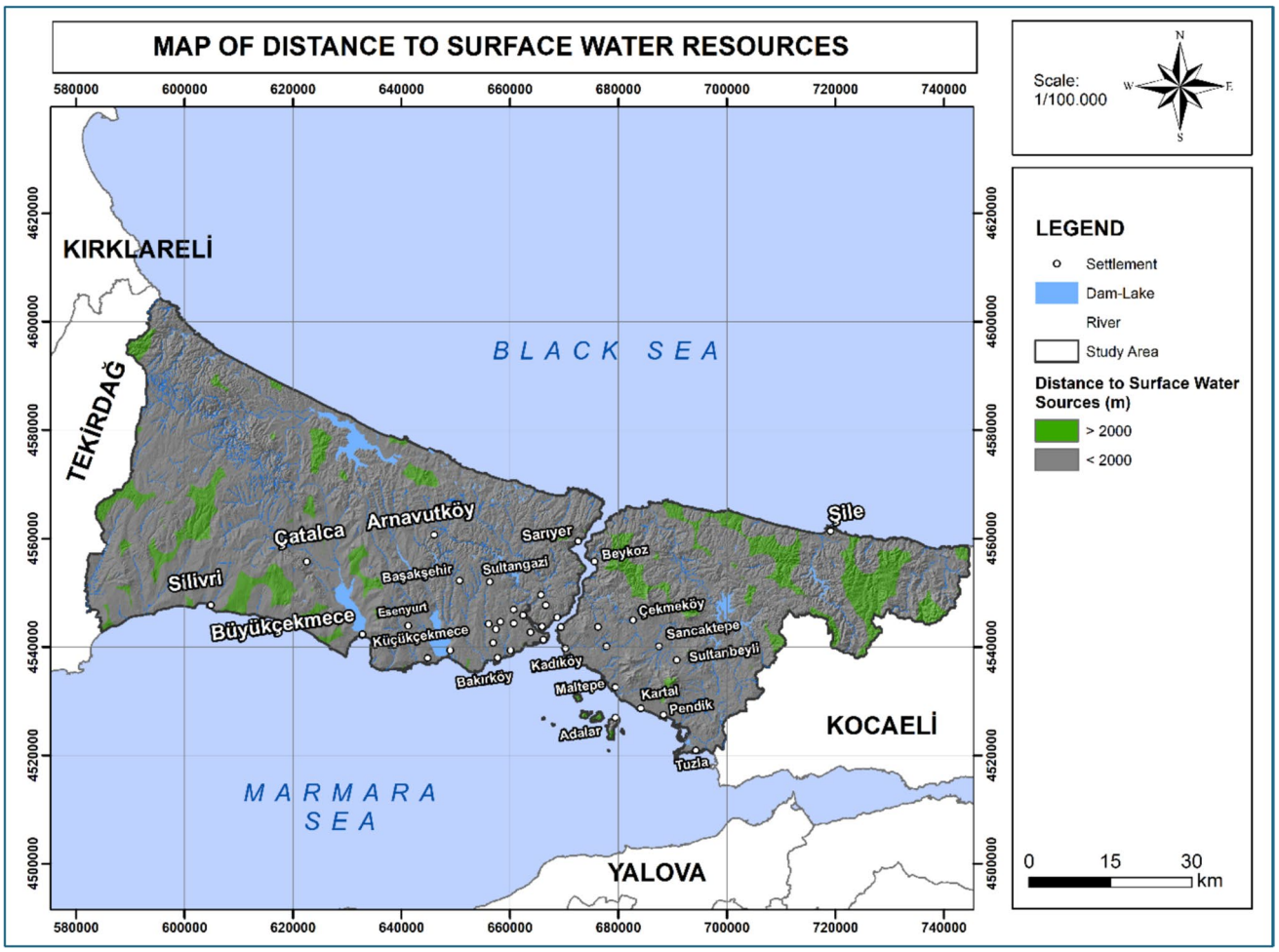

Fig. 5 Map of distance to surface water sources

the most suitable locations. A 6-point scale was developed to assess the suitability of distances on the map. According to the classification given in Table 4, areas within 1000 m are definitely unsuitable. Suitability increases as the weight level approaches 5.

When the maps in Fig. 6 are interpreted according to the scales created, the areas shown in gray are not suitable areas and will be excluded. Suitable areas are those shown on the map in red, indicating low suitability, up to those shown in green, indicating the highest suitability level.

C3-Distance to environmentally sensitive areas

The distance map to environmentally sensitive areas in this study was created by digitizing the data from the National Wetland Inventory Management Information System of the Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks in the ArcGIS program.

In site selection, areas situated 1000 m and beyond from environmentally sensitive regions, including but not limited to Nature Parks, Nature Reserves, wildlife protection areas, and development areas, were identified as the optimal locations. These areas are delineated on the map presented in Fig. 7. A 6-point scale was developed to assess the suitability of distances on the map. According to the classification given in Table 5, areas within 1000 m are definitely unsuitable. Similarly, as the weight level approaches 5, the suitability level increases.

Similarly, when the maps in Fig. 7 are interpreted according to the current scales, the areas shown in gray are not suitable areas and will be excluded. Areas ranging from the low suitability level shown in red on the map to

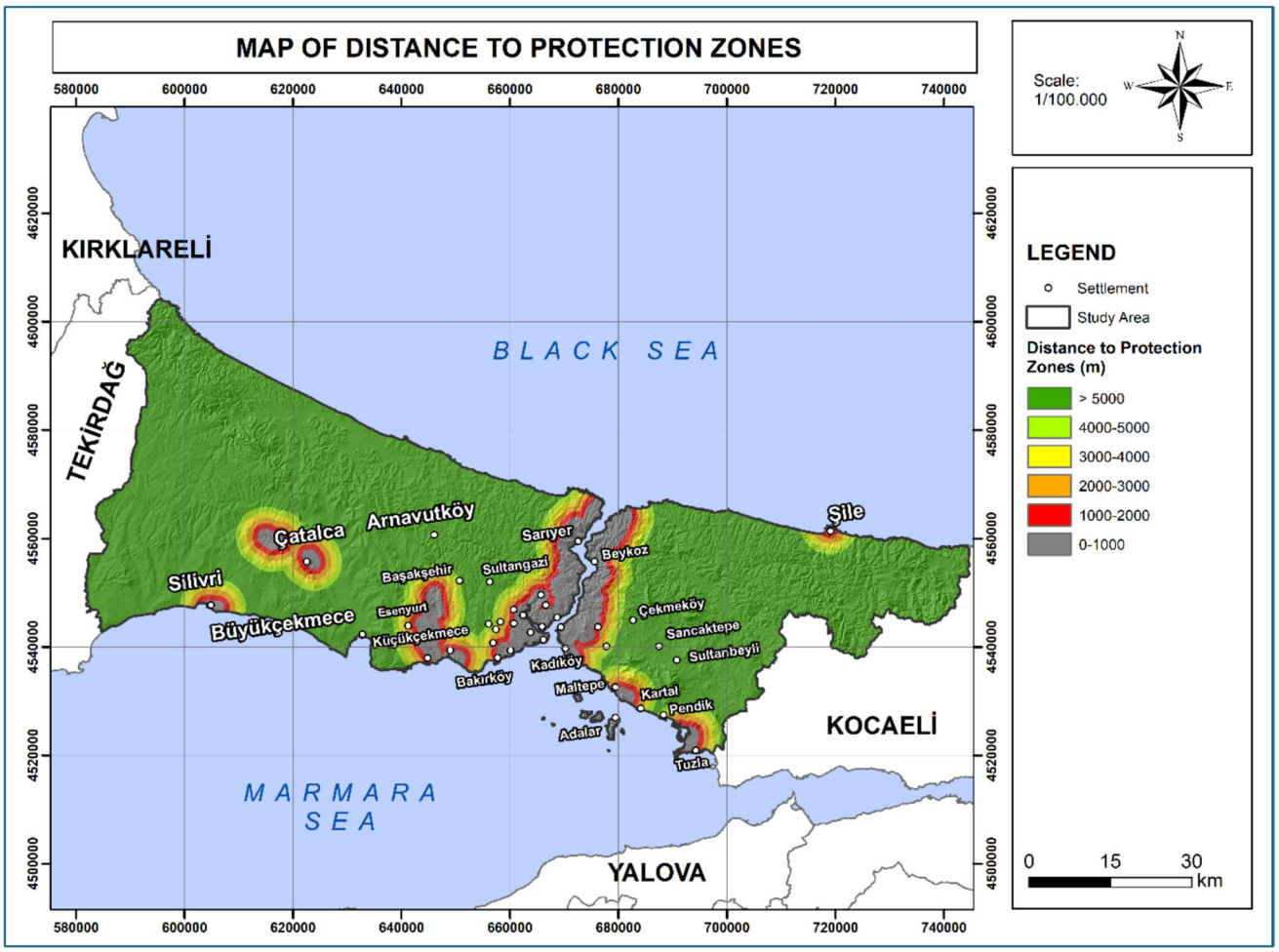

Fig. 6 Map of distance to protected areas

Table 4 Eligibility index

Eligibility scale	Eligibility	Value
5	Very suitable	> 5000 m
4	Suitable	4000–5000 m
3	Somewhat suitable	3000–4000 m
2	Moderately suitable	2000–3000 m
1	Lowly suitable	1000–2000 m
0	Not suitable at all (Exclude)	0–1000 m

the highest suitability level shown in green will be selected as suitable areas.

C4-Distance to fault lines

TSAs should be located away from fault lines. The distance to fault lines map in Fig. 8 obtained in this study was created by digitizing the General Directorate of Mineral Research and Exploration's Direct fault map in the ArcGIS program. As shown in Table 6, a 5-point scale was developed, and a suitability ranking was subsequently conducted. According to the classification module given in Table 6, areas within a close distance of 4–10 km are definitely unsuitable and have been assigned a value of 0 so that they are not included in the calculation. As the weight level approaches 4, the suitability level increases.

The scale created based on the distance from the North Anatolian Fault Line passing through the Sea of Marmara has been graded from closest to furthest. The red areas on the map will be excluded as they are the areas closest to the fault line. Suitable areas for temporary storage are ranked from lowest to highest, with dark green areas appearing as the most suitable.

C5-Flood zones

It is critical for environmental safety, public health and legal compliance that temporary waste storage areas are located

