IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 13 January 2024, accepted 28 January 2024, date of publication 31 January 2024, date of current version 9 February 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3360721

RESEARCH ARTICLE

DBDM: Dominance Based Decision Making and GIS Integrated Earthquake Vulnerability Assessment of Elazığ/Türkiye

MIHRIMAH ÖZMEN
Department of Industrial Engineering, Erciyes University, 38039 Kayseri, Turkey
e-mail: mihrimah@erciyes.edu.tr

This work was supported by the Scientific and Technological Research Council of Turkey under Project 121E406.

ABSTRACT Assessing earthquake vulnerability is important for comprehending the potential consequences of seismic events on human life and property. In Türkiye, where earthquakes pose a significant threat, earthquake hazard analysis is especially critical. Multi-criteria decision-making (MCDM) methods play a crucial role in earthquake vulnerability assessments by providing a structured and transparent approach to decision-making, considering several criteria such as building conditions, population density, accessibility, and more. The integration of Geographic Information Systems (GIS) with MCDM methods provides a powerful approach to earthquake vulnerability assessment. GIS enables the management of geographic data and facilitates the rank of alternatives. In this study, a novel MCDM method called Dominance Based Decision Making (DBDM) was introduced and the DBDM method was applied to rank renewable energy sources. Besides, we focused on assessing earthquake vulnerability in Elazığ, Türkiye with DBDM. The research evaluates the earthquake vulnerability of Elazığ's districts and its' central district neighborhoods (NH) by considering building conditions and GIS-based risk and hazard factors with DBDM. This research offers a systematic and structured approach to earthquake vulnerability assessment, providing valuable insights for disaster preparedness and risk mitigation strategies. The integration of MCDM methods with GIS enhances decision-making processes and contributes to better-informed choices in the face of seismic risks. The study's results reveal that Sivrice is the most earthquake vulnerable district and Sali Baba, Esentepe, Fevzi Çakmak, Olgunlar, and Aksaray are among the NHs most vulnerable to earthquakes in the Central District of Elazığ.

INDEX TERMS MCDM, GIS, disaster management, earthquake vulnerability assessment.

I. INTRODUCTION

In our contemporary and dynamically evolving world, decision-makers confront intricate challenges that necessitate a methodical and well-informed approach to MCDM techniques offer a systematic framework for addressing decision problems characterized by multi objectives, diverse criteria, and varying preferences [1]. Significant strides have been made in recent years within the domain of MCDM methodologies. Traditional approaches such as the Analytic Hierarchy Process (AHP) and Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS) have laid the basis for decision-making. Recent advancements in MCDM methodologies have introduced specialized techniques such as SPOTIS, COMET, SIMUS, and RANCOM [2], [3], [4], [5]. These innovative approaches contribute to the diversity of available methods, allowing decision-makers to adapt their strategies to specific decision problems. SIMUS, based on Mathematical Programming, follows a systematic process similar to AHP [3]. The COMET method is not susceptible to rank reversal, showcasing its superior accuracy in certain cases compared to TOPSIS and AHP in experimental studies [4]. SPOTIS avoids rank reversal by establishing a preference order based on the score

The associate editor coordinating the review of this manuscript and approving it for publication was Asad Waqar Malik.

matrix without relying on relative comparisons between alternatives [5]. RANCOM method, designed for determining criteria weights through expert knowledge. The method's efficacy relies on establishing the ranking order of criteria to derive the weights vector [2]. Nevertheless, innovative methodologies have arisen, including MCDM techniques that account for conflicting objectives, fuzzy-based strategies that accommodate uncertainty and imprecision, data-driven models harnessing machine learning and extensive data analytics, as well as hybrid approaches that integrate multiple methodologies [6]. Furthermore, MCDM techniques have discovered diverse applications in many areas. Ranging from business and management to engineering, environmental decision-making, healthcare, and public policy, these techniques have verifiably demonstrated their efficacy in addressing complex decision problems [7]. MCDM methods are instrumental due to their ability to address the intricate nature of decision-making involving multiple objectives, criteria, and stakeholders [8]. The significance of MCDM methods can be divided into several key aspects: a systematic approach, incorporation of multiple objectives, handling uncertainty and subjectivity, inclusion of stakeholder perspectives, and versatile applications.

MCDM methods provide a systematic and structured approach that helps decision-makers break down complex problems into manageable criteria, evaluate alternatives against these criteria, and make well-informed decisions based on defined rules [9]. This structured approach reduces ambiguity, ensures transparency, and fosters consistent decision-making. In many real-world decisions, multiple criteria need simultaneous consideration. MCDM methods allow for the explicit handling of these multiple criteria, enabling decision-makers to strike a balance among competing goals [10], [11]. They facilitate the capture of preferences and tradeoffs between objectives, aiding in the identification of optimal or satisfactory solutions that align with the preferences of the decision-maker. Decision-making often deals with uncertainty and subjectivity. MCDM methods offer techniques to manage uncertain information, such as employing fuzzy logic or probabilistic models, enabling robust decisions even in situations with incomplete or imprecise data [12]. Additionally, MCDM methods provide mechanisms to incorporate the subjective judgments and preferences of decision-makers, ensuring their perspectives are appropriately considered in the decision-making process. Many decision contexts involve multiple stakeholders with varying interests. MCDM methods facilitate the inclusion of multiple stakeholder perspectives by explicitly considering their criteria and preferences [13]. This participatory approach promotes fairness, inclusivity, and stakeholder engagement, resulting in decisions that garner broader acceptance and support. MCDM methods have found applications across various domains, including business, engineering, environmental management, healthcare, and public policy [14]. They offer valuable tools for addressing complex decision challenges in different fields, from strategic planning and project selection to resource allocation and risk assessment. Their adaptability makes them suitable for a wide range of decision-making scenarios. In essence, the significance of MCDM methods lies in their capacity to enhance decision-making through a structured, comprehensive, and inclusive approach [15]. By encompassing multiple objectives, criteria, and stakeholder perspectives, MCDM methods enable informed decision-making, enhance transparency, and lead to improved decision outcomes in complex and uncertain decision environments.

