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Earthquakes in Kahramanmaras; Assessment of Affected Areas and Recommendations for Settlement Regeneration

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Abstract: On February 6, 2023, two catastrophic earthquakes hit Turkey, causing significant damage and casualties. The main causes of these results are improper constructions and settlement placements. Regions where earthquake damage is typical are cities developed on fertile agricultural lands. Site selection for land suitability is one of the main application areas of the Geographical Information System (GIS). The Multi-Criteria Decision Approach (MCDA) has provided consistent and sufficient alternatives to decision-makers for land use planning activities for many years. This study focused on a large area covering five provinces with a total area of 36.409 km2 as the whole region represents 110.000 km2 and is challenging to manage in a single segment. Moreover, the heaviest damages were observed in the study area. Nine criteria were considered while using the weighted overlay function of the GIS via the Analytical Hierarchical Process (AHP). Agricultural and forest regions were excluded from the scope and the entire study area; 84.0% unsuitable, 0.4% low suitable, 1.5% moderately suitable, 11.3% suitable, and 3.2% highly suitable areas were identified for the post-disaster regeneration of settlements.

Keywords: Earthquake, Geographical Information System (GIS), Analytical Hierarchical Process (AHP), Site selection, Weighted overlay

Introduction

Turkey is situated in a very active tectonic area (Fig. 1) with the Northern Anatolian Fault (NAF) and Eastern Anatolian Fault (EAF) zones running through the entire country (KOERI, 2023). For a long time, these two zones have caused powerful earthquakes. There have been numerous casualties, particularly in the last 100 years. The 1936 Erzincan earthquake caused 32.968 deaths with a moment magnitude (Mw) of 7.9, and the 1999 Golcuk-Izmit (Marmara) and Duzce earthquakes caused 18.243 deaths with a moment magnitude of 7.4 (KOERI, 2023. The devastating Kahramanmaras earthquake, which hit on February 6, 2023, caused at least 50.500 deaths and caused the greatest damage in 11 provinces in Southern Turkey with moment magnitudes of 7.7 and 7.6 in a nine-hour interval. According to the Ministry of Interior Disaster and Emergency Management Presidency (AFAD), over 6,000 aftershocks have been recorded since the 7.7-magnitude earthquake hit Turkey and Syria (AFAD, 2023). Many people are still missing. According to the World Bank Disaster Assessment Report, 2023, the earthquake and aftershocks that hit southern Turkey on February 6 caused more than $34 billion in damage to the country. This amount equals 4 % of Turkey's 2021 gross domestic product (GDP).

Two primary reasons for the disaster's high number of deaths are a lack of building code enforcement and incorrect urbanization site selection. In the cities affected by the February 2023 earthquake, the widespread use of ready-mixed concrete was seen at a later date. As a result, it is a typical and expected circumstance that the concrete quality of structures built in the 1980s and 1990s, and even at the beginning of the 2000s, was below the project concrete class. At the same time, flat iron was used as rebar. Therefore, it is possible to say that

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material weaknesses are one of the crucial factors in the collapse of the buildings built in these years or the heavy damage that they cannot be used (Turkiye Muhendislik Haberleri, 2023).

Regions where earthquake damage is typical are cities developed on fertile agricultural lands. Therefore, in weak ground conditions with deep bedrock and even on soils with liquefaction potential, 10-15 storey and flexible carrier system structures were severely damaged or collapsed entirely on February 6th. However, ground liquefaction may have occurred in some regions since structures that do not collapse but sink one storey or lean to the side have been recorded (Turkiye Muhendislik Haberleri, 2023).

Site selection for land suitability is one of the main application areas of the Geographical Information System (GIS). If adequate and proper criteria are defined, spatial analysis of GIS can provide viable options to decision-makers for optimal land use. Most of the studies in the literature focused on site selection problem for the landfilling area (Guler & Yomralioglu, 2017; Kamdar et al.,2019; Bilgilioglu et al., 2021; Dolui &Sarkar, 2021; Bilgilioglu, 2022;). However, there are few studies on landscape suitability for settlement, especially after an earthquake. Jena et al. (2019) used artificial neural networks and an analytical hierarchy process (AHP) to assess earthquake risk in Banda Aceh, Indonesia. They applied AHP to set criteria weights, grouped under susceptibility and hazard vulnerability. The aim was to evaluate potential hazards in Aceh City and provide technical recommendations to the urban planners. Dunford and Li (2011) evaluated the reconstruction activities in Wenchuan (China) after an earthquake of 8.0 on the Richter scale. Economic and social aspects of the recovery activities were considered, and areas suitable for reconstruction, appropriate suitable, and ecological reconstruction areas were classified, but GIS-based site selection was not included in their study.