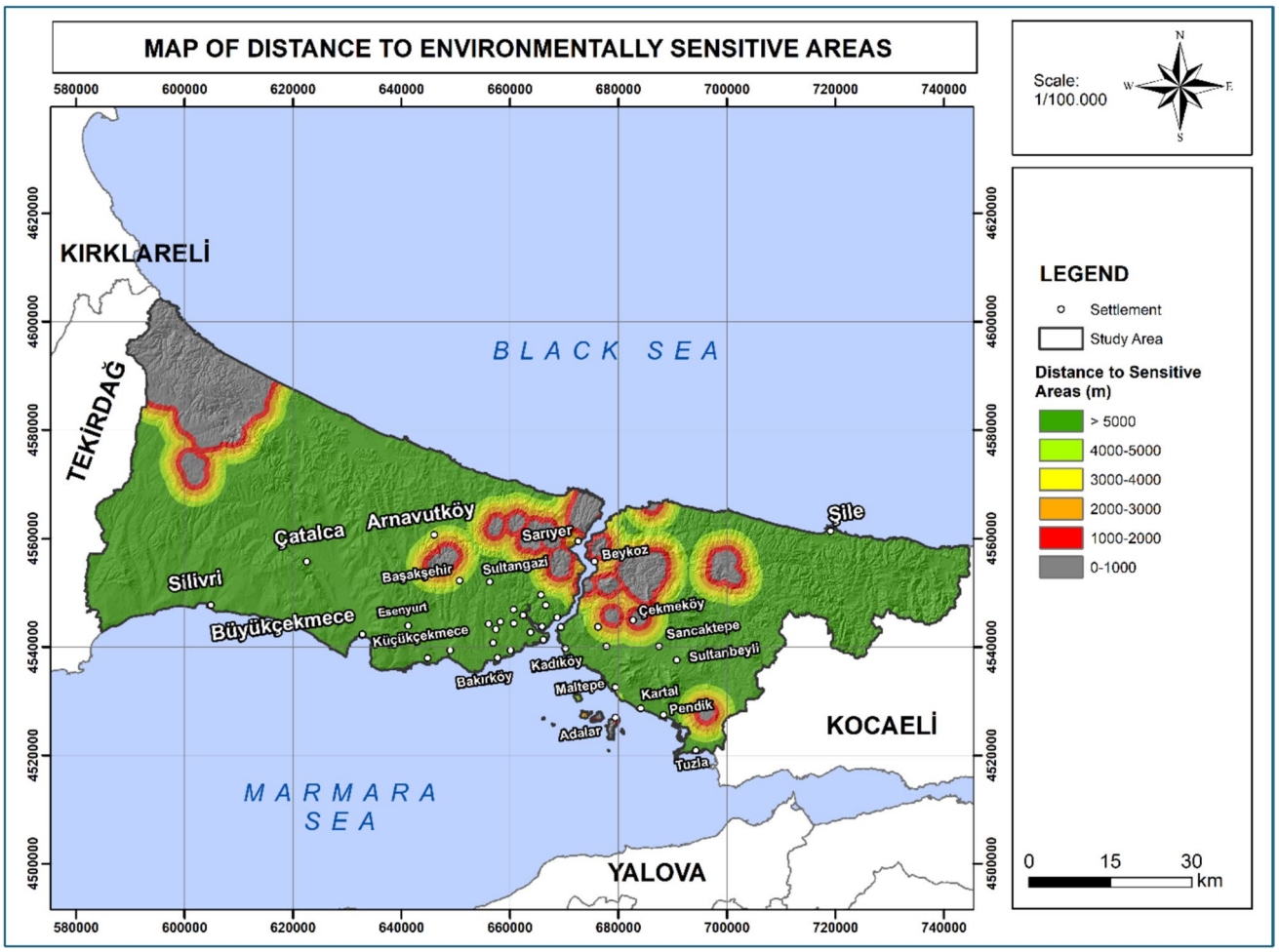

Fig. 7 Map of distance to environmentally sensitive areas

Table 5 Eligibility index

Eligibility scale	Eligibility	Value
5	Very suitable	> 5000 m
4	Suitable	4000–5000 m
3	Somewhat suitable	3000–4000 m
2	Moderately suitable	2000–3000 m
1	Lowly suitable	1000–2000 m
0	Not suitable at all (Exclude)	0–1000 m

away from flood risk areas. Floodwaters can cause waste to be dispersed in landfills and contaminate ground and surface waters, negatively affecting the ecosystem. Waste from these areas can clog sewerage systems and damage infrastructure, and the collection and disposal process becomes difficult and costly. At the same time, chemical, hazardous, medical and household wastes dispersed by floodwaters can carry microorganisms and spread epidemics, posing a threat to the environment and public health.

The flood map presented in Fig. 9, created in this study, was obtained by digitizing the flood maps in the National Water Information System of the Ministry of Agriculture and Forestry in the ArcGIS program. A key consideration was excluding flood-risk areas.

The areas marked in red on the map in Fig. 9 are flood risk zones and will be excluded. Candidate sites for the TSAs will be selected from the gray areas outside the flood risk zone.

C6-Slope

Establishing storage areas in locations with high slopes poses a significant challenge. Furthermore, the presence of pollutants generated within the storage area can contaminate surrounding areas due to the slope of the

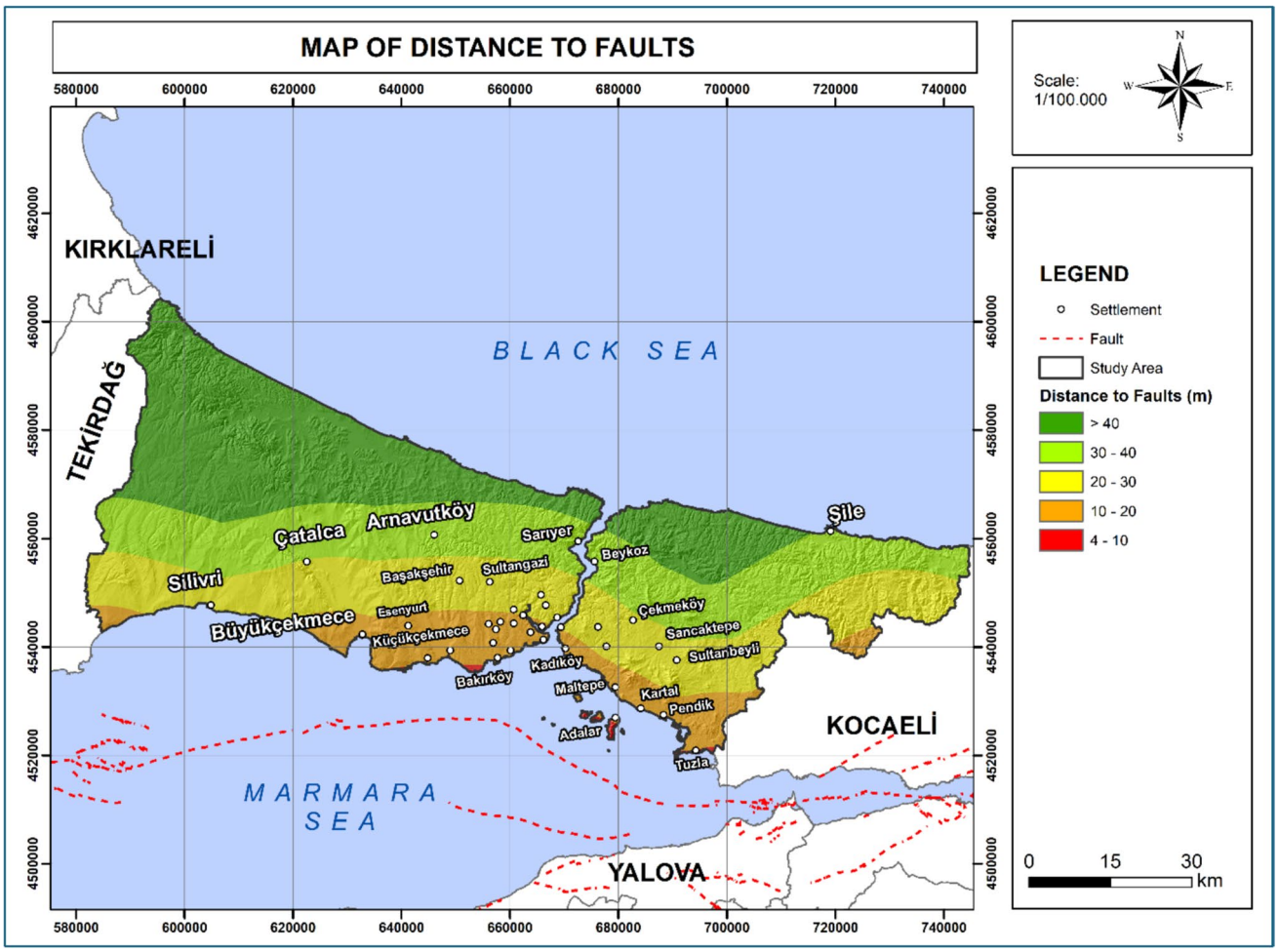

Fig. 8 Map of distance to fault lines

Table 6 Eligibility index

Eligibility scale	Eligibility	Value
4	Very suitable	> 40 km
3	Suitable	30–40 km
2	Somewhat suitable	20–30 km
1	Lowly suitable	10–20 km
0	Not suitable at all	4–10 km

terrain. Consequently, areas with less than 20% slope were identified as suitable, while those with more than 20% slope were excluded from further consideration. A 5-point scale was developed to assess the suitability of distances on the map. According to the classification module given in Table 7, areas with a slope greater than 20% are definitely unsuitable and have been assigned a value of 0 so that they are not included in the calculation. As the weight level approaches 4, the suitability level increases.

The slope map in Fig. 10, created in this study, was generated in ArcGIS using SRTM (Shuttle Radar Topography Mission) and DEM (Digital Elevation Model) data (https://earthexplorer.usgs.gov/).

In the map created in Fig. 10, areas with a slope greater than 20% shown in gray will be excluded. Suitable areas for temporary storage are ranked from least suitable to most suitable, from orange to green. The most suitable areas are dark green areas with the lowest slope percentage.

C7-Distance to roads

The strategic positioning of disaster waste TSAs is of paramount importance. They must be situated at a certain distance from existing road networks. This will reduce transportation costs and ensure the efficient waste transmission to waste processing facilities. Furthermore, it will prevent aesthetic impacts.

The proximity to roads map created in this study was constructed using vector versions of current maps from

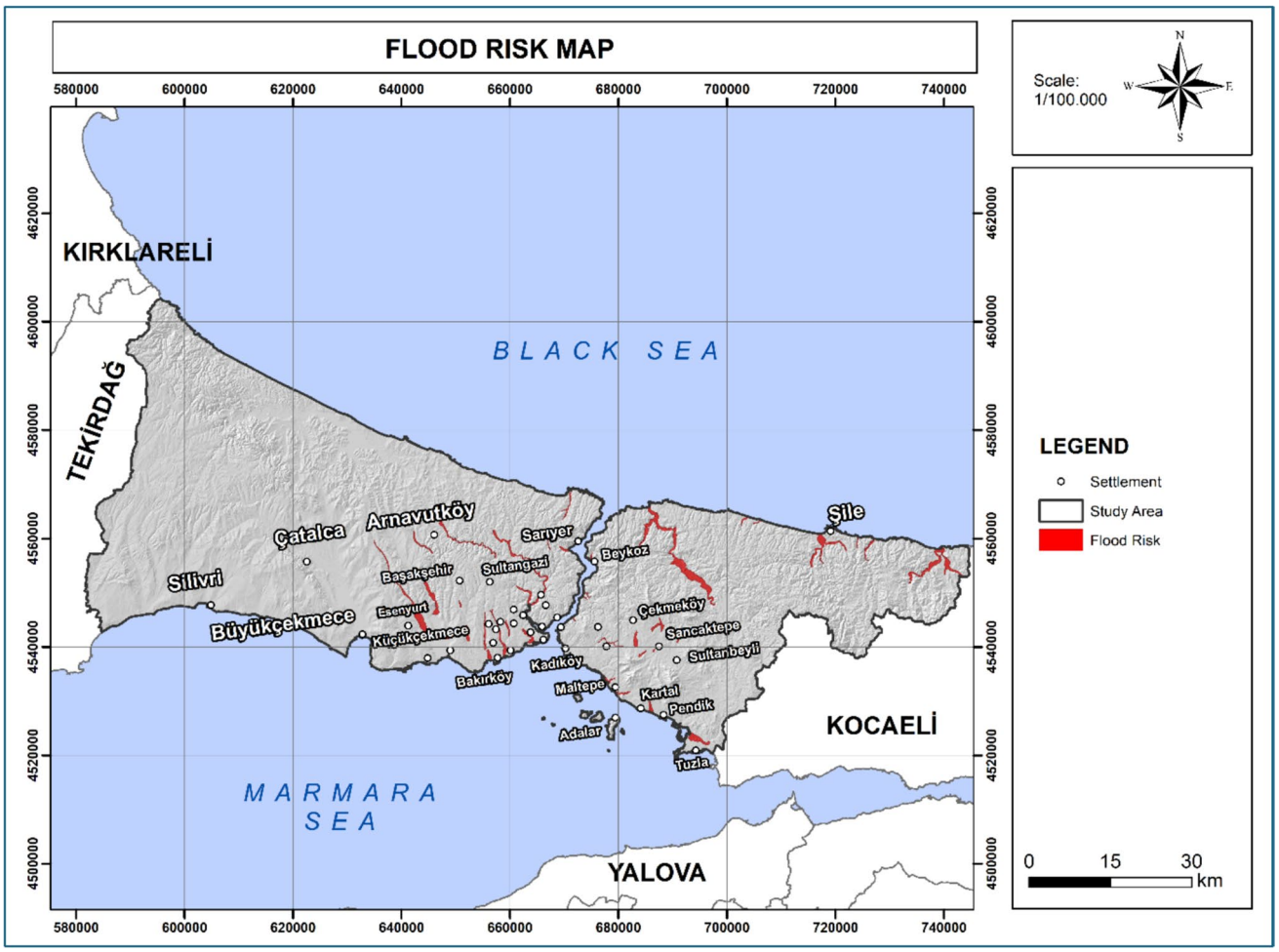

Fig. 9 Flood risk map

Table 7 Eligibility index

Eligibility scale	Eligibility	Value
4	Very suitable	%0–5
3	Suitable	%5–10
2	Somewhat suitable	%10–15
1	Lowly suitable	%15–20
0	Not suitable at all (Exclude)	> %20

the open-source mapping platform (https://www.opens treetmap.org/#map=4/38.01/-95.84) and by performing a Euclidean Distance analysis. In this instance, the focus was on highway and tier 1 roads.