As detailed above, the literature has quickly evaluated MCMD methods. These methods play an important role in decision-making processes, used to evaluate many different criteria and alternatives. MCDM methods are used in technology, business, environment, and many other fields. Growth and scalability in technology have increased the availability and importance of MCDM methods. MCDM methods help evaluate different alternatives by considering several different criteria (usually performance measures or objectives). These methods make complex decision-making processes more structured and produce results in a transparent and traceable way. This enables decision-makers to understand why they chose a particular alternative and to verify that decisions are based on a logical basis. Widespread adoption of MCDM methods increases their usability to improve decision-making processes across different industries and disciplines. These methods are especially useful in solving complex and multidimensional problems. Additionally, these methods often make it easier to take into account the views and priorities of various stakeholders, which helps make more participatory and fair decisions [16]. In this study, a new MCDM method DBDM was proposed. DBDM is based on a one-to-one comparison of alternatives and dominance information. In the MCDM approaches literature, if an alternative was much better than the other alternative in terms of one criterion, the goodness of the others in terms of other criteria could be left in the background. In the DBDM method, just because one alternative is much better than the other alternative in terms of a criterion means the same thing. Thus, an alternative that is much better in terms of one criterion cannot overshadow alternatives that are better in other criteria. Both DBDM and traditional approaches SPOTIS, TOPSIS, VIKOR, ELECTRE, PROMETHEE, RANCOM, COMET, and SIMUS exhibit distinct characteristics in the realm of MCDM and provide diverse approaches to MCDM challenges. DBDM, as a novel method, concentrates on comparing alternatives and deriving dominance information. DBDM differentiates itself by focusing on comparing alternatives and utilizing dominance information. Unlike some counterparts, DBDM does not necessitate normalization steps, ensuring more results that are consistent. DBDM stands out for its simplicity and consistency, while RANCOM provides efficiency in handling complex problems. COMET introduces the concept of immunity to rank reversal, combining expert-based and objective approaches. Compared to COMET, DBDM obtains more objective results without the need for normalization steps and the problem of rank inversion. SIMUS, with its foundation in Mathematical Programming, aims to provide more objective expert opinions. TOPSIS, VIKOR, ELECTRE, and PROMETHEE, each employ normalization steps, requiring the standardization of alternatives. TOPSIS stands out in its approach, ranking alternatives based on their similarity and dissimilarity to the best and worst solutions. VIKOR, aiming to resolve dilemmas, incorporates proximity to ideal solutions and a ranking mechanism. ELECTRE and PROMETHEE, on the other hand, focus on criteria-based ranking, involving double sorting, double comparison, and weighting steps. Unlike many other methods, the DBDM method does not require normalization, providing ease of use and at the same time providing more reliable, faster, and understandable solutions. The choice among these methods depends on specific problem contexts and user expertise. DBDM method applied to renewable energy sources ranking problem and showed the consistency between the well-known MCDM methods.

Earthquake risk encompasses the potential for both the loss of life and property damage resulting from seismic events [17]. A comprehensive earthquake hazard analysis necessitates a thorough examination of the vulnerability of an area exposed to seismic hazards. In its broadest sense, earthquake hazard analysis entails evaluating the likelihood of the most significant ground motion occurring in a specific location and time, resulting from an earthquake of sufficient magnitude to cause structural damage and loss of life [18]. Notably, according to the "2019 Overview of Disaster Management and Statistics of Natural Events" report by the Disaster and Emergency Management Presidency (AFAD) of the Ministry of Interior, earthquakes are identified as the most economically and life-threatening type of disaster in Türkiye, contributing to 60% of disaster related casualties [19].

In the framework of the National Earthquake Research Program, AFAD recently conducted an earthquake hazard analysis in Türkiye, leading to the publication of Figure 1: "Türkiye Earthquake and Elazığ Hazard Map." This map has revealed some significant findings, indicating that approximately 92% of Türkiye's geographical area is located within earthquake prone zones. Furthermore, an estimated 95% of the country's population resides in areas exposed to earthquake risks, while approximately 98% of major industrial centers are also situated in regions classified as earthquake prone [19]. The 2018 Türkiye Earthquake Hazard Map, as presented by AFAD, illustrates a notable correlation between high earthquake hazard areas and densely populated regions.

Natural disasters are events that continue to occur around the world, and therefore it is critically important to understand when these hazards become disasters. Identification, measurement, and assessment of vulnerabilities should be done periodically because this helps develop disaster preparedness and risk reduction strategies Dwyer [20]. Vulnerability analyses can provide very important information to

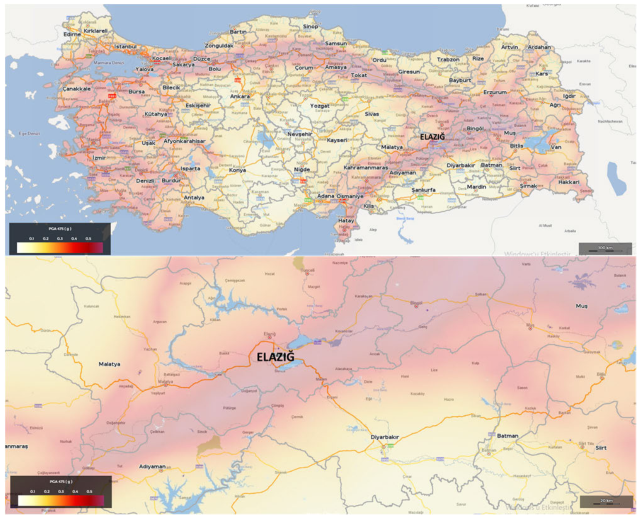


FIGURE 1. **Türkiye and Elazığ Earthquake Hazard Map [19].**

decision-makers. Such analyses evaluate the effects of potential hazards on physical, economic, social, and administrative components and thus provide a basis for developing risk mitigation strategies. Particularly in urban areas, such analyses can examine potential damages and losses caused by hazards such as earthquakes. This is important for cities to be prepared and respond more effectively in disaster situations. Vulnerability determines how susceptible an area is in the event of danger. By taking into account the combination of physical, social, economic, and environmental factors, this concept helps us better understand possible damages and losses. This information is critical to developing disaster management and preparedness plans and can help communities stay safer.

Assessment of vulnerability to earthquakes is a complex and multidimensional problem, and an integrated approach is required to perform these assessments effectively [21]. MCDM methods are widely used techniques for earthquake vulnerability assessment [22], [23]. These methods help analyze earthquake risk and vulnerability by taking into account different criteria. These criteria may include physical building conditions, accessibility, and many other factors. Additionally, an integrated approach should be adopted to assess vulnerability to earthquakes. These factors can affect possible damage and losses after an earthquake. Shayannejad and Angerabi [24] proposed an MCDM model for assessing earthquake susceptibility in the Tehran region of Iran. They used the AHP method to obtain the importance ratings of criteria and applied Fuzzy Logic for normalization. Peng [25] and Chen et al. [26] evaluate earthquake risk in China. Yariyan et al. [27] and Jena et al. [28] obtain earthquake risk maps. Güler et al. [29], Yücel [30], Balyemez and Berköz [32], Ozmen [32], and Kundak [33] evaluated the earthquake vulnerability of Türkiye and Türkiye's regions.

MCDM provides decision-makers with the ability to store, analyze, and visualize data, while GIS offers a platform for assessing the desirability of alternatives based on their spatial characteristics and geographic values. This combination of MCDM and GIS is particularly powerful for decision-making in various fields, especially in spatial analysis and location-based assessments. MCDM methods are used for decision support and evaluation. They allow decision-makers to consider multiple criteria and constraints when assessing alternatives or potential solutions. MCDM techniques enable the quantification and comparison of various factors that contribute to decision-making, taking into account both quantitative and qualitative data. GIS, on the other hand, provides a platform for working with geographic data. It allows for the storage, visualization, and analysis of spatial information, making it possible to understand the spatial relationships and patterns within data. GIS tools can be used to create maps, perform spatial analyses, and generate visualizations. By integrating MCDM with GIS, decision-makers can leverage the strengths of both technologies. They can use MCDM to define criteria, assign weights to these criteria, and perform evaluations based on these criteria. Meanwhile, GIS provides the spatial context for these evaluations.