Constructions of 405,000 new residences have been planned by the government in the Kahramanmaras earthquake area, according to the Post-Earthquake Assessment Report prepared by the Strategy and Budget Office (SBB, 2023). The location of new settlement sites will be critical in protecting people from future hazards and the environment from agricultural and forestry locations. This paper addresses a general review of the post-disaster area and recommendations on site selections using AHP and GIS for settlement regeneration, lacking in the scientific literature.

An Overview of the Disaster Area

The disaster area is located on and around the Eastern Anatolian Fault Zone (Fig. 1). Two consecutive earthquakes in Southeastern Turkey have affected eleven provinces (Adana, Adiyaman, Diyarbakir, Elazig, Gaziantep, Hatay, Kahramanmaras, Kilis, Malatya, Osmaniye, and Sanliurfa).

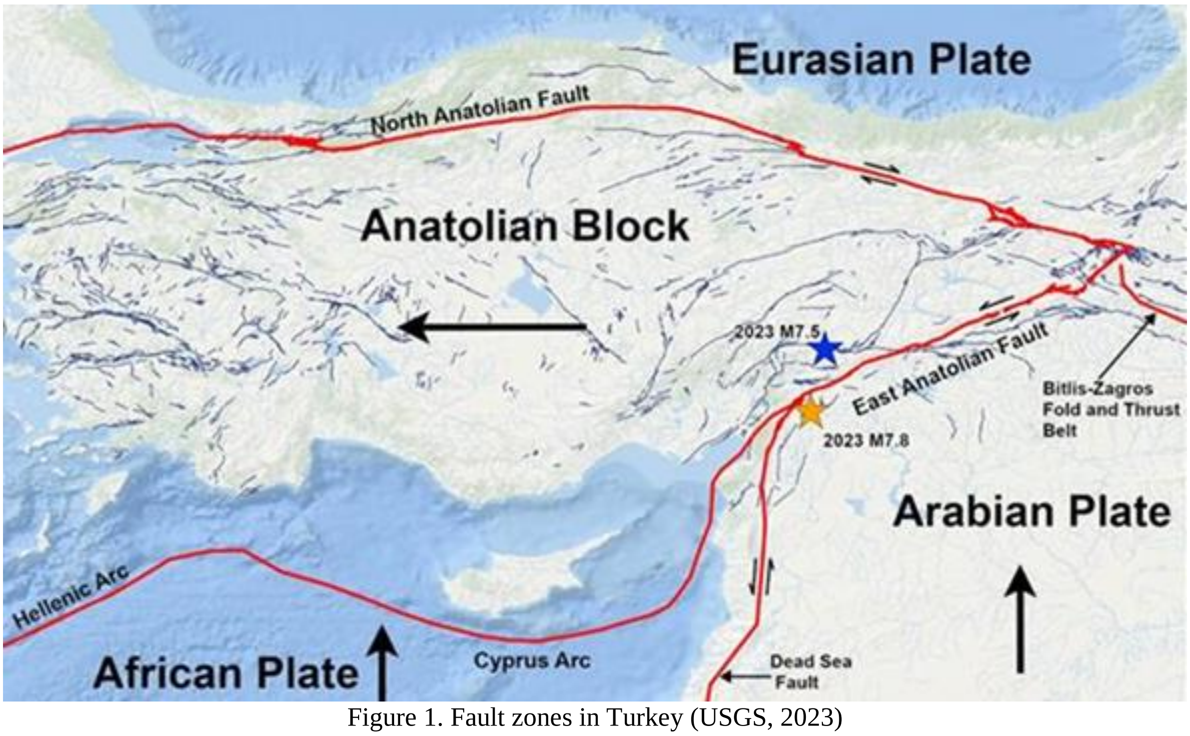

Figure 1. Fault zones in Turkey (USGS, 2023)

According to studies conducted by the Istanbul Technical University (ITU) and the Eurasia Institute of Earth Sciences, that fault zone is 550 km long and nearly 400 km long in section, causing 8-9 m positional shifts (ITU, 2023).

The first epicenter was at Yamacoba-Gaziantep, (06.02.2023 04:17), latitude 37º.1757- longitude 37º.0850, Mw=7.7, 5.4 km. depth and second epicentre is Ekinozu-Kahramanmaras, (06.02.2023 13:24, latitude 38º.0717- longitude 37º.2063), Mw=7.6, 5 km. depth (KOERI, 2023). Another third serious earthquake also happened at Samandag (Hatay) on February 20, 2023; Mw=6.4 and depth=13.4 km (36.0620 E, 36.1107 N).