When selecting suitable sites, areas within a 200-m radius of roads are deemed unsuitable. Table 8 outlines the rating of regions outside these areas. According to the scale given in Table 8, areas within a distance of 0–200 m are definitely unsuitable and have been assigned a value of 0 so that they are not included in the calculation. As the weight level approaches 5, the suitability level increases.

When examining the map in Fig. 11, created according to scale, areas within 200 m of the roads shown in gray will be excluded. At the same time, areas more than 4000 m from the roads shown in red will also be unsuitable due to the difficulty of transporting waste. The most suitable areas for temporary storage are seen to be those shown in green.

C8-Distance to the nearest settlement

Since waste collected in TSAs may have negative environmental impacts, such as odor, dust, and noise, the selected areas should be located at a certain distance from urban settlement centers, such as settlements, schools, places of worship, and health facilities, as much as possible. These areas should avoid interrupting traffic flow, interfering with commercial activities, or creating hazards in residential areas.

In this study, the distance to the nearest settlement map in Fig. 12 was created in the ArcGIS program using the

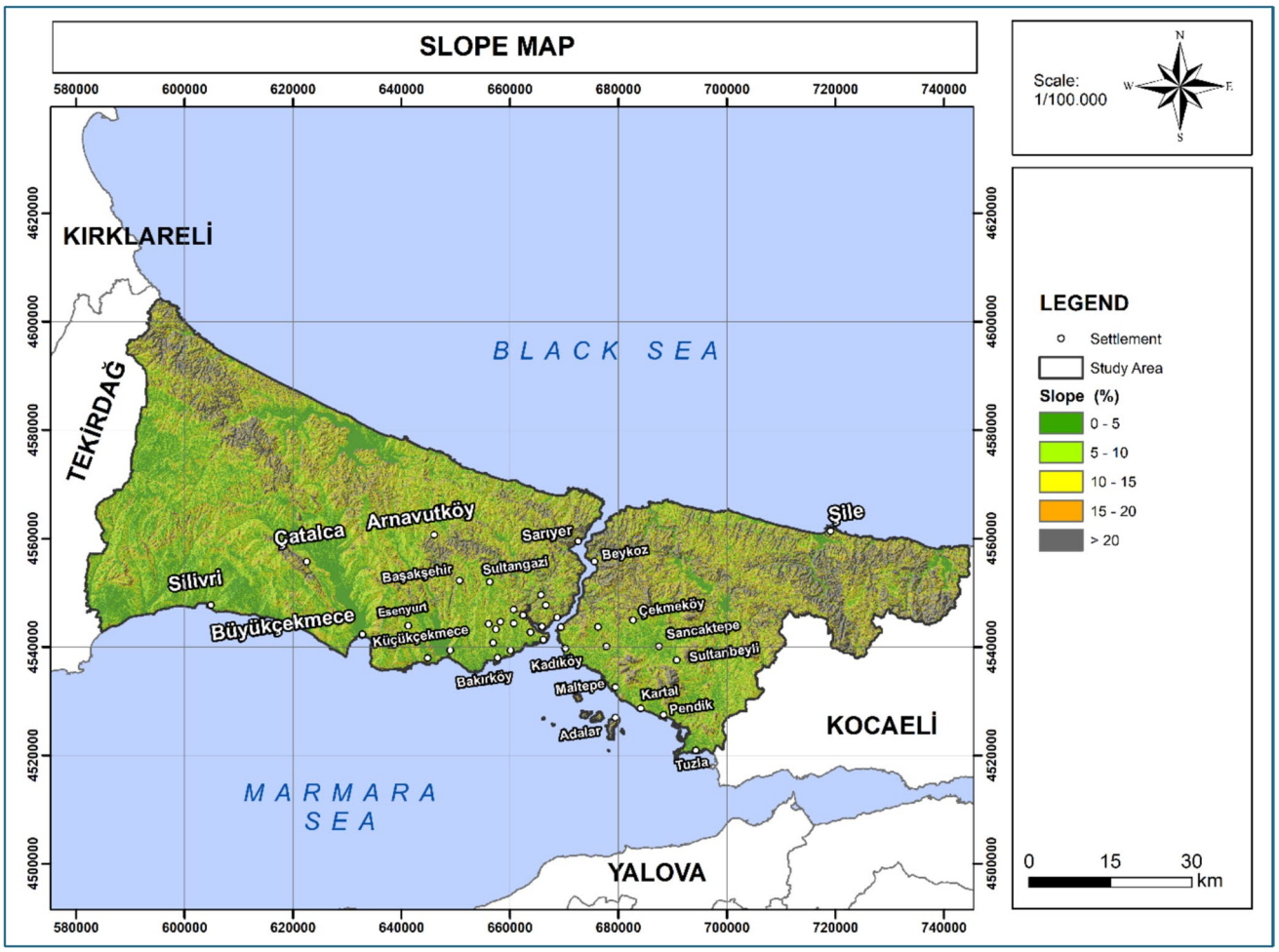

Fig. 10 Slope map

Table 8 Eligibility index

Eligibility scale	Eligibility	Value
5	Very suitable	200–1000 m
4	Suitable	1000–2000 m
3	Somewhat suitable	2000–3000 m
2	Lowly suitable	3000–4000 m
1	Not suitable	> 4000 m
0	Not suitable at all (Exclude)	0–200 m

Corine Land Cover (CLC) 2018 map data (https://land.copernicus.eu/en/products/corine-land-cover). A 6-point scale was developed in Table 9, and the suitability ranking was made. According to the scale given in Table 9, areas up to 1000 m are definitely unsuitable and have been assigned a value of 0 so that they are not included in the calculation. As the weight level approaches 5, the suitability level increases.

The areas shown in gray on the map in Fig. 12 are unsuitable and will be excluded. Areas more than 5000 m away, shown in red, are also unsuitable. The most suitable areas for temporary storage will be selected from the regions shown in green.

C9-land use

The land use map in Fig. 13 was created in the ArcGIS program using the Corine Land Cover (CLC) 2018 map data (https://land.copernicus.eu/en/products/corine-land-cover). As in Table 10, a 5-point scale was created, and a suitability ranking was made. Water sources at risk of contamination according to the scale given in Table 10 have been assigned a value of 0 so that they are not included in the calculation.

As shown on the map in Fig. 13, wetlands and surface waters will be excluded. The TSAs will be selected from other areas.

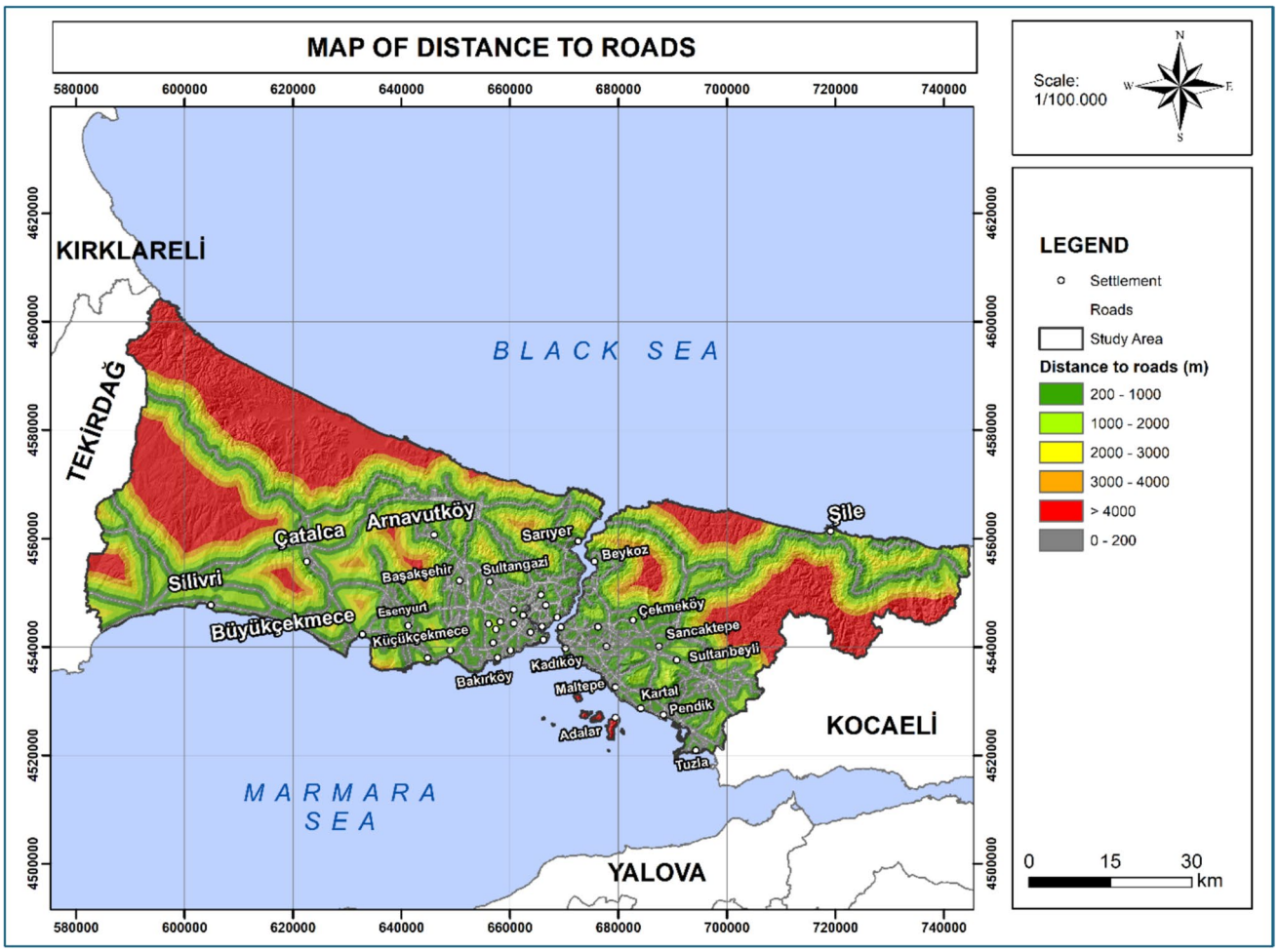

Fig. 11 Map of distance to roads

C10-Elevation

The elevation criterion is a pivotal factor, given that high-altitude regions are challenging to access and that establishing TSA is difficult. Conversely, low-elevation regions are susceptible to flood risk.

The elevation map created in this study was obtained in the ArcGIS program using the Shuttle Radar Topography Mission (SRTM) and Digital Elevation Model (DEM) data https://earthexplorer.usgs.gov/).

According to the literature, areas with elevations below 1100 m are suitable for ǀ temporary storage. However, Istanbul does not have a high-elevation topography. The city's average elevation is 100 m, with a maximum of 500 m. In this case, an acceptance scale ranging from 0 to 200 m was created, and areas exceeding 200 m were excluded. The suitability map was prepared according to the 5 -point scale given in Table 11. This scale was used to determine the suitability ranking shown in Fig. 14. According to the scale, areas above 200 m are definitely unsuitable and have been assigned a value of 0 so they are not included in the calculation. As the weight level approaches 4, the suitability level increases.

According to the suitability map created in Fig. 14, areas colored red with an elevation above 200 m are not suitable for site selection and have been excluded. For the TSAs, candidate sites will be selected from areas with an elevation below 200 m, and the areas shown in dark green with the lowest elevation range will be suitable for site selection.

Weighting of criteria with RANCOM method

Step 1: *Establishing the ranking of criteria*

To establish the ranking of criteria, one of the four available methods must be applied. In this instance, the tournament method is selected, which requires the expert to compare pairs of criteria manually in succession.