This integrated approach is valuable in a wide range of applications. It empowers decision-makers to make more informed and geospatially aware choices. Nyimbili et al. [34] utilized GIS and TOPSIS integrated with AHP to analyze earthquake monitoring and risk. Kumlu and Tüdeş [35] employed a GIS-based AHP and TOPSIS approach to identify earthquake prone areas in Yalova, Türkiye, considering 28 indicators. Jena et al. [36] suggested an MCDM model using AHP, VIKOR, and GIS for earthquake susceptibility assessment. Jena et al. [37] applied an integrated AHP for earthquake damage susceptibility assessment, estimating the weights of various criteria. Milad Moradi et al. [38] proposed a GIS-based model using an ordered weighted averaging operator that can analyze different seismic vulnerability maps based on optimistic and pessimistic scenarios. Delavar et al. [39] focus on evaluating the vulnerability of hospital buildings in Tehran, Iran, to earthquakes by utilizing a combination of GIS and a Group Multi-criteria Decision Making (GMCDM) approach. Kumlu and Tüdeş [35] represent a research study or project focused on identifying areas within Yalova City Center in the Marmara region of Türkiye that are at higher risk for earthquakes. This study employs GIS in combination with MCDM techniques, specifically the AHPS and the TOPSIS.

As detailed above, the literature has successfully evaluated earthquake vulnerability by MCDM methods. Therefore, in this study, all districts of Elazığ and central district NHs of Elazığ/Türkiye earthquake vulnerability were evaluated with GIS aspects according to the two main criteria: A: Buildings and B: GIS-based risk and hazard. All districts of Elazığ and NHs of central district earthquake vulnerability ranked using with newly proposed MCDM method called DBDM.

The structure of the study is as follows. The proposed DBDM was introduced in Section II. The DBDM method is used in Section III to rank the renewable energy sources, and in Section IV GIS based earthquake vulnerability assessment of Elazığ, TÜRKİYE with the DBDM method and its' results and discussion was introduced. Lastly, Section V provides conclusions and recommendations for future work.

A. STUDY NOVELTY AND CONTRIBUTIONS

As mentioned above, natural disasters, particularly earthquakes are of utmost importance on a global scale. The identification, measurement, and periodic evaluation of vulnerabilities must be conducted as this aids in developing preparedness and risk reduction strategies [20]. The 2018 Türkiye Earthquake Hazard Map illustrates that approximately 92% of Türkiye s geographical area is in earthquake-prone zones, with around 95% of the population exposed to earthquake risks [19]. Assessing vulnerability to earthquakes is a complex and multidimensional problem, requiring an integrated approach for effective evaluation [21]. MCDM methods are widely used techniques for analyzing earthquake risk and vulnerability [22], [23]. MCDM methods are employed for decision support and evaluation, allowing decision-makers to consider multiple criteria and constraints when assessing alternatives or potential solutions [16]. In the literature on MCDM, when one alternative demonstrates a considerable advantage over another in a specific criterion, the excellence of other alternatives in different criteria might be overlooked. The effectiveness of MCDM methods, particularly in spatial analysis and location-based assessments, is observed as a powerful tool for improving decision-making processes in various domains. When integrated with Geographic Information Systems (GIS), decision-makers can leverage the strengths of both technologies, making more informed decisions.

In conclusion, Earthquake are important on a global scale, especially in Türkiye. Earthquake Vulnerability Assessment as Natural Disaster Preparedness is very important. The literature has successfully assessed earthquake vulnerability through MCDM methods. Besides, Integration with GIS is a valuable approach allowing decision-makers to leverage the strengths of both technologies and make more informed decisions.

In this study initially provides an overview of the earthquake vulnerability of all districts in Elazığ province. Subsequently, building upon this general perspective, a detailed seismic sensitivity analysis is conducted focusing on the central district, which boasts the highest population density. This dual approach allows for a comprehensive assessment of seismic sensitivity at both the general and local levels, thereby ensuring the integrity of the article. By first outlining a general framework to analyze the overall situation, the article establishes a foundation. It then transitions to a more specific focus, offering an in-depth analysis. This methodology provides a holistic understanding of seismic sensitivity.

The main novelties and contributions of this work are as follows:

i) A novel MCDM Method, DBDM, is developed and appears for the first time in the literature;

ii) The developed method is applied in the context of the renewable energy sources (RENS) ranking problem;

iii) The proposed method is compared with several existing MCDM methods and shows a high level of robustness.

iv) The introduced DBDM method is general and is not limited to the RENs selection problem. It can be applied to any other MCDM problem.

v) The GIS-based earthquake vulnerability of Elazığ, TÜRKİYE is evaluated with DBDM.

vi) Active fault and earthquake hazard map considered in earthquake vulnerability for the first time in the literature

II. THE PROPOSED DBDM: DOMINANCE-BASED DECISION-MAKING METHOD

Numerous MCDM methods have been proposed over time, including AHP [40], TOPSIS [41], PROMETHEE [42], VIKOR [43], ELECTRE [44], Weighted Sum Model [45], Weighted Product Model (WPM) [46], and WASPAS [47]. Scholars have identified rank reversal as one of the most significant shortcomings of MCDM methods, primarily attributable to normalization. The normalization process can lead to changes in ranked values when new alternatives are introduced or existing ones are removed, affecting the overall ranking when MCDM methods recalculate it. In this paper, DBDM is a new MCDM method, and it is based on the dominance relation between the alternatives. Most of the MCDMs have normalization steps, the results varying according to the normalization techniques. DBDM does not need any normalization step, so DBDM obtains more consistent result than other MCDM techniques which needs a normalization step. DBDM consists of four steps and they are detailed below.

Step 1: Construct a Decision Matrix.

Determine m alternatives and n criteria. Forming decision-making matrix (X). Alternatives are represented in vector form, where the value of alternative i according to criterion j is denoted by x_{ij} *(i=1, 2, …, m; j=1,2, …,n)*. Determine all criteria benefit or cost. If a criterion is smaller is better than it is a cost criterion. Moreover, if a criterion is bigger is better than it is benefit criterion.

$$X = \left[x_{ij}\right]_{m\times n} = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \vdots & & \ddots & \vdots \\ x_{m1} & x_{22} & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

Step 2. Construct Is Dominated Matrix (IDoM) and Dominated Matrix (DoM).