Figure 2. The disaster area (General directorate of mapping, 2021)

96.7% of the population resides in cities and towns, 3.3% in villages, and 1.7 million immigrants (mainly from Syria) are in the area. According to SSB Report, 2023, with 637.222 independent units, the total number of destroyed, urgently needing to be demolished, and significantly damaged constructions was 227.027. In eleven provinces, 52% of all structures were built after 2001, 26.4% between 1981 and 2000, and 10% before 1980 (SBB, 2023).

There are no qualification requirements, including education level, to be a contractor. Quite recently, considerable attention has been paid to 797 individuals who are constructors or have official responsibility under legal issues. Another crucial issue is related to land use/planning. The entry flats of particular apartments have sunk into the ground as a result of inadequate attention for the soil research of settlements, particularly in Malatya and Hatay (Fig. 3).

Figure 3 Liquefaction-related building collapse (SSB Post-Earthquake Assessment Report, 2023)

As seen from Fig.4, most provinces in a disaster area are located on flat arable land with a 0-5^o slope. Hatay Province's airport and the highway between Hatay and Gaziantep have been significantly damaged, causing substantial harm in settlements.

Materials and Methods

Study Area

Kahramanmaras Earthquakes affected an area of over 110.000 km^2 in southeast Turkey (Fig. 2). Four 1:250.000 map sheets (Adana, Mersin, Gaziantep, and Kahramanmaras) covering a total area of 36.409 km^2 in the west with the most severe damages were utilized to choose the research region, as shown in Figs. 4.

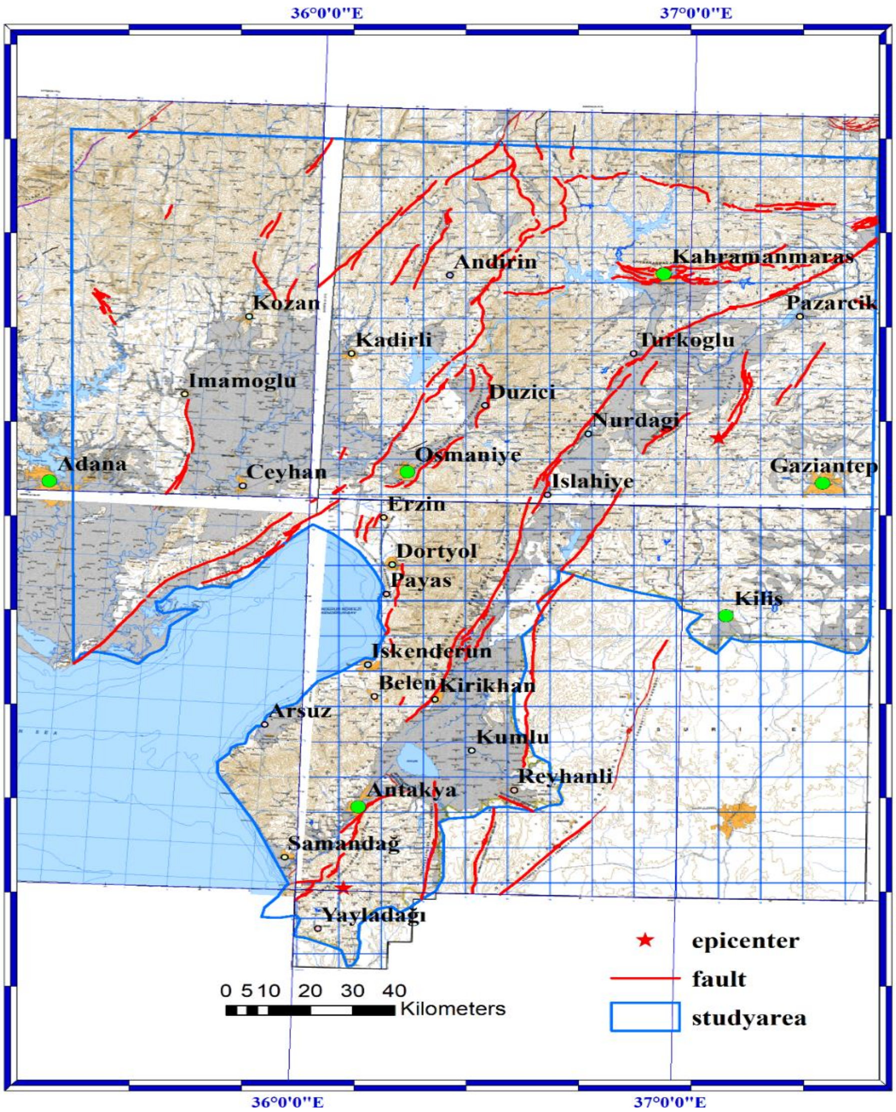

Figure 4. Study area

According to land use data (Corine, 2018), residential areas cover 610.9 km^2 and industrial areas cover 163.38 km^2 in the study region. The region's ground elevations vary between 0 to 2812 m. Nearly 60% of the land is hilly, while most settlements are on or near fault lines and flat areas.