In order to address the issue of site selection, a comprehensive set of ten criteria was established. The evaluation of these criteria according to their perceived level

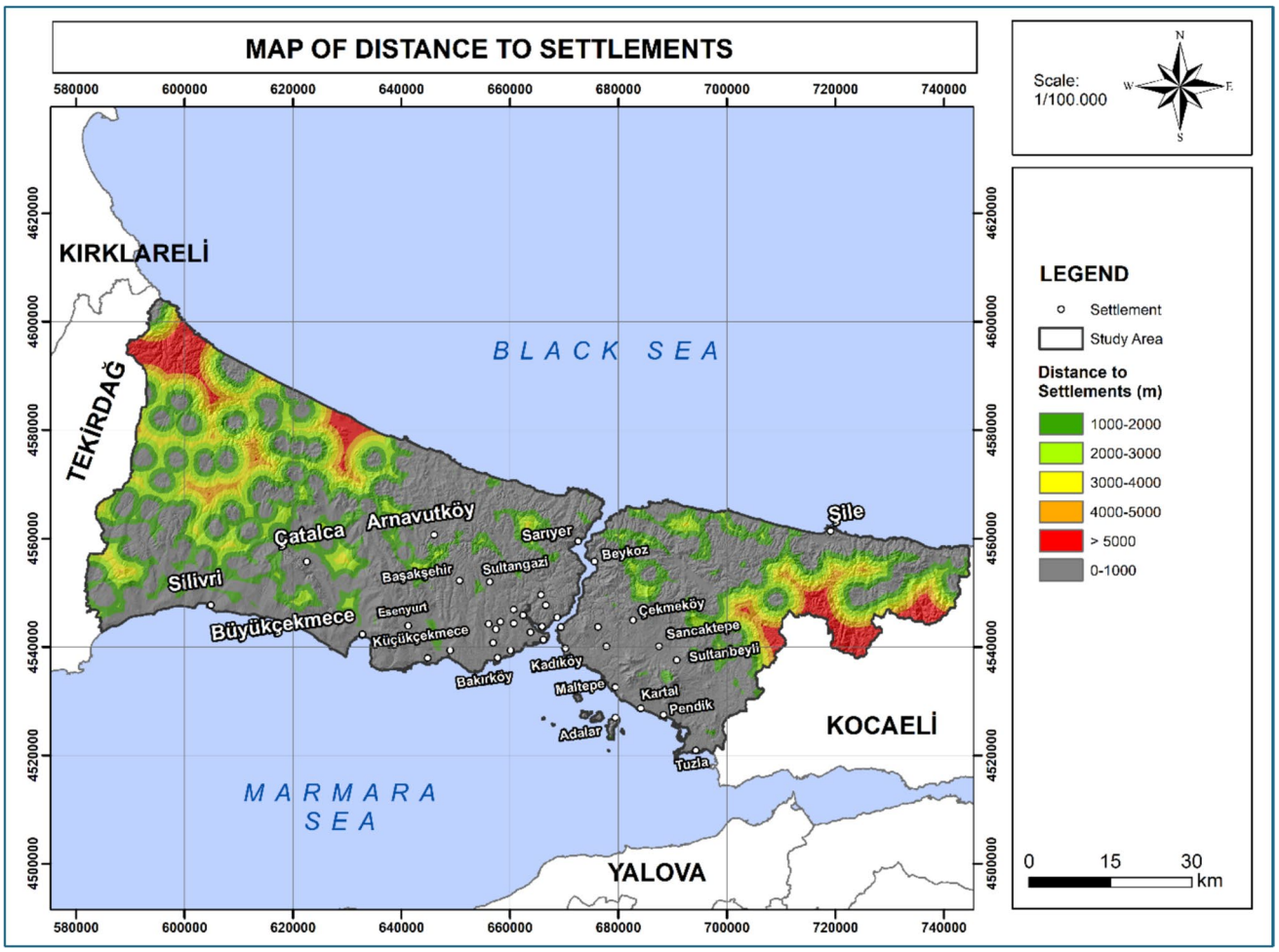

Fig. 12 Map of distance to settlements

Table 9 Eligibility index

Eligibility scale	Eligibility	Value
5	Very suitable	1000–2000 m
4	Suitable	2000–3000 m
3	Somewhat suitable	3000–4000 m
2	Lowly suitable	4000–5000 m
1	Not suitable	> 5000 m
0	Not suitable at all (Exclude)	0–1000 m

of importance was delegated to three experts, whose details are provided in Table 12.

The RANCOM methodology used in the study was developed through a weighting process involving stakeholders with expertise in disaster management, waste management, and environmental sustainability in Istanbul.

The composition of the expert panel includes not only academic expertise but also representatives from institutions directly responsible for post-disaster waste management in Istanbul, such as municipalities and central government agencies.

The selection of experts on the panel was based on two key criteria: their professional experience and institutional positions. These experts were selected from among individuals who are familiar with the city's unique conditions and are directly involved with local regulations, implementation challenges, and post-disaster operational processes.

All experts have extensive field experience in waste management and disaster response in Istanbul and represent municipal authorities, national environmental agencies, and academia. This targeted selection ensured that local knowledge about Istanbul's specific regulatory, logistical, and geographical conditions was incorporated into the weighting process.

Therefore, despite the panel being numerically limited (consisting of three people), the composition of the panel provides sufficient robustness and representativeness for the

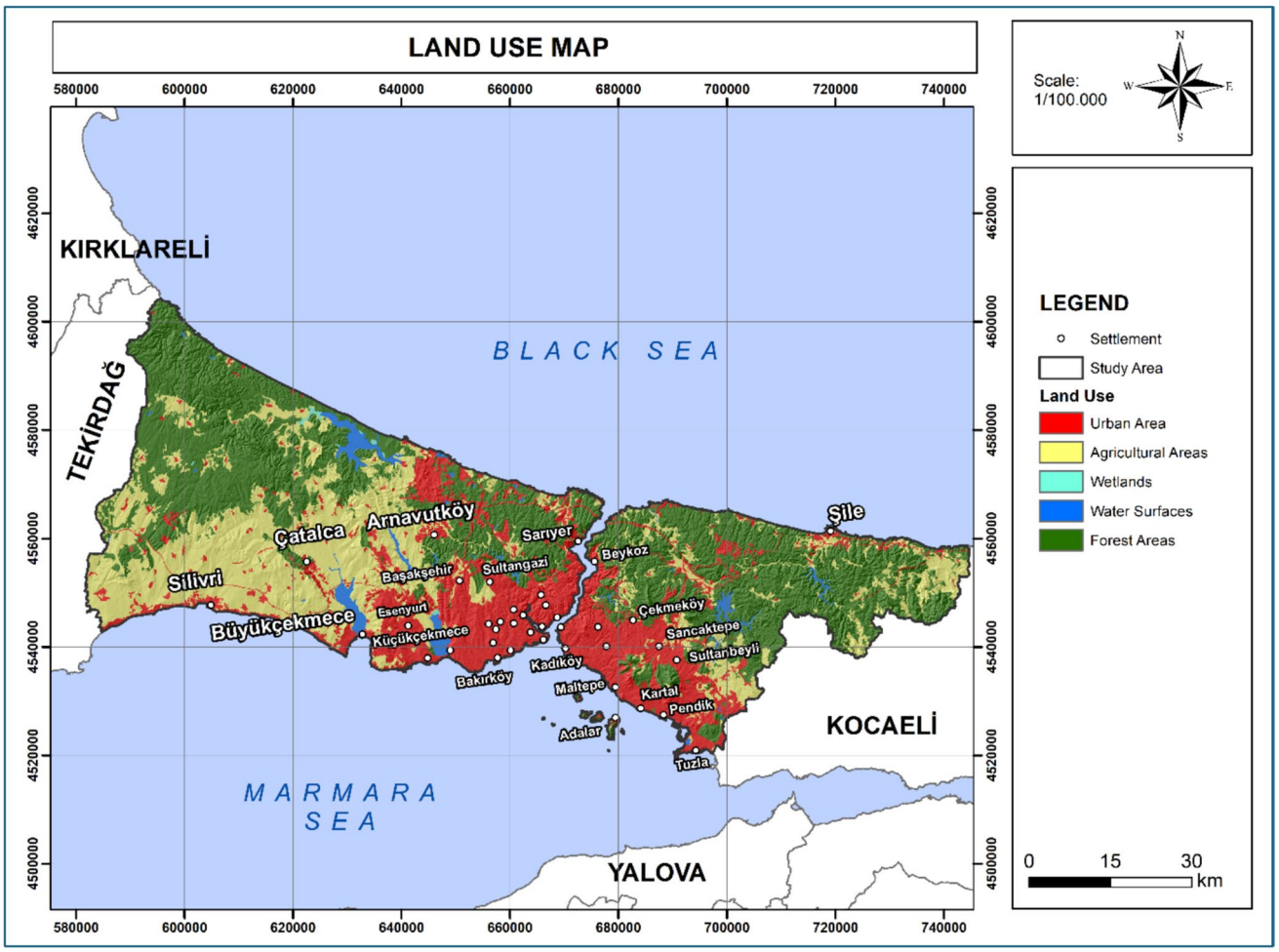

Fig. 13 Land use map

Table 10 Eligibility index

Eligibility scale	Eligibility	Value
4	Somewhat suitable	Agriculture areas
3	Moderately suitable	Urban areas
2	Lowly suitable	Forest areas
1	Not eligible (Exclusion)	Wetlands
0	Strongly not applicable (Exclude)	Water surfaces

Table 11 Eligibility index

Eligibility scale	Eligibility	Value
4	Very suitable	0–50 m
3	Suitable	50–100 m
2	Somewhat suitable	100–150 m
1	Lowly suitable	150–200 m
0	Not suitable at all (Exclude)	> 200 m

purpose of this study, thanks to the experts' decision-making authority and practical experience.

The experts defined the relationship between the importance of criteria C_i and C_j. The criteria were then assigned a ranking for each expert, with the smallest value representing the most significant importance in the ranking. These rankings are shown in Table 13.

Step 2: *Formulate the ranking comparison matrix*

The expert's comparisons result in the Matrix of Ranking Comparison, where the *MAC* has dimensions of $\times n$, with n representing the number of criteria considered. In the location selection problem, the *MAC* is a 10×10 matrix. Each criterion is systematically compared with others to establish all ranking relationships. The tournament method is applied to define the *MAC* for each expert. The matrices for all three experts are given in Eq. (5).