$d_{ii'j}$ defines whether alternative i is better than alternative i' for criterion j. If alternative i is better than alternative i' according to the criteria j, then $d_{ii'j}$ is equal to 1 otherwise is equal to 0. DoM is a $m \times m \times n$ matrix and is defined below and consists of $\left[d_{ii'j}\right]_{m\times m\times n}$ values.

$$DoM = \left[\begin{bmatrix} d_{111} & d_{112} & \ldots & d_{11n} \\ d_{211} & d_{212} & & d_{21n} \\ \vdots & & \ddots & \vdots \\ d_{m11} & d_{m12} & \cdots & d_{m1n} \end{bmatrix} \ldots \begin{bmatrix} d_{1m1} & d_{1m2} & \ldots & d_{1mn} \\ d_{2m1} & d_{2m2} & & d_{2mn} \\ \vdots & & \ddots & \vdots \\ d_{mm1} & d_{mm2} & \cdots & d_{mmn} \end{bmatrix}\right] \tag{2}$$

$id_{ii'j}$ defines whether alternative i is worse than alternative i' for criterion j. If alternative i is worse than alternative i' according to the criteria j, then $id_{ii'j}$ is equal to 1 otherwise is equal to 0. DoM is defined below and consists of $\left[id_{ii'j}\right]_{m\times m\times n}$ values.

$$DoM = \left[\begin{bmatrix} id_{111} & id_{112} & \ldots & id_{11n} \\ id_{211} & id_{212} & & id_{21n} \\ \vdots & & \ddots & \vdots \\ id_{m11} & id_{m12} & \cdots & id_{m1n} \end{bmatrix} \ldots \begin{bmatrix} id_{1m1} & id_{1m2} & \ldots & id_{1mn} \\ id_{2m1} & id_{2m2} & & id_{2mn} \\ \vdots & & \ddots & \vdots \\ id_{mm1} & id_{mm2} & \cdots & id_{mmn} \end{bmatrix}\right] \tag{3}$$

Step 3: Construct Weighted Is Dominated Matrix (WIDoM) and Weighted Dominated Matrix (WDoM).

$$W = \left[w_j\right]_{1\times n} = \left[\, w_1 \;\; w_2 \;\; \ldots \; w_j \,\right] \tag{4}$$

$$WDoM = W.DoM = \left[wd_{ii'j}\right]_{m\times m\times n} \tag{5}$$

$$WIDoM = W.IDoM = \left[wid_{ii'j}\right]_{m\times m\times n} \tag{6}$$

Step 4: Calculate the Total Dominated and Dominated of Each Alternative.

$$TDoM = [TDoM_i]_{mx1} = \sum\nolimits_{i'=1}^{m} \sum\nolimits_{j=1}^{n} wd_{ii'j} \forall i \tag{7}$$

$$TIDoM = [zxzTIDoM_i]_{mx1} = \sum\nolimits_{i'=1}^{m} \sum\nolimits_{j=1}^{n} wid_{ii'j} \forall i \tag{8}$$

Step 5. Calculate the Dominance Coefficient and Rank the Order of Alternatives.

$$SDoM = [zxzSDoM_i]_{mx1} = TDoM_i/(TDoM_i + TIDoM_i)\forall i \tag{9}$$

where $SDoM_i \in [0; 1]$ with $i = 1, 2, \ldots, m$. The value is the more the better.

III. RENEWABLE ENERGY SOURCES RANKING USING DBDM

In computer science and engineering, MCDM techniques have been employed in diverse applications, including web service selection [48], cloud service selection in cloud computing [49], trustworthiness assessment of Cloud Service Providers [50], cryptocurrency mining strategy selection [51], and fog broker selection in fog computing [52].

TABLE 1. Criteria of RENS ranking.

Criteria		Criteria type	Description
Economic			
Investment cost	CEC1	Cost	Expenditure on equipment and installation
O&M cost	CEC2	Cost	Employees' wages, the funds spent for energy, and products and services for energy system operation
Electric cost	CEC3	Cost	The cost of various energy generation systems
Technical			
Efficiency	CT1	Benefit	Efficiency is defined as the ratio of the output energy to the input energy
Capacity factor	CT2	Benefit	The ratio of annual total generation and installed capacity
Technical maturity	CT3	Benefit	Technology refers to the reliability degree of the adopted technology and its spread at the national level
Environmental			
GHG emission	CEN1	Cost	The life cycle GHG emissions (in equivalent emission of CO2) from the technology
Land use	CEN2	Cost	Land area needed for the technology
Social			
Job creation	CS1	Benefit	Potential employment opportunities to be created by the energy project
Social acceptance	CS2	Benefit	Public acceptance of the RE technology/project

TABLE 2. Decision matrix.

	Solar PV	Wind	Hydro	Biomass	Geothermal
CEC1	4550	3005	2040	3370	3920
CEC2	30	60.86	14.85	99.4	112.6
CEC3	6.74	2.4	1.7	3.25	4.93
CT1	20	35	90	25.3	11.4
CT2	15	27	25	54	71.7
CT3	5	4	5	3	2
CEN1	85	26	26	45	50
CEN2	150	200	500	222	100
CS1	0.87	0.17	0.27	0.21	0.25
CS2	4.76	4.51	4.19	3.78	4.11

TABLE 3. DoM and IDoM matrices of alternative Hydro.

	DoM	IDoM	DoM	IDoM	DoM	IDoM	DoM	IDoM	DoM	IDoM
	Solar PV		Wind		Hydro		Biomass		Geothermal	
CEC1	1	0	1	0	0	0	1	0	1	0
CEC2	1	0	1	0	0	0	1	0	1	0
CEC3	1	0	1	0	0	0	1	0	1	0
CT1	1	0	1	0	0	0	1	0	1	0
CT2	1	0	0	1	0	0	0	1	0	1
CT3	0	0	1	0	0	0	1	0	1	0
CEN1	1	0	0	0	0	0	1	0	1	0
CEN2	0	1	0	1	0	0	0	1	0	1
CS1	0	1	1	0	0	0	1	0	1	0
CS2	0	1	0	1	0	0	1	0	1	0

The crucial role of energy in economic development and its environmental impact, emphasizes the shift to renewable energy sources (RENS) to combat climate change. Taiwan's efforts to promote RENS due to energy security concerns are highlighted. Global statistics indicate significant growth in RENS capacity, investment, and employment, with projections suggesting a substantial share of global energy production by 2030. However, challenges such as variability in solar and wind power, higher electric costs, and the importance of infrastructure management are recognized [53], [56].

A. DATASET

Lee and Chang [57], present an MCDM model for assessing and ranking RENS in the context of Taiwan's renewable energy RENS development. The model considers economic, technical, environmental, and social factors simultaneously. The criteria selected in the Lee and Chang [57] study are given in Table 1, and the decision matrix is given in Table 2. In this study, five types of RENS include wind, solar photovoltaic (PV), hydro, biomass, and geothermal energy.

B. RANKING RENEWABLE ENERGY SOURCES

Now we illustrate how REs get ranked when the DBDM method is implemented on the above-said dataset.

i=Solar PV, Wind, Hydro, Biomass, Geothermal

j= Investment cost, O&M cost, Electric cost, Efficiency, Capacity factor, Technical maturity, GHG emission, Land use, Job creation, Social Acceptance

Step 1: Construct a Decision Matrix

The Decision Matrix of RENS given in Table 2 Decision Matrix $= X = \left[x_{ij}\right]_{m\times n}$

Step 2: Construct Is Dominated Matrix (IDoM) and Dominated Matrix (DoM)

All alternatives were compared with each other according to all criteria. In below Table 3, alternative Hydro's DoM and IDoM matrices are given. $d_{ii'j}$ defines whether alternative i is better than alternative i' for criterion j. $id_{ii'j}$ defines whether alternative i is worse than alternative i' for criterion j. The values in Table 3 belong to alternative Hydro. Analyzing the initial line, it becomes apparent that the focus is on the investment cost criterion. The values in this row show the comparison of the Hydro alternative with other alternatives. Since the Hydro alternative is better than Solar PV in terms of investment cost criterion, the DOM value is $d_{Hydro,SolarPV,CEC1} = 1$, and the IDOM value is $id_{Hydro,SolarPV,CEC1} = 0$. Usually, the sum of d and id values is 1. One takes the value 1 while the other takes the value 0, one takes the value 0 and the other takes the value 1. Only in case of equality do both take the value 0.