Data Acquisition and Processing

This study intended to use the Multi-Criteria Decision Method (MCDM) in the Geographical Information System (GIS) by using AHP to assign weights to the specified criterion. Hence, data collection was implemented according to the criteria. Lithology is one of the most important criteria, but since all municipalities in the study area experienced significant damage and personal loss, there was no chance to obtain the data. Active fault line maps on a 1:250.000 scale are accessible on the General Directorate of Mineral Exploration and Research's website (MTA, 2023). Using ArcGIS 10.4, four raster map sheets were georeferenced, and active fault lines digitized in vector format are depicted as red lines in Fig. 4.

12.5 m resolution Alos Palsar Digital Elevation Model (DEM) data (EarthData, 2023) was used to create an area slope map. Because all raster data utilized in the study had 10 m pixel size, DEM data were resampled by 10 m pixel size. Sentinel-2 10 m high-resolution terrain-corrected satellite images (ESA, 2023) have been used to construct a study area mosaic using ArcGIS. Agricultural areas, forests, water bodies and watercourses, residential and industrial areas, and roads have been extracted from Corine 2018 data and verified-edited on Sentinel 2 images. Four airports in the study area were manually digitized from Sentinel images.

Criteria

The 1999 Marmara and 2023 Karamanmaras earthquakes provided conclusive evidence that soil characteristics have a significant role in building destruction even far from epicenters. Hatay province's Antakya city center is 134 kilometers from the first epicenter (Sofalica-Gaziantep); most of the province's settlements are on alluvial agricultural land and had heavy damage. As a result, the Strategy and Budget Office (SBB, 2023) reported that the study area experienced significant damage, with 215.255 units collapsed or demolished. According to the authors, a similar situation occurred in the Yalova Hacimehmet Plate area, with a narrow stream and alluvial plains used for agricultural activities for many years. After the Marmara Earthquake in 1999, nearly all of the eight-story structures in this area collapsed.

Distance from Fault Lines

It is well-known that seismic intensity is strongest near fault lines and in their immediate vicinity. (Degerliyurt, 2014; Kalafat et al., 2021; USGS, 2023). Official governmental declarations specify that new settlement zones must be at least 500 meters from fault lines (SBB, 2023). Academicians from the ITU Eurasia Institute of Earth Science conducted an observatory study along fault lines, defining strike slips of 8-8.9 m and observing the heaviest damages at Nurdagi, Hatay, and Kirikhan centers located near fault lines (ITU, 2023). In the present study, a minimum distance of 1000 meters from fault lines was chosen: 0-1 km (1: unsuitable), 1-2 km (2: low suitable), 2-3 km (3: moderately suitable), 3-4 km (4: suitable), <5 km (high suitable).

Distance from Agricultural Areas

According to the Turkish Statistical Institute, agricultural regions in the seismic zone account for 16% of all agricultural areas in Turkey (TUIK, 2022). As indicated by Zeydan et al. (2018), fertile agriculture areas should be kept out of settlement enlargement zones. This has led the authors to choose 250 m—minimum distance to agricultural areas.

Distance from Water Bodies

Many dam reservoirs and ponds provide drinking water to settlements, agricultural watering, and hydroelectric energy production. In the study on landslide susceptibility evaluation, Ambarwulan et al. (2022) selected a 100 m minimum distance from rivers, whereas Wang et al.,2022 used a 100 m minimum distance from rivers. To protect drinking water sources, the Istanbul Municipality has enacted a regulation (ISKI, 2011) on basin protection, which states that settlement is prohibited between a radius of 0–1000 meters. Based on the law, the same value was applied in this study.

Slope

The most commonly accepted slope suitability in the literature or in various studies (Degerliyurt, 2014; Partigoc, 2018; Ambarwulan et al., 2022) is less than 5-8%. Nevertheless, 6°-10° high suitable and 0°-5° suitable approaches were applied in this study, as the flat areas are generally agricultural fields in the region.

Distance from Forests

Like agricultural areas, the minimum distance from forests was maintained at 250 m.

Distance from Industrial Areas

Considering the environmental conditions such as pollution, noise, and traffic jams, the minimum distance was considered as 2 km.

Distance from Airports

The precise approach radius for an airport runway is 1800 m, and the minimum distance should be greater than 3 km (Directorate General of Civil Aviation, 2016).