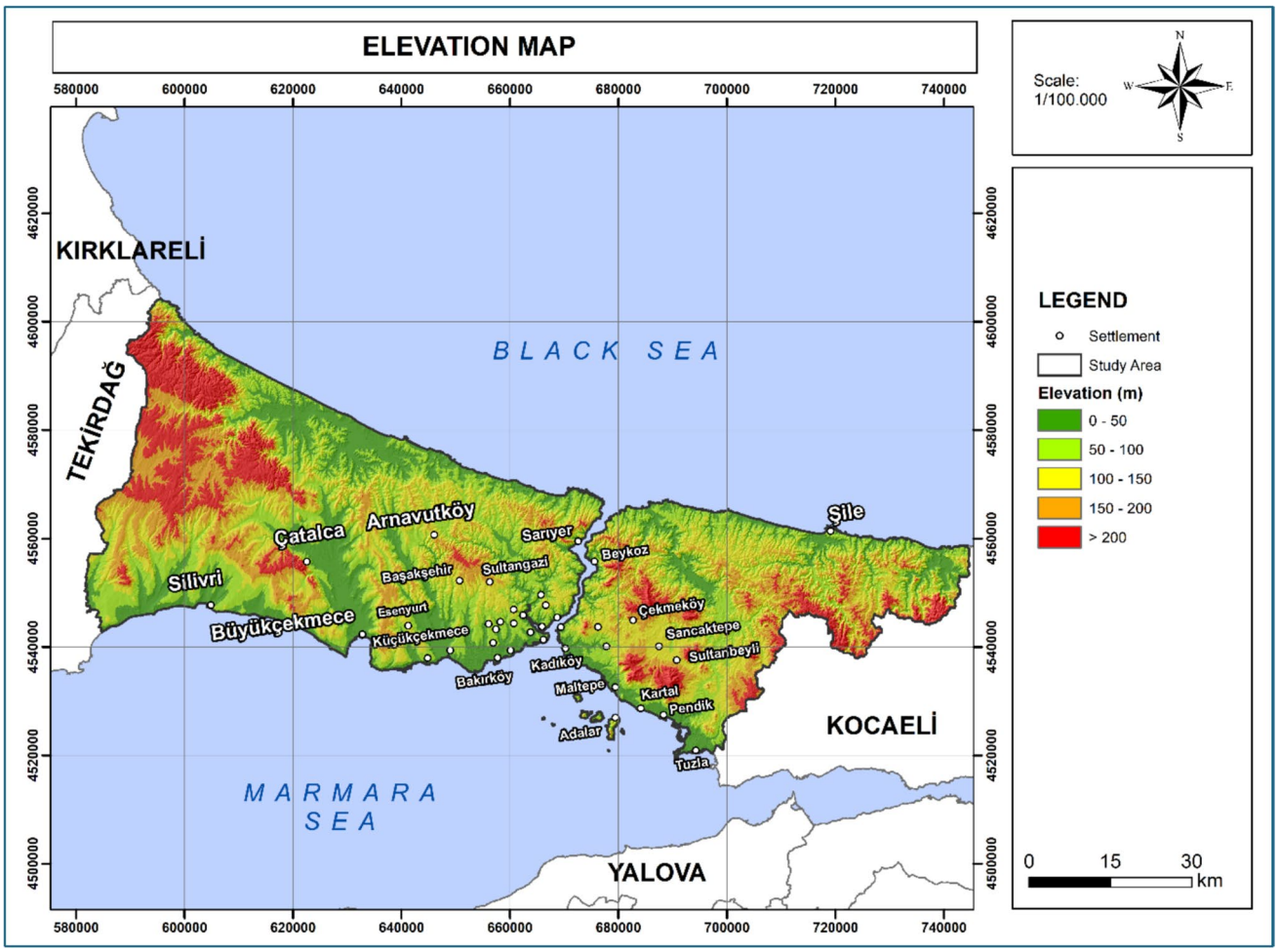

Fig. 14 Elevation map

Table 12 Information from the experts conducting the assessment

Participant experts	Job title	Field of specialization	Work experience (Years)
Expert 1	Environmental engineer, PhD, Director of Waste Management at the Metropolitan Municipality	Waste management practices in municipalities	15
Expert 2	Department director at the Ministry of Environment, Urbanization, and Climate Change	Waste management	20
Expert 3	Professor of Environmental Engineering	Waste management, solid waste, environmental technologies	23

Table 13 Expert's criteria rankings

	Ci									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Expert1	6	5	4	1	2	7	8	3	9	10
Expert2	1	8	7	10	3	6	2	5	4	9
Expert3	1	4	2	10	5	8	3	6	9	7

Table 14 Matrix of ranking comparison and summed and final criteria weights (Expert 1)

Criteria	Step 2										Step3	Step 4
	Matrix of ranking comparison										SCW_1	w_1
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
C1	0.5	0	0	0	0	1	1	0	1	1	4.5	0.0957
C2	1	0.5	0	0	0	1	1	0	1	1	5.5	0.1170
C3	1	1	0.5	0	0	0	0	1	0	0	3.5	0.0745
C4	1	1	1	0.5	1	1	1	1	1	1	9.5	0.2021
C5	1	1	1	0	0.5	1	1	1	1	1	8.5	0.1809
C6	0	0	0	0	0	0.5	1	0	1	1	3.5	0.0745
C7	0	0	0	0	0	0	0.5	0	1	1	2.5	0.0532
C8	1	1	1	0	0	1	1	0.5	1	1	7.5	0.1596
C9	0	0	0	0	0	0	0	0	0.5	1	1.5	0.0319
C10	0	0	0	0	0	0	0	0	0	0.5	0.5	0.0106
										$\sum$	**47**	

Table 15 Matrix of ranking comparison and summed and final criteria weights (Expert 2)

Criteria	Step 2										Step 3	Step 4
	Matrix of ranking comparison										SCW_2	w_2
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
C1	0.5	1	1	1	1	1	1	1	1	1	9.5	0.1900
C2	0	0.5	0	1	0	0	0	0	0	1	2.5	0.0500
C3	0	1	0.5	1	0	0	0	0	0	1	3.5	0.0700
C4	0	0	0	0.5	0	0	0	0	0	0	0.5	0.0100
C5	0	1	1	1	0.5	1	0	1	1	1	7.5	0.1500
C6	0	1	1	1	0	0.5	0	0	0	1	4.5	0.0900
C7	0	1	1	1	1	1	0.5	1	1	1	8.5	0.1700
C8	0	1	1	1	0	1	0	0.5	0	1	5.5	0.1100
C9	0	1	1	1	0	1	0	1	0.5	1	6.5	0.1300
C10	0	0	0	1	0	0	0	0	0	0.5	1.5	0.0300
										$\sum$	**50**	

Table 16 Matrix of ranking comparison and summed and final criteria weights (Expert 3)

Criteria	Step 2										Step 3	Step 4
	Matrix of ranking comparison										SCW_3	w_3
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10		
C1	0.5	1	1	1	1	1	1	1	1	1	9.5	0.1900
C2	0	0.5	0	1	1	1	0	1	1	1	6.5	0.1300
C3	0	1	0.5	1	1	1	1	1	1	1	8.5	0.1700
C4	0	0	0	0.5	0	0	0	0	0	0	0.5	0.0100
C5	0	0	0	1	0.5	1	0	1	1	1	5.5	0.1100
C6	0	0	0	1	0	0.5	0	0	1	0	2.5	0.0500
C7	0	1	0	1	1	1	0.5	1	1	1	7.5	0.1500
C8	0	0	0	1	0	1	0	0.5	1	1	4.5	0.0900
C9	0	0	0	1	0	0	0	0	0.5	0	1.5	0.0300
C10	0	0	0	1	0	1	0	0	1	0.5	3.5	0.0700
										$\sum$	**50**	

$$
\boldsymbol{MAC}_1 = \begin{bmatrix}
0.5 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 \\
1 & 0.5 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 \\
1 & 1 & 0.5 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
1 & 1 & 1 & 0.5 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 0 & 0.5 & 1 & 1 & 1 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0.5 & 1 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 0 & 1 & 1 \\
1 & 1 & 1 & 0 & 0 & 1 & 1 & 0.5 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5
\end{bmatrix}
$$

$$
\boldsymbol{MAC}_2 = \begin{bmatrix}
0.5 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 0.5 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 1 & 0.5 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 1 & 0.5 & 1 & 0 & 1 & 1 & 1 \\
0 & 1 & 1 & 1 & 0 & 0.5 & 0 & 0 & 0 & 1 \\
0 & 1 & 1 & 1 & 1 & 1 & 0.5 & 1 & 1 & 1 \\
0 & 1 & 1 & 1 & 0 & 1 & 0 & 0.5 & 0 & 1 \\
0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0.5 & 1 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0.5
\end{bmatrix} \quad (5)
$$

$$
\boldsymbol{MAC}_3 = \begin{bmatrix}
0.5 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 0.5 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\
0 & 1 & 0.5 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 0 & 0 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0.5 & 1 & 0 & 1 & 1 & 1 \\
0 & 0 & 0 & 1 & 0 & 0.5 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 & 1 & 1 & 0.5 & 1 & 1 & 1 \\
0 & 0 & 0 & 1 & 0 & 1 & 0 & 0.5 & 1 & 1 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0.5 & 0 \\
0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0.5
\end{bmatrix}
$$

Step 3. *Calculate the summed criteria weights*

Based on the *MAC* values obtained for each expert in the previous step, the horizontal vectors of the Summed Criteria Weights (*SCW*) have been calculated as follows. In other words, the Summed criteria weights (SCW) vector was obtained by taking the sum of each row in the MAC matrices. This calculation was calculated separately for all expert opinions.

$$
\mathbf{SCW}_1 = \begin{bmatrix} 4.5 \\ 5.5 \\ 3.5 \\ 9.5 \\ 8.5 \\ 3.5 \\ 2.5 \\ 7.5 \\ 1.5 \\ 0.5 \end{bmatrix} \mathbf{SCW}_2 = \begin{bmatrix} 9.5 \\ 2.5 \\ 3.5 \\ 0.5 \\ 7.5 \\ 4.5 \\ 8.5 \\ 5.5 \\ 6.5 \\ 1.5 \end{bmatrix} \mathbf{SCW}_3 = \begin{bmatrix} 9.5 \\ 6.5 \\ 8.5 \\ 0.5 \\ 5.5 \\ 2.5 \\ 7.5 \\ 4.5 \\ 1.5 \\ 3.5 \end{bmatrix} \quad (6)
$$

For example: The calculation for row 1 of MAC_1 Matrix is as follows.

$=0.5+0+0+0+0+1+1+0+1+1=4.5$

Step 4:*Determine the final weights of the criteria*

In this step, the final criteria weights were calculated by normalizing the SCW values calculated for each expert. Equation (4) was used for this process. The final weights calculated for the TSAs location selection problem are below (7). In addition, Tables 14, 15 and 16 show all values calculated for the three experts.

$$
\mathbf{w}_1 = \begin{bmatrix} 0.0957 \\ 0.1170 \\ 0.0745 \\ 0.2021 \\ 0.1809 \\ 0.0745 \\ 0.0532 \\ 0.1596 \\ 0.0319 \\ 0.0106 \end{bmatrix} \mathbf{w}_2 = \begin{bmatrix} 0.1900 \\ 0.0500 \\ 0.0700 \\ 0.0100 \\ 0.1500 \\ 0.0900 \\ 0.1700 \\ 0.1100 \\ 0.1300 \\ 0.0300 \end{bmatrix} \mathbf{w}_3 = \begin{bmatrix} 0.1900 \\ 0.1300 \\ 0.1700 \\ 0.0100 \\ 0.1100 \\ 0.0500 \\ 0.1500 \\ 0.0900 \\ 0.0300 \\ 0.0700 \end{bmatrix} \quad (7)
$$

For example: SCW Total for Expert.$_{1 = 4.5 + 5.5 + 3.5 + 9.5 + 8.5 + 3.5 + 2.5 + 7.5 + 1.5 + 0.5 = 47}$

For C1, $w_1 = 4.5/47 = 0.0957$

Step 5: *Combining the weights of experts*

In the final stage, each expert is considered to be of equal importance and the final weights are calculated by taking the arithmetic average of the expert weights.

The three experts participating in the evaluation have similar levels of professional experience (15–23 years) and were selected from complementary institutions such as academia, local government, and national environmental management. Therefore, it was assumed that the experts' opinions had equal weight in the weighting process. Accordingly, the final criterion weights were obtained by taking the simple arithmetic average of each expert's individual weights. This ensures that information from different areas of expertise is integrated in a balanced manner and that the transparency of the method is maintained. (Table 17)

$$
w_{\text{final}} = \frac{w_{E1} + w_{E2} + w_{E3}}{3}
$$

Example Calculation (for criterion C1)

: $W_{C1=}(0.0957 + 0.1900 + 0.1900)/3 = 0.159.$

A significant value of the criterion weight indicates the criterion exerts a greater influence on selecting a suitable location. In contrast, a small value means that it exerts a lesser impact. Upon calculating the criterion weights, it becomes evident that criterion C1, which possesses the highest criterion weight, is the most significant criterion

Table 17 Weights and rankings of criteria

Criteria	Description	Criteria weight	Criteria ranking
C1	Distance from surface water sources	0.159	1
C2	Distance to protected areas	0.099	6
C3	Distance to environmentally sensitive areas	0.105	5
C4	Distance to fault lines	0.074	7
C5	Flood zones	0.147	2
C6	Slope	0.071	8
C7	Distance to roads	0.124	3
C8	Distance to the nearest settlement	0.120	4
C9	Land use	0.064	9
C10	Elevation	0.037	10

in site selection. Conversely, criterion C10 is the least important criterion.

Constructing the suitability map

In the final stage, maps were created using weighted overlay analysis in the ArcGIS program. The overlay and merging process performed after these maps enabled the identification of suitable alternative debris waste collection areas. This process was carried out by considering the ranking of criteria weights determined by the RANCOM method. Figure 15 presents a suitability map showing the locations of candidate areas. The resulting suitability index map shows areas with different suitability levels for TSA. The green areas on the map indicate the most suitable regions, while the gray areas indicate unsuitable regions.