TABLE 4. WDoM and WIDoM matrices of alternative Hydro.

	WDoM	IDoM	WDoM	IDoM	WDoM	IDoM	WDoM	IDoM	WDoM	IDoM
	Solar PV		Wind		Hydro		Biomass		Geothermal	
CEC1	0.026	0	0.026	0	0	0	0.026	0	0.026	0
CEC2	0.154	0	0.154	0	0	0	0.154	0	0.154	0
CEC3	0.089	0	0.089	0	0	0	0.089	0	0.089	0
CT1	0.199	0	0.199	0	0	0	0.199	0	0.199	0
CT2	0.115	0	0	0.115	0	0	0	0.115	0	0.115
CT3	0	0	0.039	0	0	0	0.039	0	0.039	0
CEN1	0.08	0	0	0	0	0	0.08	0	0.08	0
CEN2	0	0.123	0	0.123	0	0	0	0.123	0	0.123
CS1	0	0.172	0.172	0	0	0	0.172	0	0.172	0
CS2	0	0.003	0	0.003	0	0	0.003	0	0.003	0

TABLE 5. DBDM Results of RENS.

	Solar PV	Wind	Hydro	Biomass	Geothermal
TDoM	1.847	2.053	2.866	1.621	1.494
TIDoM	2.114	1.867	1.015	2.379	2.506
SDoM	0.466296	0.523724	0.738469	0.40525	0.3735
Rank	3	2	1	4	5

Step 3: Construct Weighted Is Dominated Matrix (WIDoM) and Weighted Dominated Matrix (WDoM).

$$\text{Criteria weights of RENS } \boldsymbol{W} = [w_j]_{1\times n} = \begin{bmatrix} 0.026 \\ 0.154 \\ 0.089 \\ 0.199 \\ 0.115 \\ 0.039 \\ 0.08 \\ 0.123 \\ 0.172 \\ 0.003 \end{bmatrix}$$

All WDoM and WIDoM matrices were calculated according to equations (5) and (6). In the below, alternative Hydro's WDoM and WIDoM matrices are given in Table 4.

Step 4: Calculate the total dominated and dominated of each alternative and **Step 5.** Calculate the dominance coefficient and rank the order of alternatives.

Each alternative *TDoM* and *TIDoM* values were calculated according to equations (7) and (8). *SDoM* and rank the order of alternatives were calculated according to equation (9). The results are given in Table 5.

The well-known MCDM methods (WSM, TOPSIS, VIKOR, and ELECTRE) and DBDM were applied to the data. The ranking results are presented in Table 6. Hydro was the optimal alternative in all methods. The rankings of these five methods were similar, although not entirely equal. All the approaches, except for VIKOR and DBDM, ranked solar PV 2nd and wind 3rd. Biomass and geothermal were the low ranking alternatives. TOPSIS and ELECTRE; VIKOR and DBDM produced equal rankings of the alternatives. As a result, DBDM results are compatible with well-known MCDM methods.

TABLE 6. The ranking of RES in different MCDM methods and DBDM.

	WSM	TOPSIS	VIKOR	ELECTRE	**DBDM**
Solar PV	2	2	3	2	**3**
Wind	3	3	2	3	**2**
Hydro	1	1	1	1	**1**
Biomass	4	5	4	4	**4**
Geothermal	5	4	5	5	**5**

The results obtained from WSM, TOPSIS, VIKOR, ELECTRE, and DBDM methods are subsequently compared using similarity coefficients to assess the concurrence of rankings across these methodologies.

C. THE RANKING SIMILARITY COEFFICIENTS OF RENEWABLE ENERGY SOURCES

In aiding the decision-making process within this domain, there is an increasing reliance on the application of MCDM methods. However, when addressing a particular issue with diverse MCDM approaches, disparate rankings emerge due to the distinct methodological foundations of each method. Consequently, the challenge lies in establishing a dependable decision-making framework. Shekhovtsov et al. address this challenge by measuring the similarity of these rankings [58].

When MCDM methods yield divergent outcomes for a given problem, it becomes essential to evaluate the degree of similarity in the obtained results [59]. To accomplish this, correlation coefficients offer a quantitative assessment of the concordance among the analyzed rankings. Particularly, Spearman's weighted correlation coefficient can be employed for this purpose. It enables the quantification of the strength of dissimilarity in the outcomes produced by the utilized methods. The concept of employing similarity coefficients for comparing rankings is not novel and has been extensively explored in previous studies [60], [61]. A recent contribution by Sałabun introduces a novel coefficient [62], which is an asymmetric measure where the weight assigned to a particular comparison is the significance of its position in the reference ranking. These coefficients are expressed as equations (10) and (11) respectively:

$$r_w = 1 - \frac{6.\sum_{i=1}^{n}\left(R_{xi} - R_{yi}\right)^2 \left(\left(n-R_{xi}+1\right)+\left(n-R_{yi}+1\right)\right)}{n.\left(n^3+n^2-n-1\right)} \tag{10}$$

$$WS = 1 - \sum_{i=1}^{n}\left(2^{-R_{xi}} \frac{\left|R_{xi} - R_{yi}\right|}{max\left\{\left|1-R_{xi}\right|, \left|N-R_{xi}\right|\right\}}\right) \tag{11}$$

In this section, the similarity of the obtained rankings was calculated. For this purpose, the decision was made to utilize the weighted Spearman correlation coefficient and the *WS* similarity coefficient. Both of them are reliant on the ranking

TABLE 7. Rankings correlation for Spearman weighted correlation coefficient r_w.

r_w	WSM	TOPSIS	VIKOR	ELECTRE	DBDM
WSM	1	0.95	0.88	1	0.88
TOPSIS	0.81	1	0.85	0.47	0.81
VIKOR	0.31	0.85	1	0.25	0.31
ELECTRE	0.81	0.47	0.25	1	0.81
DBDM	1	0.81	0.31	0.81	1

TABLE 8. Rankings correlation for WS similarity coefficient.

WS	WSM	TOPSIS	VIKOR	ELECTRE	DBDM
WSM	1	0.97	0.85	1	0.85
TOPSIS	0.81	1	0.85	0.7	0.81
VIKOR	0.6	0.86	1	0.48	0.6
ELECTRE	0.67	0.72	0.84	1	0.67
DBDM	1	0.89	0.68	0.79	1

values in Table 6. Table 7 illustrates the correlations between the obtained rankings using the weighted Spearman correlation coefficient. This similarity ensures values within the interval [−1.0, 1.0], where a value of −1.0 signifies a complete lack of similarity, while 1.0 indicates complete equality. It is important to note that when examining the correlation of a ranking with itself, the coefficient consistently obtains a value of 1.0. In Table 8, the results of the similarity assessments were obtained using the WS similarity coefficient. The values acquired through this metric denote similarity within the interval (0.0, 1.0]. A value of 0.0 implies no similarity among rankings, while a value of 1.0 signifies identical rankings.