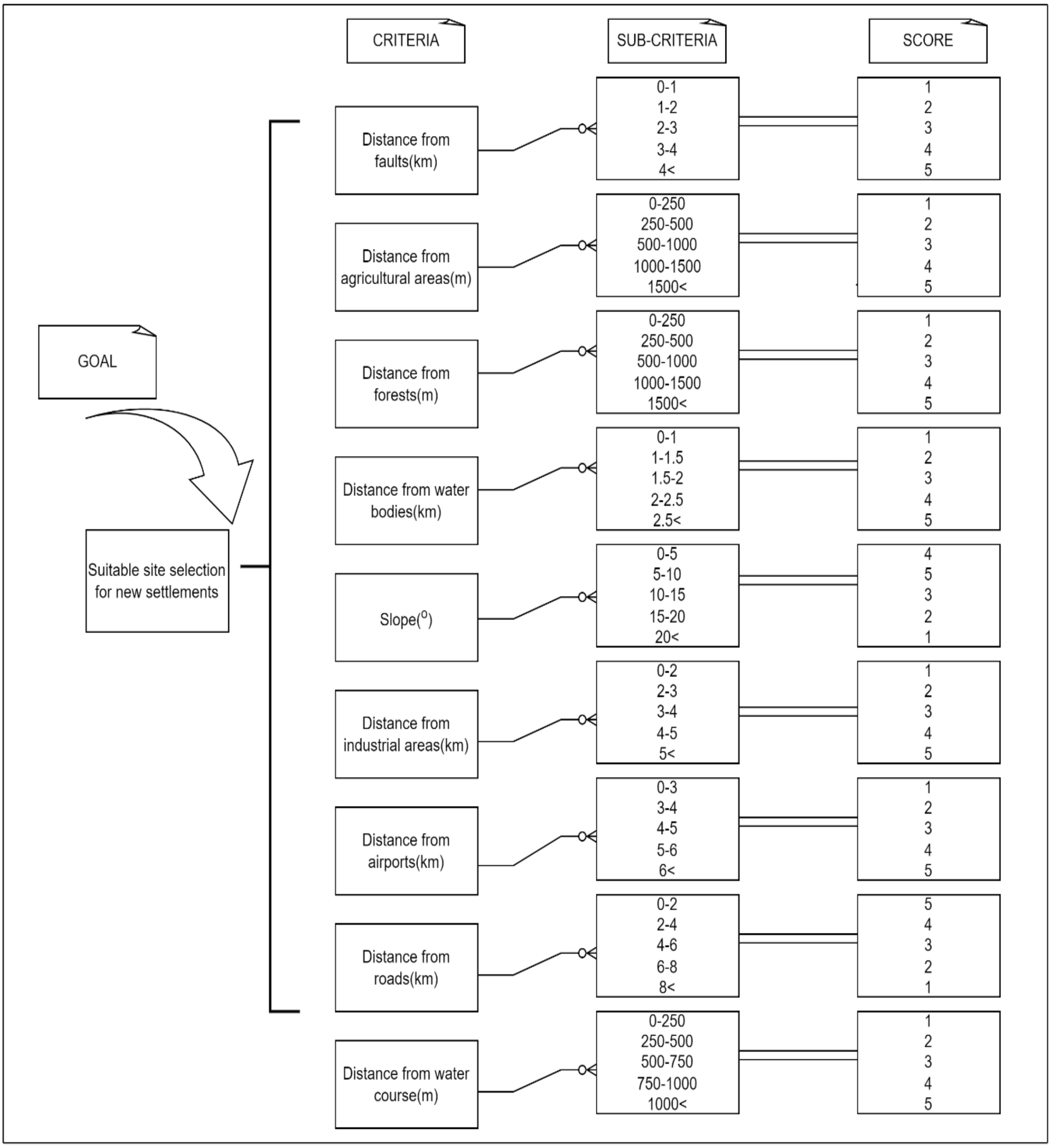

Figure 5. MCDM Conceptual design

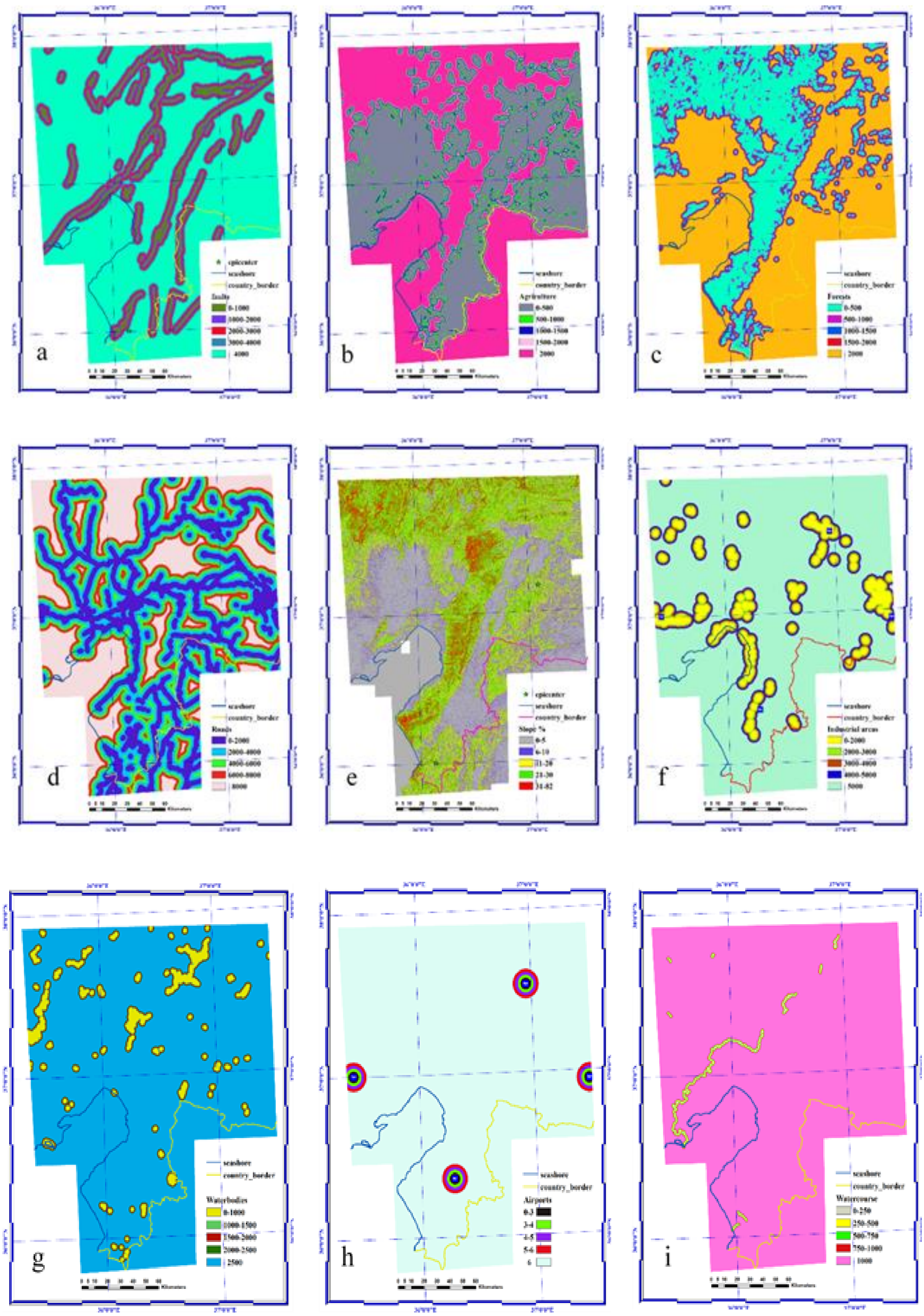

Figure 6. Thematic maps of criteria (a. Distance from fault lines, b. distance from agricultural areas, c. distance from forests, d. distance from water bodies, e. slope, f. distance from industrial areas, g. distance from airports, h. distance from roads, i. distance from the watercourse)

Distance from Roads

Access to major transportation routes is an essential economic consideration in developing a new settlement area. Therefore, a distance of 0 to 2 km is quite suitable.

Distance from Watercourse

In this study, 250 m was chosen as the minimal distance from watercourses. The conceptual design of the MCDM by GIS is shown in Fig. 5, considering nine criteria and sub-criteria ratings.

Weights by AHP

AHP is one of the most widely applied methods for assigning consistent weights to the criteria used in MCDM in order to provide options to decision-makers on land use planning activities (Ustaoglu et al., 2021; Liu., 2022; Kilicet al., 2023). According to Saaty (1980) AHP is a process that establishes a pair-wise comparison matrix of criteria. That step requires the researcher to conduct experiments on the subject under study so that it can be interpreted as a somewhat subjective component of the methodology. A fundamental scale with values ranging from 1 (equal importance) to 9 (great importance) was used to determine the priority score, as developed by Saaty et al. (1980). Table 1 shows the pairwise comparison matrix of this study.