Studies conducted on satellite images have resulted in 15 candidate sites being proposed for the Anatolian and European sides. Since the European side is larger than the Anatolian side in terms of population density, demographic structure, and surface area, and therefore has a higher potential for debris production, more candidate points have been identified for the European side. Nine candidate points have been identified for the European side and six for the Anatolian side, and these points are shown in Figs. 16 and 17.

Information regarding the coordinates, area, and ownership status of the identified candidate sites is provided in Table 18. The coordinates, size, and ownership information for these areas have been evaluated in detail.

The current waste management infrastructure in Istanbul includes integrated waste disposal facilities operated by the Istanbul Metropolitan Municipality, which comprise structures such as regular landfill sites and recycling plants. There are also waste transfer stations where waste is collected from the source and transferred to these facilities before disposal, as well as landfill sites for the disposal of construction and demolition waste. These waste disposal facilities are located in Kömürcüoda in the Şile district on the Anatolian side and in Odayeri in the Eyüpsultan district and Seymen Waste Disposal Facilities in the Silivri districts on the European side. Facilities with suitable location, infrastructure, capacity, and accessibility can also be used as TSA in emergencies. The locations of these facilities are shown on the map in Fig. 15.

When selecting optimal locations for TSA, spatial comparison factors such as compatibility with existing waste management infrastructure and proximity to these facilities should be taken into account.

Land ownership and size are among the most important factors in TSA selection. The size of the site depends on the amount of debris stored and processed. The site must be large enough to process various debris materials, store heavy equipment, and allow trucks and large processing equipment to maneuver. Considering past disaster data, experiences, and operational conditions, it is estimated that at least 40 hectares of land will be needed to process 0.76 million cubic meters of debris (FEMA 2007). For Istanbul, 25 million tons of debris waste is expected to be generated after a possible severe earthquake (Istanbul Metropolitan Municipality 2019). In this case, 820 hectares of land will be needed for the waste.

Since waste generation sources will be dispersed across multiple TSA points, and existing integrated waste disposal facilities or transfer stations may also be used, the identified areas are deemed sufficient.

In particular, the ownership status has been considered a critical selection criterion due to the time-consuming nature of potential expropriation processes. In this regard, areas under public ownership appear to be more advantageous.

Based on this information and considering other factors, the No. 12 Site on the Anatolian side and the No. 1 Site

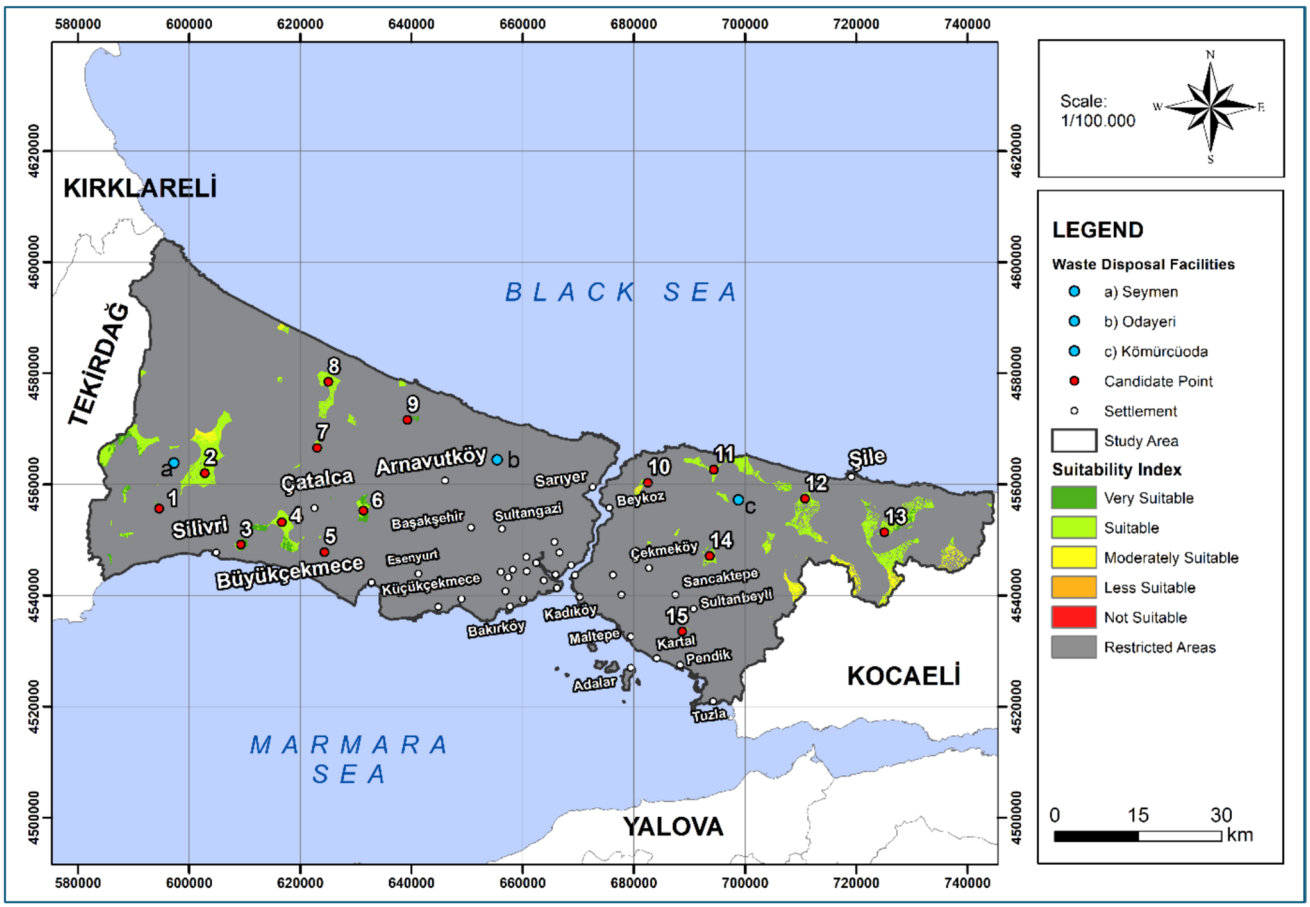

Fig. 15 TSAs candidate point map

on the European side stand out due to their proximity to the waste disposal site and their status as state property. Additionally, the No. 15 Site on the Anatolian side is noteworthy due to its proximity to areas with high population density and where a large amount of debris waste is expected.

The methodology developed in this study was applied in the context of a potential earthquake scenario in Istanbul. This methodology can be used in various regions around the world and in the context of different disaster scenarios. However, to obtain meaningful results, it is crucial to determine appropriate site selection criteria based on the region under investigation and the type of disaster. To map these criteria using GIS, it is necessary to obtain and work with up-to-date and accurate data. Furthermore, to eliminate subjectivity in the study, it is possible to obtain a more objective result by relying on the contributions of stakeholders who are familiar with the relevant disaster scenario and region and have sufficient knowledge on the subject, rather than relying on the opinion of a single expert when weighting the criteria. Considering these points, it is clear that the methodology will find a wide range of applications.

The selection of TSA for disaster waste should be based on a comprehensive assessment covering physical and spatial suitability as well as operational and economic factors. This multidimensional approach will contribute to the more effective, sustainable, and environmentally sensitive management of post-disaster response and recovery processes.

Other theoretical developments in the main categories of the study and their implications for practice are shown in Table 19.

In determining the TSA criteria, the study drew upon guidelines prepared by organizations such as FEMA, EPA, and UNEP/OCHA. There are international examples demonstrating how the guidelines prepared by these organizations are applied in real disaster scenarios. The Christchurch earthquake in New Zealand (Domingo and Luo 2017), the use of government-approved temporary debris storage sites during the 2011 Great East Japan Earthquake (MOEJ 2011), the establishment of risk-based temporary debris storage areas by UNEP during the Haiti earthquake (UNEP

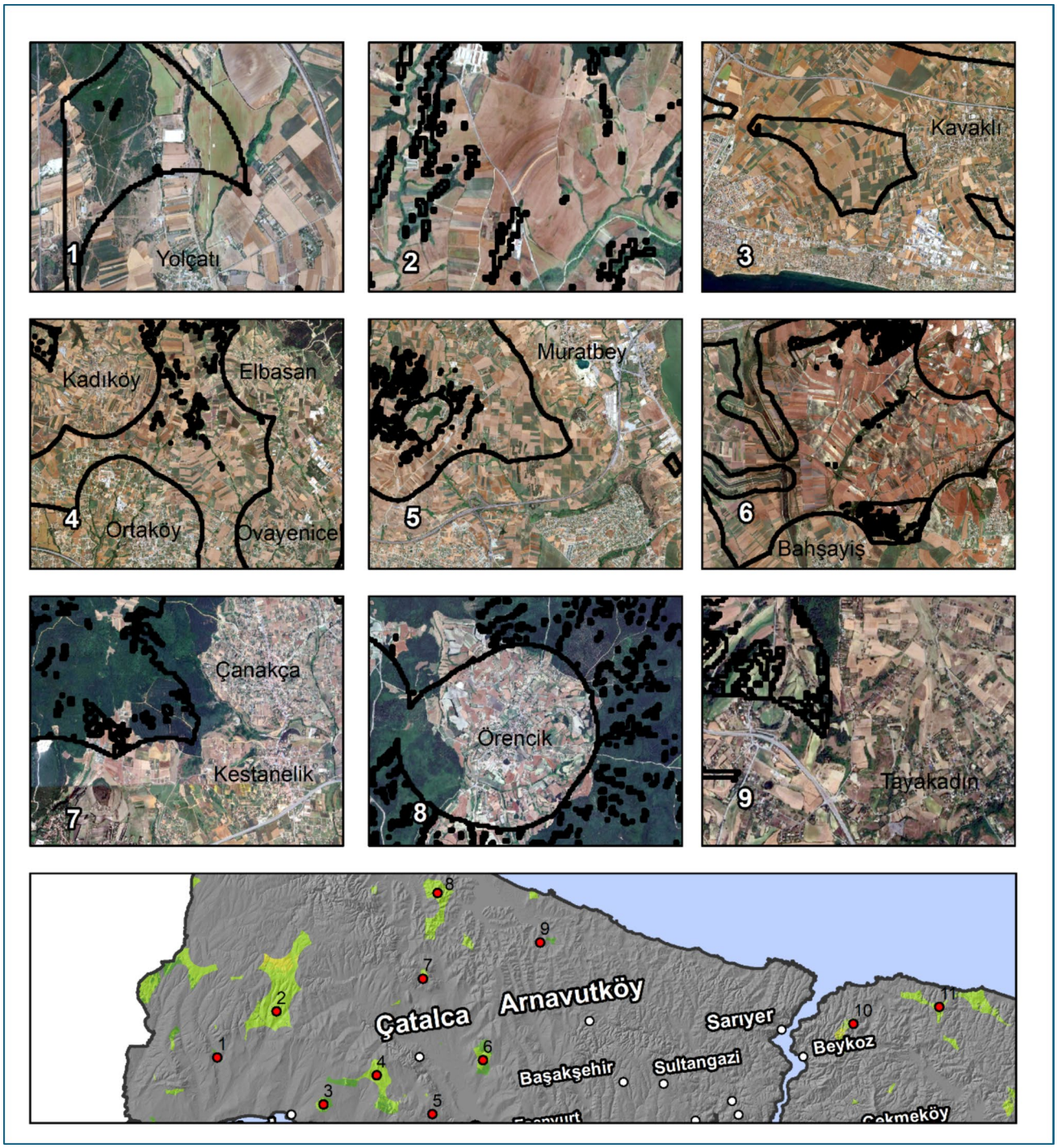

Fig. 16 European side TSAs candidate points map

2011), and the implementation of UNEP/OCHA guidelines at the municipal level during the Nepal earthquake (UNEP/OCHA 2015) can be cited as examples of these good practices. These international events demonstrate that the criteria used in our study are consistent with globally accepted best practices and validate the applicability and robustness of the proposed TSA site selection methodology.