In terms of r_w, DBDM shows a strong similarity with WSM, TOPSIS, ELECTRE with a value of 0.883. VIKOR vs. DBDM shows perfect similarity with a value of 1.000.

In terms of WS, DBDM shows a high similarity with TOPSIS with a value of 0.826, while it shows a strong similarity with WSM and ELECTRE with a value of 0.854. As in r_w VIKOR is perfectly similar to the DBDM value of 1.000.

On both coefficients, we see that DBDM ranks highly similar to other methods. In particular, the excellent similarity between VIKOR and DBDM shows that the rankings of these two algorithms are identical. High values in the r_w and WS coefficients indicate that DBDM is in strong agreement with other algorithms in rankings and produces highly similar rankings with other MCDM methods.

IV. GIS-BASED EARTHQUAKE VULNERABILITY ASSESSMENT OF ELAZIĞ, TÜRKİYE

Elazığ province is in the southwestern part of the Eastern Anatolia Region in Türkiye. It covers a total area of 9,151 square kilometers, with 8,455 square kilometers of it being land, and 826 square kilometers consisting of reservoirs and natural lake areas. The average elevation of the province from sea level is approximately 1,067 meters. In Elazığ province, several geological formations are identified. These formations include filled, alluvion, Karabakır, Alibonca, Kırkgeçit, Seske Formations, Elazığ Magmatites,

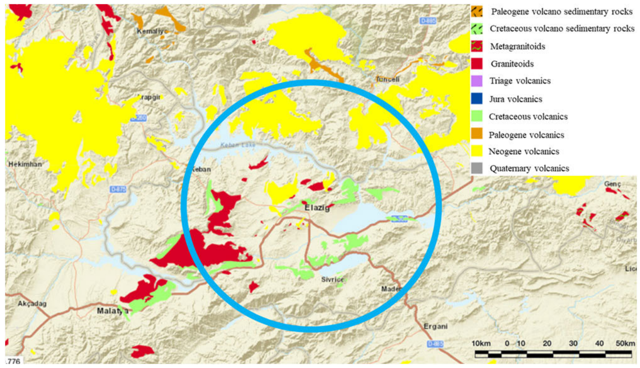


FIGURE 2. **Magmatic Rocks of Elazığ [64].**

and Keban Metamorphics. These geological features are briefly described as follows. Filled is found in the eastern part of the city, consisting of excavation materials. Alluvion is widespread in the central settlement area of Elazığ province, characterized by various soil types such as sandgravel, sandygravelly clay, and silty clay. Karabakır Formation is comprised of basalt and located in the western part of the Doğukent district, Salıbaba, and Çatalçeşme NH. Alibonca Formation presents in areas affected by marine influences, particularly around Karakaya and Keban Dams, consisting of conglomerate, sandy limestone, sandstone, and marl. Kırkgeçit Formationcis are common in various parts of Elazığ province, predominantly to the west and southwest of the city center, comprising marl, limestone, claystone, and sandstone. Seske Formation is generally found in a small area in the northeastern part of Elazığ province, primarily consisting of limestone and containing abundant microfossils. Elazığ Magmatites occur in several areas including Fevzi Çakmak NH, Esentepe NH, Zafran NH, the northern part of Fırat University, Cumhuriyet NH, Abdullahpaşa NH, and between the old Beyyurdu and Karşıyaka NHs. These magmatites are primarily composed of gabrodiorites at the base, overlaid by basalticandesitic volcanic rocks, and intersected by dasite dykes. Keban Metamorphics are in areas such as Abdullahpaşa, Sarıçubuk NHs, and the southwestern part of Sürsürü NH near the foothills of Meryem Dağı. The Keban metamorphics consist of recrystallized limestonescalcschists, marbles, and metaconglomeratescalcsilicates. Magmatic Rocks of Elazığ are given in Figure 2. This geological information serves as the foundation for interpreting structural damages in the region and understanding the geological characteristics of Elazığ province [63].

Elazığ province emerged as the settlement spread from Harput city towards the plain. The settlement history of the Harput region dates back more than 5,000 years.

As given in Figure 3, Elazığ Province has 11 districts, including one central district and 10 districts. East of; Karakoçan, Palu, Kovancılar, Arıcak, west of; Baskil, in the south; Sivrice, Maden, Alacakaya, and Ağın and Keban are located to the north.

FIGURE 3. Elazığ Districts Map [76].

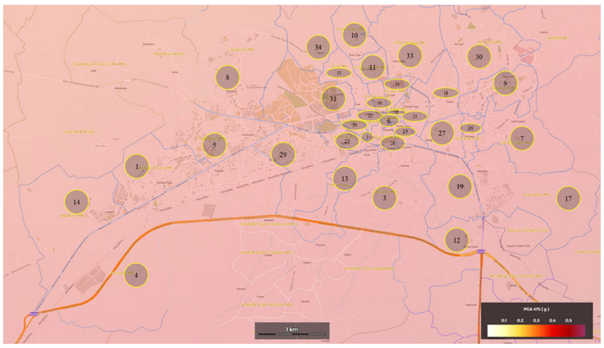


FIGURE 4. Elazığ Central District NHs satellite image and NHs on Türkiye Earthquake Hazard Map.

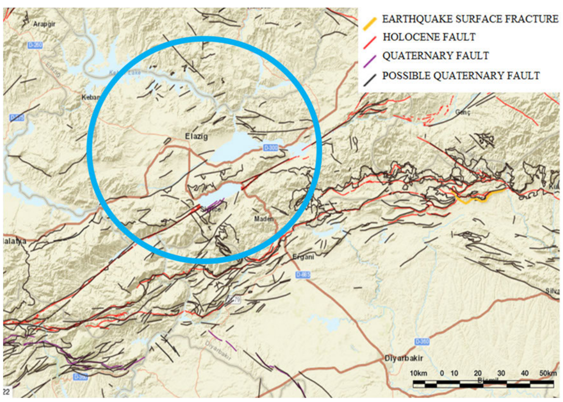


FIGURE 5. Elazığ Active Fault Map [64].

As the population increased and settlement areas expanded, the number of NHs grew, and as of 2020, Elazığ Central district consists of 34 NHs. These NHs have seen construction developments throughout their history, with building stocks changing several times over the years. The first NHs established were Mustafa Paşa, İcadiye, Çarşı, Akpınar, Sarayatik, Nail Bey, Rızaiye, Rüstempaşa, and İzzetpaşa NHs. Consequently, during the early years, these NHs had the highest population density due to the migration of people from Harput to the plains after the 1900s. As one moved away from the city center towards the outskirts, population density decreased. However, after the 1960s, the growth of Elazığ city towards the west along Malatya Avenue led to changes in population density distribution. In the 2000s, the construction of housing complexes in the north and east also led to increased population density in those areas [65]. Elazığ central district NHs are given on the Türkiye Earthquake Hazard Map in Figure 4.