Table 1. Pair-wise comparison matrix of criteria

CRITERIA	FL	AA	F	WB	S	IA	A	R	WT	W
FL	1	2	2	3	3	3	4	5	5	0.247
AA	1/2	1	2	2	3	3	3	4	5	0.190
F	1/2	1/2	1	2	3	3	3	4	4	0.160
WB	1/3	1/2	1/2	1	2	2	3	4	4	0.120
S	1/3	1/3	1/3	1/2	1	2	2	2	3	0.082
IA	1/3	1/3	1/3	1/2	1/2	1	2	3	3	0.075
A	1/3	1/3	1/3	1/3	1/2	1/2	1	2	3	0.057
R	1/5	1/4	1/4	1/4	1/2	1/3	1/2	1	2	0.039
WT	1/5	1/5	1/4	1/4	1/3	1/3	1/3	1/2	1	0.030
SUM	3.64	5.44	6.99	9.83	13.83	15.16	18.83	25.5	30	1

FL: Fault lines; AA: Agricultural areas; F: Forests; WB: Water bodies; S: Slope; IA: Industrial areas; A: Airports; R: Roads; WT: Watercourses; W: Weight

The eigenvector, which gives the criteria weights, is calculated by the solution of the normalized comparison matrix (Table 1). Eigenvalue (λ_{max}) was calculated to check consistency, the consistency index (CI) was calculated by CI= λ_{max}-n/n-1, where n represents the dimension of the matrix, and the consistency ratio (CR) was calculated as; CR=CI/RI, where RI is the random index shown in Table 2. If CR< 0.10, it is considered to be consistent. (Saaty, 1990). In this study, the following values: λmax = 9.3833, CI =0.048, and CR =0.033 have been calculated, and the weights in Table 1 were accepted as consistent.

Table 2. Random inconsistency indices for different values of n (Isalou et al.,2013)

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.90	1.12	1.24	1.35	1.41	1.45	1.49	1.51	1.48	1.56

Thematic layers (Fig. 6) were produced using Euclidean distance and reclassified with ArcGIS 10.4. In the weighted overlay, all raster data had a resolution of 10 m and were classified into five categories: 1: not suitable, 2: low suitable, 3: moderately suitable, 4: suitable, and 5: highly suitable.

Results and Discussion

The land suitability map can be seen in Fig. 7 as a result of a weighted overlay, with weights assigned using an AHP method. 84% of the research area is unsuitable for settlement regeneration due to the presence of forests and agricultural areas (Table 3).