The criteria established by the study for TSA site selection are entirely consistent with the fundamental constraints outlined in post-disaster waste management guidelines from

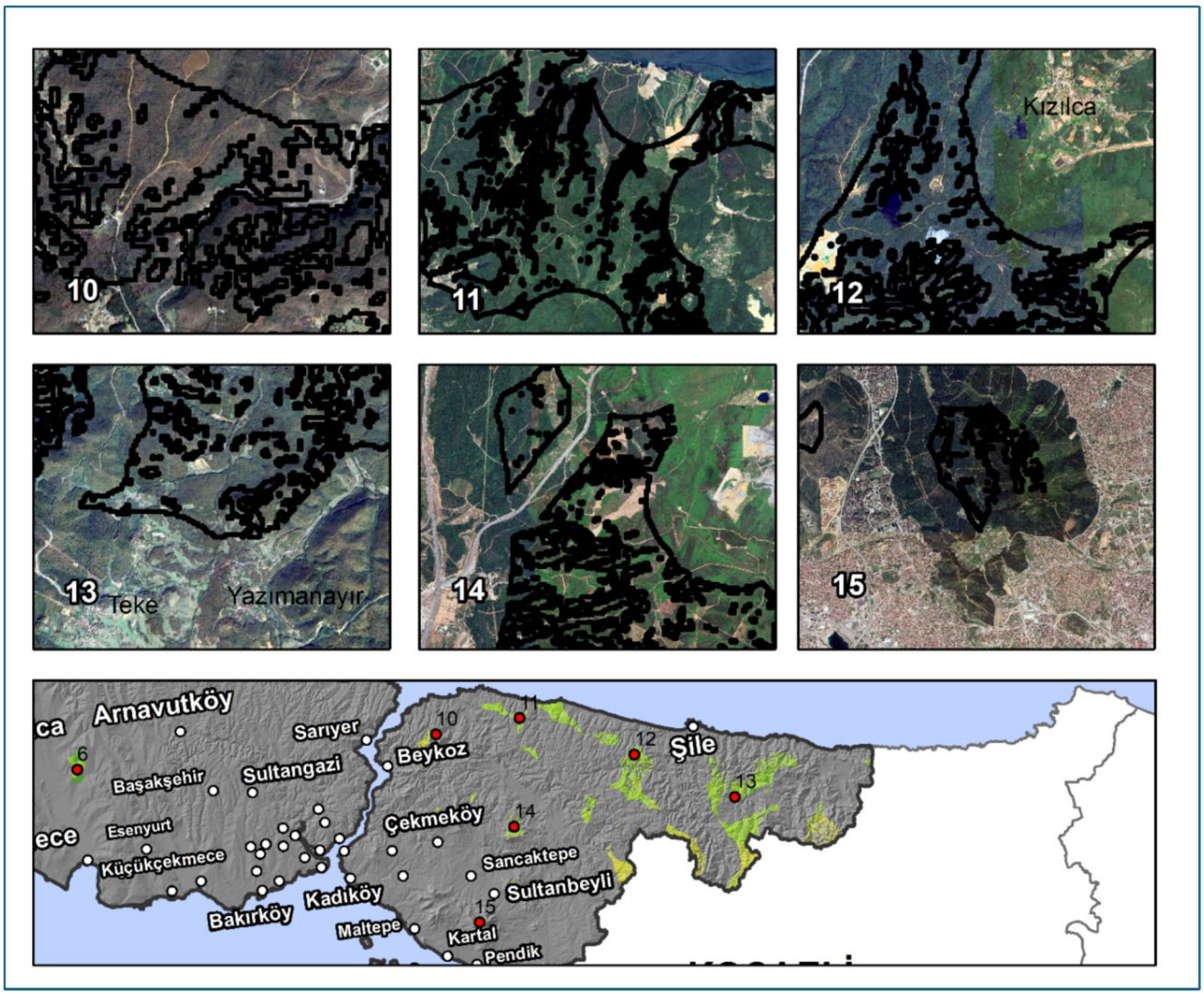

Fig. 17 Anatolian (Asian) side TSAs candidate points map

international organizations such as the United Nations (UN), FEMA, EPA, and UNEP/OCHA. Studies in the literature demonstrate that the problem is addressed and criteria are established to minimize environmental, geological, and public health risks in TSA selection (Cheng and Thompson 2016; Habib and Sarkar 2017; Kamdar et al. 2019; Demir and Dinçer 2023).

When the study is evaluated in terms of environmental impacts, the criterion with the highest weight in the RANCOM method is "Distance from Surface Water Sources." This directly aligns with the need to "prevent water pollution," as emphasized in international literature (especially the UNEP/OCHA guidelines). The potential for hazardous substances to leak from debris and contaminate groundwater and surface water is also considered the most critical risk in the literature (Demir and Dinçer 2023).

The prominence of the C4 (Distance from Fault Lines) and C5 (Distance from Flood Zones) criteria confirms that post-disaster site selection studies in the literature prioritize safety and environmental protection over logistical convenience (Wang et al. 2019). This study supports a risk-based disaster management approach that accounts for geological constraints in a metropolis such as Istanbul.

The research findings were evaluated against the relevant UN Sustainable Development Goals and are presented in Table 20 (UN 2025).

These assessments highlight the study's qualitative contributions to environmental, spatial, and managerial

Table 18 Characteristics of the identified TSA candidate points

Region	Coordinates longtitude latitude	Area (m^2)	Owner district
1	28,12,748 41,14,669	6.549	Public Silivri
2	28,22,626 41,20,302	50.211	Private Silivri
3	28,30,133 41,08642	33.988	Private Silivri
4	28,38,952 41,12,177	10.880	Private Çatalca
5	28,48,027 41,07213	7.600	Private Çatalca
6	28,56,489 41,13,827	25.710	Private Çatalca
7	28,46,824 41,24,086	2.202	Private Çatalca
8	28,49,488 41,34,752	16.392.635	Public Çatalca
9	28,6628 41,28,356	18.340	Private Arnavutköy
10	29,17,569 41,17,355	610.868	Public Beykoz
11	29,31,787 41,19,173	15.097.553	Public Beykoz
12	29,51,153 41,1408	19.986.136	Public Şile
13	29,67,932 41,08264	17.027	Private Şile
14	29,3041 41,05232	28.289.604	Public Çekmeköy
15	29,2415 40,93,093	6.496.135	Public Kartal

sustainability rather than providing direct quantitative measurements for specific UN Sustainable Development Goals. The SDG connections are therefore interpretive and contextual.

Overall, the findings demonstrate that the proposed TSA planning approach contributes comprehensively to multiple UN Sustainable Development Goals by integrating environmental protection, public health, resilient infrastructure, and sustainable resource use into disaster waste management. The study not only supports operational efficiency in post-disaster processes but also aligns with global sustainability principles by reducing environmental risks, strengthening institutional preparedness, and promoting circular economy practices. This holistic contribution highlights the broader significance of TSA identification as a strategic tool for sustainable and resilient urban development.

The research also reveals that Turkey's current knowledge base and legal framework regarding TSAs remain insufficient for effective post-disaster waste management. This inadequacy indicates an urgent need for a comprehensive and independent legislative structure dedicated specifically to disaster waste management at the national level. Therefore, the study offers a valuable academic foundation for the development of such legislation and contributes to national level policy discussions.

Table 19 Advancements in theory and operational outcomes of the study's core themes

Key categories	Theoretical advancement	Practical impacts
Disaster waste site planning	Integrates spatial and decision-making models (GIS + RANCOM) to establish a replicable methodology for post-disaster debris site selection	Provides a location-based decision support tool for municipalities to pre-plan TSAs and reduce response time
Governance and stakeholder coordination	Emphasizes multi-actor cooperation and shared data for disaster management planning	Guides collaboration among municipalities, ministries, and agencies to ensure unified response actions
Policy and regulation development	Identifies legislative gaps in disaster waste management and proposes a theoretical basis for new national regulations	Supports formulation of a dedicated regulatory framework for post-disaster waste in Turkey
Sustainability and logistics	Links debris logistics with sustainability concepts (cost, emissions, environmental protection)	Optimizes transport and minimizes environmental impacts in post-earthquake operations
Transferability of the model	Demonstrates adaptability of the GIS–RANCOM framework across different countries and disaster types	Encourages integration of this model into international disaster preparedness and mitigation strategies

Table 20 The impact of research findings in the context of the UN Sustainable Development Goals

Sustainable Development Goal (SDG)	Purpose	The contribution and importance of the study
SGD3	Good health and well-being	The unregulated storage of post-disaster waste causes air, water, and soil pollution, threatening public health. This study aims to reduce the risk of pollution-related diseases by keeping TSA away from water sources (C1) and residential areas (C8). Effective waste management is critical in preventing public health crises
SDG9	Industry, Innovation and Infrastructure	The research aims to increase the infrastructure resilience of a large metropolis such as Istanbul. The integrated use of GIS and RANCOM offers an innovative and scientific approach to disaster management. In addition, mobile units for recycling and on-site processing contribute to the creation of resilient infrastructure by converting debris waste into new resources
SDG11	Sustainable cities and communities	This study aims to increase the resilience of a megacity like Istanbul, which is vulnerable to earthquakes, against disasters. The prior identification of TSAs supports the creation of inclusive and sustainable cities. Effective waste logistics accelerate the recovery process, facilitating the city's return to normalcy
SDG12	Responsible consumption and production	The study recommends not only the disposal of construction and demolition waste but also its separation, recovery, and reuse. Integrating materials obtained from construction and demolition waste into the circular economy increases resource efficiency and reduces waste volume. This approach represents a significant step toward sustainable waste management
SDG13	Climate action	Reducing the distance waste is transported lowers carbon emissions and air pollution caused by transportation. Effective waste separation contributes to mitigating climate change by reducing landfill volume and methane emissions
SDG14-15	Life below water-life on land	SDG 14 and SDG 15 targets are supported by TSA selection criteria. The study aims to protect water ecosystems and biodiversity by keeping TSAs away from surface water sources (C1) and environmentally sensitive areas such as nature reserves (C2-C3)

Limitations and future works

As this is a preliminary study, detailed engineering analyses, soil surveys, and environmental impact studies must be conducted in the proposed candidate areas. The study is based on technical and spatial criteria; however, social acceptance by the community is a critical factor in sensitive issues such as debris management. Public perception, psychosocial impacts, and local acceptance processes are beyond the scope of this study and are recommended to be addressed in future research.

Although cost analyses, particularly transportation distances and infrastructure investments, are decisive in TSA selection, this study is limited to preliminary analyses for decision support. Necessary economic assessments should be the subject of advanced feasibility studies. Additionally, limitations regarding the timeliness and accuracy of some data may affect the precision of GIS-based analyses.

Table 21 Validation matrix

Reference class	Restricted	Low	Moderate	Suitable	Highly suitable	User's accuracy (%)
Restricted	140	0	0	0	0	100
Low	0	5	0	0	0	100
Moderate	0	0	14	3	1	77.78
Suitable	0	0	0	29	0	100
Highly Suitable	0	0	0	2	6	75
Producer's Accuracy (%)	100	100	100	85.29	85.71	–

Validation assessment

Due to limited field accessibility and the vastness of the study area, reference data from high-resolution satellite imagery (Google Earth) was used for accuracy assessment. Images with a spatial resolution of 0.5–1 m enabled the visual differentiation of the five defined suitability classes. Two hundred randomly selected points across the study area were subjected to image analysis, and each point was assigned to a suitability class.

These reference data were compared with GIS-based classification to create a 5 × 5 error matrix; user and producer accuracies were calculated, and overall accuracy and Cohen's kappa coefficient were obtained. Table 21 shows an overall accuracy of 92% and a kappa coefficient of 0.94. 194 out of 200 examples were classified correctly. These results indicate an "almost perfect" match between the model outputs and the image-based reference data.

Conclusion

Identifying TSAs for disaster waste is vital for resilient urban planning, particularly in earthquake-prone megacities like Istanbul. The absence of pre-designated TSAs creates significant vulnerability, as rapid management of large debris volumes becomes nearly impossible without predetermined logistics. This study underscores the need for carefully planned storage sites to ensure rapid response, environmentally responsible recovery, and efficient resource allocation after a destructive seismic event.

a guiding framework for authorities responsible for earthquake preparedness in Istanbul.

Because disaster management requires collaboration among municipalities, local administrations, and central institutions, this study offers a framework for authorities responsible for earthquake preparedness in Istanbul.The proposed approach supports coordinated action and shared strategies across stakeholders, strengthening the city's overall resilience. In this regard, the study represents a substantial step toward enhancing Istanbul's capacity for effective post-disaster operations.