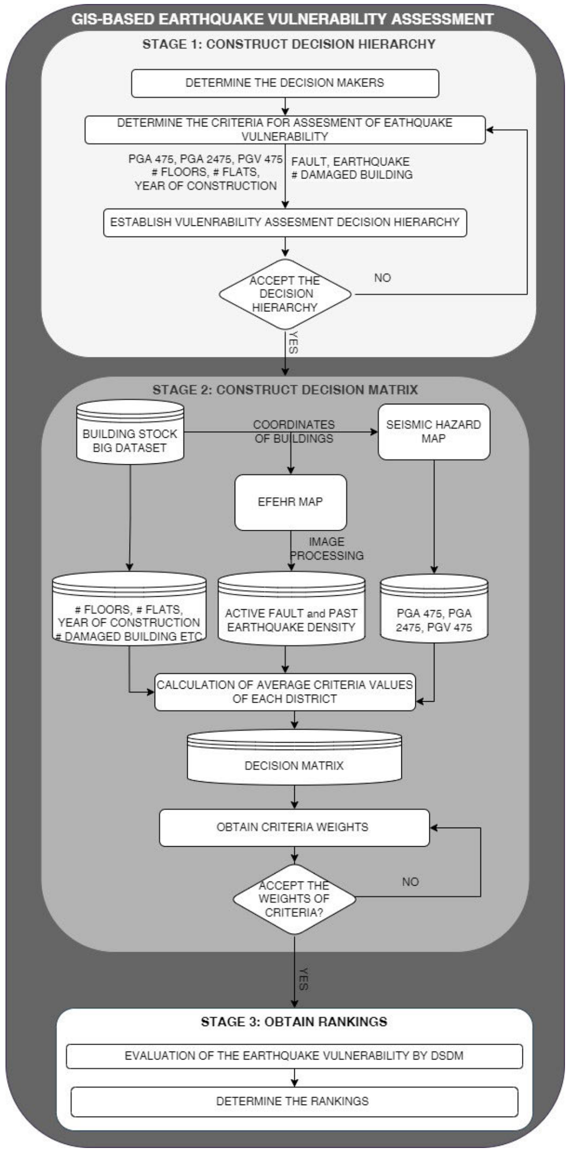


FIGURE 6. Flowchart for GIS based earthquake vulnerability assessment.

Until 1965, the building stock in Elazığ consisted mainly of one or two-story loadbearing brick buildings. Brick masonry materials were used in the city center, while adobe was used as one moved away from the center. Until this period, a significant portion of the population lived in villages, and urban migration had not yet started significantly. However, in 1965, the Condominium Ownership Law was enacted, allowing the establishment of separate property rights for apartment units [66]. With the introduction of the Condominium Ownership Law, the number of residential

TABLE 9. GIS-based earthquake vulnerability assessment criteria.

A. Buildings
A. 1. General properties of buildings
A. 1. 1. Average number of independent sections of the buildings
A. 1. 2. Average number of floors of the buildings
A. 1. 3. Average year of building construction
A. 2. Structural system of building
The structural system types are divided into carcass structure and masonry structure. Although masonry structures are superior in some respects, they are not generally qualified as earthquake resistant structures because they are cumbersome and have low resistance to dynamic and horizontal loads such as earthquakes. Carcass reinforced concrete structures are more resistant to earthquakes compared to masonry structures.
A. 2. 1. Carrier system type of building
A. 2. 1. 1. Carcass structure building percentage
A. 2. 1. 2. Masonry structure building percentage
A. 2. 2. Durability of buildings
A. 2. 2. 1. Percentage of buildings in good condition
A. 2. 2. 2. Percentage of buildings in medium condition
A. 2. 2. 3. Percentage of buildings in bad condition
B. GIS-based risk and hazard.
B. 1. Fault
The criteria, which incorporate active fault data, were applied based on the building coordinates sourced from publicly accessible maps as part of the EFEHR European Union project. These criteria were computed individually for various radii, including 0.05km, 0.10km, 0.20km, 0.25km, 0.40km, and 5km.
B. 1. 1. 0.05 km fault
B. 1. 2. 0.1 km fault
B. 1. 3. 0.2 km fault
B. 1. 4. 0.4 km fault
B. 1. 5. 5 km fault
B. 2. Earthquake
B. 2. 1. 0.05 km earthquake
B. 2. 2. 0.1 km earthquake
B. 2. 3. 0.2 km earthquake
B. 2. 4. 0.4 km earthquake
B. 2. 5. 5 km earthquake
B. 3. Average Ground Acceleration and Velocity
Peak Ground Acceleration (PGA) refers to the maximum horizontal ground movement experienced at the surface during an earthquake. Its expected value for a construction site is determined through seismic hazard analysis. Peak Ground Velocity (PGV) represents the rate at which a specific location on the ground vibrates due to an earthquake, reflecting the highest recorded shaking velocity during the event.
B. 3. 1. PGA 475
B. 3. 2. PGA 2475
B. 3. 3. PGV 475

units started to increase rapidly. Especially until the 1970s, two and three-story brick masonry buildings were constructed extensively. Until the 1980s, most of the buildings were multistory brick masonry structures, with a few concrete frame buildings. As the 1980s approached, brick masonry buildings were generally built with three or four floors. During this period, there was a rapid increase in the number of multistory reinforced concrete frame buildings. Simultaneously, while the number of brick masonry structures decreased, the number of floors in these buildings increased. During this period, four-story brick masonry buildings were commonly constructed, and even five and six-story brick masonry buildings were boldly built.

Between 1980 and the 1990s, buildings with basement + ground floor + first floor constructed in reinforced concrete frames became prevalent. In the following years, additional brick masonry floors were added to these buildings, resulting in a significant building stock. By the 1990s, almost all buildings in central district NHs were constructed as reinforced concrete frame structures. After this period, brick masonry buildings rarely exceeded three stories. In the 2000s, a Mass Housing project, that introduced the tunnel formwork system

TABLE 10. Decision matrix of Elazığ's districts.