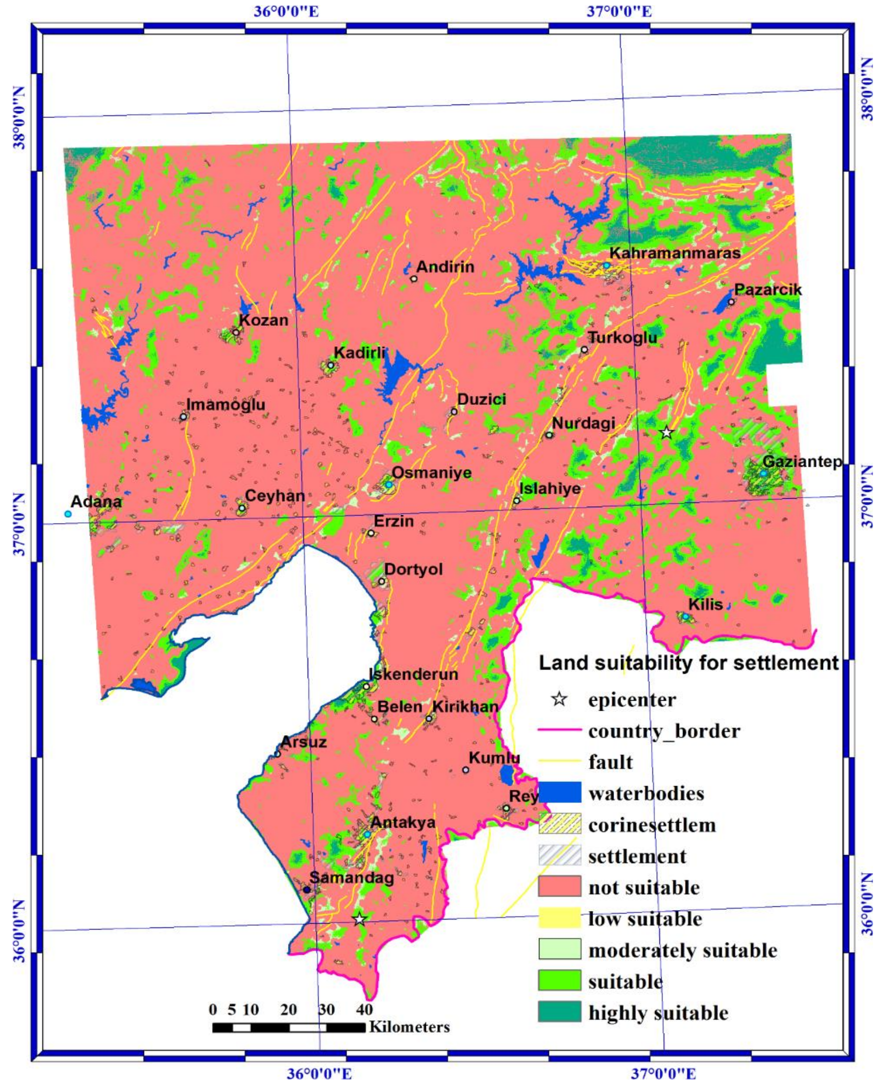

Figure 7. Suitability map for new settlements

Table 3. Suitability classes and area size

Class	Unsuitable	Low suitable	Moderately suitable	Suitable	Highly suitable
Area (ha)	2 406 395	20	24 128	367 474	76 285
%	84	0.4	1.5	11.3	3.2

However, it should be noted that data referring to geological ground characteristics are essential in such an application but were not applicable in our study due to the exceptional conditions in the municipalities. In addition to a suitable site selection process by GIS, geotechnical analysis must be completed at the optional locations before construction activities. The final map (Fig. 7) was superimposed on the Sentinel 2 satellite image of the study area and areas of existing locations of settlements measured by ArcMap 10.4. The following findings are evident;

- Kahramanmaras province covered 58.53 km^2 area (before the earthquake), and 0.09% of the city center was suitable, 8% was moderately suitable, and 91.1% was on the unsuitable area; the city center was on dense fault lines,
- The suitability map indicates that the city has to be relocated 5 kilometers to the North,
- Nurdagi, the closest settlement to the first epicenter, has a 7.58 km^2 area, of which 9.5% is appropriate, and 8.4% is moderately suitable,
- Hatay Province's City center, Antakya, has a 68.26 km^2 area, with 13% being moderately appropriate and 14% suitable.

In three provinces: Kahramanmaras 99.326 (Total: 481.362), Hatay 215.255 (Total: 847.380), and Gaziantep 29.155 (Total: 893.558), buildings have collapsed or have sustained significant damage. Even though Gaziantep is closer to the first epicenter (Yamacoba) than the other two provinces, buildings in that province have a significantly lower level of damage (SBB, 2023) than those with 3%, as it appears that most of them are in a suitable location. On the contrary, Hatay had the worst case in the region, constructed mainly on an alluvial area, as also indicated by ITU (2023).

Almost 58% of all settlements in Kadirli (in Osmaniye Province) are in suitable or moderately suitable locations but in Erzin (in Hatay Province) this rate is just 16.4% moderately suitable. As a result, low-rise structures and high-quality construction averted considerable damage in those regions.

Conclusions

There are many lessons to be learned from those two devastating earthquakes related to precautions, alleviating, and reviving activities before and after earthquakes. According to seismology experts such as Sengor, C. and Gorur, N., the NAF and EAF zones junctions at the North (Bingol-Karliova area) of the disaster area and potentially create destructive earthquakes in the near future. On the other hand, Turkey has already experienced two powerful earthquakes in the Marmara Region in 1999. and it is evident that individuals with management and decision-making responsibilities did not receive adequate training.

Most importantly, human life should be prioritized; governments must seek to improve the standard of living. Lithological characteristics, geotechnical analysis, and construction standards must never be overlooked; otherwise, terrible outcomes will be unavoidable. After an earthquake, a GIS-based disaster management system (also known as a disaster management information system) is a useful tool for organizing temporary settlements, suitable site selection for debris removal, logistic routes for aid materials, and site selection for permanent settlements.

Right after the Kahramanmaraş earthquake, there were many problems with first aid activities, a lack of coordination, delays in vital attempts, inappropriate tent locations (one near a river, another near the coast in Samandag city), and even wrong site selection for permanent settlements. Some of the temporary container houses were built on agricultural land, and domestic waste was transported to agricultural or nearby regions. Sanliurfa and Adiyaman provinces experienced massive flooding one month after the earthquake, and 18 people were killed. Sanliurfa province has experienced flooding on multiple occasions in the past, yet land use decisions have been made without considering topography, lithography, or other critical factors.

In conclusion, constructions can be performed in various soil conditions, but the soil should be improved to carry the superstructure loads safely. The right foundation system and superstructure carrier system should be selected according to the conditions, and it should not be forgotten that the design process should be carried out with a meticulous engineering approach, and expert engineers should supervise its design.

Scientific Ethics Declaration

The authors declare that the scientific, ethical, and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgments or Notes

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