The hybrid methodology developed in this study is adaptable to various disaster types and applicable across different geographical contexts both in Turkey and internationally. By minimizing transportation distances and optimizing logistical processes, the model contributes to sustainable economic and ecological goals. These benefits include reduced logistical costs and lower atmospheric emissions associated with waste transport, making the methodology suitable for integration into broader national and international disaster management strategies.

The province-wide assessment identified 15 potential TSAs with 92% classification accuracy and a kappa coefficient of 0.94, indicating strong consistency between model outputs and reference data. These results confirm the scientific rigor and practical value of the model, while emphasizing the importance of strategic TSA planning and institutional cooperation ahead of disasters. Ultimately, the framework strengthens Istanbul's preparedness and offers a scalable approach that can guide disaster waste management efforts in varied global contexts.(https://data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2024-53783)

Authors contribution Miraç Fatma Uzun: Investigation, Methodology, Formal analysis, Validation, Visualization, Writing—Original Draft. Özge Nalan Bilişik: Investigation, Methodology, Conceptualization, Supervision, Writing—review & editing. Hayri Baraçlı: Conceptualization, Supervision.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interest to disclose.

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References

Akbari V, Rajabi MA, Chavoshi SH, Sham R (2008) Landfill site selection by combining GIS and fuzzy multi-criteria decision analysis, case study: Bandar Abbas, Iran. World Appl Sci J 3(Supplement 1):39–47

Ayaim MK, Fei-Baffoe B, Sulemana A, Miezah K, Adams F (2019) Potential sites for landfill development in a developing country: a case study of Ga south municipality Ghana. Heliyon 5(10):1–8. https://doi.org/10.1016/j.heliyon.2019.e02537

Bilgilioglu SS, Gezgin C (2022) Suitable site selection for landfill with the integration of geographic information systems (GIS) and fuzzy analytical hierarchy process (FAHP) methods in Nevsehir. Afyon

Kocatepe Univ J Sci Eng 22:836–849. https://doi.org/10.35414/akufemubid.1105426
Boonmee C, Arimura M, Asada T (2018) Location and allocation optimization for integrated decisions on post-disaster waste supply chain management: on-site and off-site separation for recyclable materials. Int J Disaster Risk Reduct 31:902–917. https://doi.org/10.1016/j.ijdrr.2018.07.003
Campbell JB (2007) Introduction to remote sensing, Remote 4. The Guilford Press, New York
Cheng C, Thompson R (2016) Application of Boolean logic and GIS for determining suitable locations for temporary disaster waste management sites. Int J Disaster Risk Reduct. 20:78–92. https://doi.org/10.1016/j.ijdrr.2016.10.011
Congalton RG (1991) A review of assessing the accuracy of classifications of remotely sensed data, remotely sensed data. Remote Sens Environ 37:35–46. https://doi.org/10.1016/0034-4257(91)90048-B
Demir A, Dincer AE (2023) Efficient disaster waste management: identifying suitable temporary sites using an emission-aware approach after the Kahramanmaraş earthquakes. Int J Environ Sci Technol 20:13143–13158. https://doi.org/10.1007/s13762-023-05123-0
Dogdu G, Alkan SN (2023) Management of post-earthquake construction and demolition waste: 6 February, 2023 Kahramanmaraş Earthquake disasters. Artvin Coruh Univ J Eng Sci 1(1):38–50. https://doi.org/10.1111/mice.12410
Domingo N, Luo H (2017) Canterbury earthquake construction and demolition waste management: issues and improvement suggestions. Int J Disaster Risk Reduct 22:130–138. https://doi.org/10.1016/j.ijdrr.2017.03.003
Emergency Management and Homeland Security Division (2008) Michigan department of state police. Local disaster debris management planning handbook. MSP/EMHSD Pub. 109a
EPA (2019) Planning for natural disaster debris
FEMA (2007) Public assistance debris management guide. Washington, D.C, U.S. Dept. of Homeland Security, Federal Emergency Management Agency
Gabrielli F, Amato A, Balducci S, Magi GL, Beolchini F (2018) Disaster waste management in Italy: analysis of recent case studies. Waste Manag 71:542–555. https://doi.org/10.1016/j.wasman.2017.10.012
Grzeda S, Mazzuchi TA, Sarkani S (2014) Temporary disaster debris management site identification using binomial cluster analysis and GIS. Disasters 38(2):398–419. https://doi.org/10.1111/disa.12040
Habib MS, Sarkar B (2017) An integrated location-allocation model for temporary disaster debris management under an uncertain environment. Sustain Supply Chain Manag J 9(5):716. https://doi.org/10.3390/su9050716
Hahashi H, Katsumi T (1996) Generation and management of disaster waste. Special Issue Soils Found Japanese Geotech Soc 36:349–358. https://doi.org/10.3208/sandf.36.Special_349
Istanbul governorship provincial directorate of disaster and emergency (2023) Istanbul provincial disaster mitigation plan. Istanbul Governorship, Istanbul
Istanbul Metropolitan Municipality, (2019) Istanbul earthquake workshop
Istanbul Metropolitan Municipality (2021) Management plan for potential debris in the event of a destructive earthquake in Istanbul
Istanbul Planning Agency (2024) The heritage of the past and the possibilities for the future in Istanbul
Jalloul H, Choi J, Yesiller N, Manheim D, Derrible S (2022) A systematic approach to identify, characterize, and prioritize the data needs for quantitative sustainable disaster debris management. Resour Conserv Recycl 180:106174. https://doi.org/10.1016/j.resconrec.2022.106174
Jensen JR (2005) Introductory digital image processing: a remote sensing perspective, 3rd Edition. Pearson Prentice Hall, Upper Saddle River, NJ
Kamdar I, Ali S, Bennui A, Techato K, Jutidamrongphan W (2019) Municipal solid waste landfill siting using an integrated GIS-AHP approach: a case study from Songkhla, Thailand. Resour Conserv Recycl 149:220–235. https://doi.org/10.1016/j.resconrec.2019.05.027
Kim J, Deshmukh A, Hastak M (2014) Selecting a temporary debris management site for effective removal. In: Proceedings of the 10th international conference of the international institute for infrastructure resilience and reconstruction (I3R2), Purdue University, West Lafayette, Indiana, USA, pp 674–687. https://doi.org/10.5703/1288284315362
Kishimoto K, Okajima T, Yan W (2017) Modelling the site selection of temporary yards for disaster waste treatment: case study of Enshu Area, Shizuoka Prefecture, Japan. Int J Soc Soc Manag Syst 11(1):170–179
Lee YH, Kim YC, Lee HK (2022) Framework for selection of temporary disaster waste management sites for post-flood recovery in Seoul, South Korea. Int J Disaster Risk Reduct 71(102832):1–15. https://doi.org/10.1016/j.ijdrr.2022.102832
Lontoc GD, Diola MB, Peralta MH (2023) Multi-criteria evaluation of suitable locations for disaster waste storage sites: the case of Cavite, Philippines. J Mater Cycles Waste Manag 25:2794–2808. https://doi.org/10.1007/s10163-023-01705-9
Ministry of the Environment Japan (MOEJ) (2011) Disaster waste management guidelines after the great East Japan earthquake. Government of Japan
Ministry of the Environment (2018) Japan, Tokyo. Disaster waste management guideline for asia and the pacific Japan, pp 100–8975. https://www.env.go.jp/en/headline/2383.html
Montoya AGA, Saucedo ALB, Padilla FH (2021) Location of a temporary site to earthquake waste separation. Case study: Mexico City, In: Proceedings of the international conference on industrial engineering and operations management, Monterrey, Mexico
Nickdoost N, Jalloul H, Choi J (2022) An integrated framework for temporary disaster debris management sites selection and debris collection logistics planning using geographic information systems and agent-based modeling. Int J Disaster Risk Reduct 80:1–30. https://doi.org/10.1016/j.ijdrr.2022.103215
Onan K (2013) Disaster waste management: an evolutionary multi—objective optimization approach. Marmara University, Istanbul
Onan K, Ülengin F, Sennaroğlu B (2015) An evolutionary multi-objective optimization approach to disaster waste management: a case study of Istanbul Turkey. Expert Syst Appl 42(22):8850–8857. https://doi.org/10.1016/j.eswa.2015.07.039
Presidency of disaster and emergency management (2022) Turkey disaster response plan
Republic of Turkey Ministry of Environment and Forestry (2017) Regulation on landfilling of waste.
Republic of Turkey Ministry of Environment and Forestry (1991) Regulation on solid waste control
Republic of Turkey Ministry of Forestry and Water Affairs (2017) Regulation on the protection of drinking-use water basins.
Republic of Turkey Ministry of Interior Turkish Statistical Institute. https://www.data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2024-53783
Rwanga S, Ndambuki JM (2017) Accuracy assessment of land use/land cover classification using remote sensing and GIS. Int J Geosci 8:611–622. https://doi.org/10.4236/ijg.2017.84033
Saffarzadeh A, Shimaoka T, Nakayama H, Hanashima T, Yamaguchi K, Manabe K (2016) Tasks and problems involved in the handling of disaster waste upon April 2016 Kumamoto earthquake, Japan. Nat Hazards 89:1273–1290. https://doi.org/10.1007/s11069-017-3021-1

Sakai S, Yoshioka T, Tojo Y, Tasaki T, Takigami H, Watanab K (2013) Strategy for separation and treatment of disaster waste: a manual for earthquake and tsunami disaster waste management in Japan Misuzu Asari. J Mater Cycles Waste Manag 15:290–299. https://doi.org/10.1007/s10163-013-0154-5

Sakai S, Poudel R, Asari M, Kirikawa T (2019) Disaster waste management after the 2016 Kumamoto earthquake: a mini-review of earthquake waste management and the Kumamoto experience. Waste Manag Res 37(3):247–260. https://doi.org/10.1177/0734242X18815948

Sałabun W, Shekhovtsov A, Kizielewicz B (2021) A new consistency coefficient in the multi-criteria decision analysis domain. In: Part I (ed) Computational science–ICCS 2021: 21st international conference, Krakow, Poland, proceedings. Springer, Cham, pp 715–727

Sengun T, Engin F, Siler M (2018) Use of GIS in the selection of solid waste warehouse areas: sample of Malatya. J of World Turks ZfWT 10(1):159–180

Senturk E, Erener A (2017) Determination of temporary shelter areas in natural disasters by GIS: a case study, Gölcük/Turkey. Int J Eng Geosci (IJEG) 2(03):84–90. https://doi.org/10.26833/ijeg.317314

Söder AB, Müller R (2011) Disaster waste management guidelines, Geneva Switzerland: United Nations Office fort he Coordination of Humanitarian Affairs Environmental Emergencies Section (UNEP/ OCHS Environment Unit)

Tabata T, Onishib A, Saekic T, Tsaib P (2019) Earthquake disaster waste management reviews: prediction, treatment, recycling, and prevention. Int J Disaster Risk Reduct 36(101119):1–7. https://doi.org/10.1016/j.ijdrr.2019.101119

Tajima R, Hirayama N, Osako M (2014) Theory and practice of pre - disaster planning for disaster waste management. Society Soc Manag Sys Internet J 9:1–12

UN (2025) The sustainable development goals report.

UNEP (2011) Haiti earthquake disaster waste management report. United Nations environment programme.

UNEP/OCHA (2015) Disaster waste management guidelines, Nepal earthquake.

Uzun H (2023) Evaluation of 6 February 2023 Kahramanmaraş Earthquakes in terms of infrastructure and waste Management, Academic Suggestions for the Aftermath of Kahramanmaraş Centred Earthquakes. https://doi.org/10.58830/ozgur.pub99

Wang Z, Hu H, Guo M, Gong J (2019) Optimization of temporary debris management site selection and site service regions for enhancing postdisaster debris removal operations. Comput Aided Civ Infrastruct Eng 34:230–247. https://doi.org/10.1111/mice.12410

Więckowski J, Kizielewicz B, Shekhovtsov A, Sałabun W (2023) RANCOM: a novel approach to identifying criteria relevance based on inaccuracy expert judgments. Eng Appl Artif Intell. https://doi.org/10.1016/j.engappai.2023.106114

Więckowski J, Wątróbskı J, Sałabun W (2024) Inaccuracies in expert judgment: Comparative analysis of RANCOM and AHP Methods in housing location selection problem. IEEE Access 12:142083–142100. https://doi.org/10.1109/ACCESS.2024.3443451

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