	Central	Sivrice	Kovancılar	Palu	Karakoçan	Maden	Baskil	Keban	Arıcak	Alacakaya	Ağın
A.1.1.	4.11	1.59	2.57	1.93	1.87	1.82	1.57	1.47	1.69	1.29	1.58
A.1.2.	2.83	1.83	2.13	1.83	1.72	1.8	1.69	1.83	2.01	1.88	2.29
A.1.3.	1991.23	1989.89	1991.33	1990.84	1991.18	1989.82	1988.24	1990.57	1990.07	1989.58	1991.92
A.2.1.1.	0.37	0.2	0.31	0.16	0.28	0.16	0.07	0.01	0.01	0	0.02
A.2.1.2.	0.51	0.7	0.44	0.49	0.59	0.67	0.55	0.15	0.06	0	0.05
A.2.2.1.	0.45	0.28	0.49	0.48	0.56	0.45	0.31	0.15	0.15	0.27	0.42
A.2.2.2.	0.37	0.29	0.3	0.33	0.29	0.33	0.4	0.51	0.48	0.41	0.42
A.2.2.3.	0.18	0.43	0.21	0.19	0.15	0.22	0.29	0.34	0.38	0.32	0.17
B.1.1.	0.31	0.03	0.04	0.03	0.02	0.01	0	0	0	0	0
B.1.2.	0.31	0.03	0.04	0.03	0.02	0.01	0	0	0	0	0
B.1.3.	0.99	0.11	0.11	0.11	0.05	0.05	0.02	0	0	0	0
B.1.4.	3.04	0.32	0.35	0.33	0.16	0.17	0.06	0	0.01	0.01	0
B.1.5.	42.32	559.03	272.08	585.39	317.67	533.75	18.23	19.89	414.22	516.56	148.71
B.2.1.	0.56	0.03	0.09	0.07	0.03	0.06	0.06	0.01	0	0	0
B.2.2.	0.56	0.03	0.09	0.07	0.03	0.06	0.06	0.01	0	0	0
B.2.3.	1.68	0.09	0.26	0.21	0.09	0.18	0.17	0.02	0	0	0
B.2.4.	5.03	0.28	0.77	0.62	0.26	0.53	0.5	0.06	0	0.01	0
B.2.5.	575.09	605.73	593.66	606.06	573.75	586.09	405.75	555.05	603.26	606.2	595.04
B.3.1.	0.41	0.62	0.53	0.65	0.55	0.57	0.38	0.3	0.49	0.51	0.42
B.3.2.	0.76	1.09	0.94	1.13	0.98	1.02	0.7	0.58	0.91	0.92	0.77
B.3.3.	22703.72	36862.4	11312.75	39941.83	439.6	33276	10647.44	9918.38	29.64	30.87	9294.32

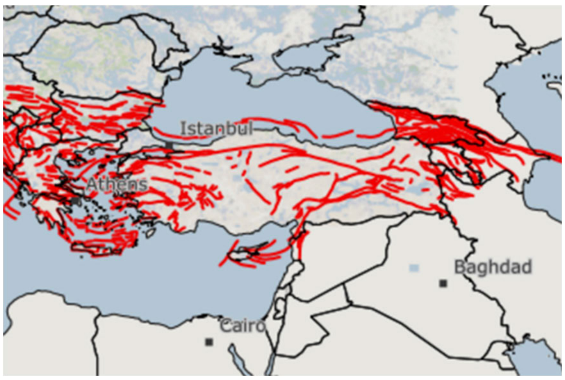


FIGURE 7. Active faults on the generic ground acceleration hazard map [73].

FIGURE 8. Earthquakes between 1000 AD and 2014 on the generic ground acceleration hazard map [73].

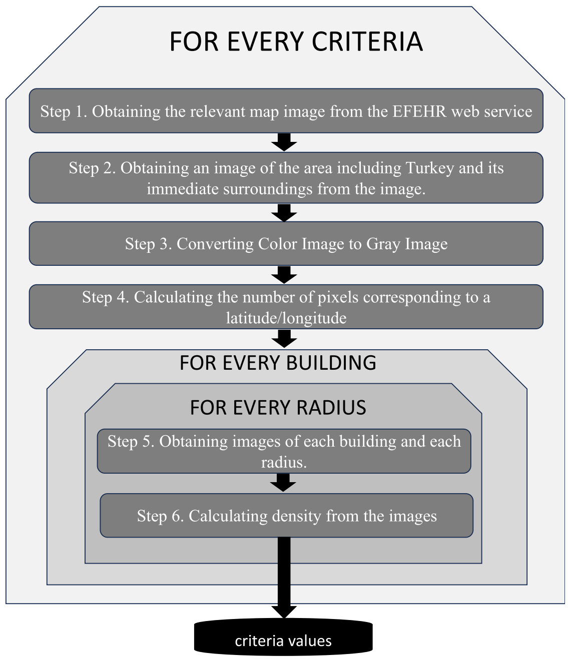


FIGURE 9. Flow diagram of calculating criteria values from EFEHR Maps.

in Elazığ, changed the city's approach to building quality. Until the early 2000s, aggregates were used without classification or washing in concrete production, and concrete was produced onsite rather than using ready-mixed concrete. The foundation of the first ready-mixed concrete plant in Elazığ was laid in 1999. Building inspections were not conducted from 1965 when construction started until the 2000s. After the 1990s, many buildings in NHs were demolished, and multistory reinforced concrete frame buildings were constructed in their place, typically around 2030 years old. Newly established NHs also featured multistory reinforced concrete frame structures. Buildings with similar structural systems and quality were generally constructed within the same or nearby NHs.

A significant portion of Türkiye's population is located on or near active faults that have the potential to produce major earthquakes. Active Faults of Elazığ are given in Figure 5.

TABLE 11. ***DoM*** **and** ***IDoM*** **matrices of alternative district Sivric.**

	Central	Sivrice	Kovancılar	Palu	Karakoçan	Maden	Baskil	Keban	Arıcak	Alacakaya	Ağın
A.1.1.	0	0	0	0	0	0	1	1	0	1	1
A.1.2.	0	0	0	0	1	1	1	0	0	0	0
A.1.3.	1	0	1	1	1	0	0	1	1	0	1
A.2.1.1.	1	0	1	0	1	0	0	0	0	0	0
A.2.1.2.	1	0	1	1	1	1	1	1	1	1	1
A.2.2.1.	1	0	1	1	1	1	1	0	0	0	1
A.2.2.2.	0	0	0	0	1	0	0	0	0	0	0
A.2.2.3.	1	0	1	1	1	1	1	1	1	1	1
B.1.1.	0	0	0	0	1	1	1	1	1	1	1
B.1.2.	0	0	0	0	1	1	1	1	1	1	1
B.1.3.	0	0	0	0	1	1	1	1	1	1	1
B.1.4.	0	0	0	0	1	1	1	1	1	1	1
B.1.5.	1	0	1	0	1	1	1	1	1	1	1
B.2.1.	0	0	0	0	1	0	0	1	1	1	1
B.2.2.	0	0	0	0	1	0	0	1	1	1	1
B.2.3.	0	0	0	0	1	0	0	1	1	1	1
B.2.4.	0	0	0	0	1	0	0	1	1	1	1
B.2.5.	1	0	1	0	1	1	1	1	1	0	1
B.3.1.	1	0	1	0	1	1	1	1	1	1	1
B.3.2.	1	0	1	0	1	1	1	1	1	1	1
B.3.3.	1	0	1	0	1	1	1	1	1	1	1

	Central	Sivrice	Kovancılar	Palu	Karakoçan	Maden	Baskil	Keban	Arıcak	Alacakaya	Ağın
A.1.1.	1	0	1	1	1	1	0	0	1	0	0
A.1.2.	1	0	1	1	0	0	0	1	1	1	1
A.1.3.	0	0	0	0	0	1	1	0	0	1	0
A.2.1.1.	0	0	0	1	0	1	1	1	1	1	1
A.2.1.2.	0	0	0	0	0	0	0	0	0	0	0
A.2.2.1.	0	0	0	0	0	0	0	1	1	1	0
A.2.2.2.	1	0	1	1	0	1	1	1	1	1	1
A.2.2.3.	0	0	0	0	0	0	0	0	0	0	0
B.1.1.	1	0	1	1	0	0	0	0	0	0	0
B.1.2.	1	0	1	1	0	0	0	0	0	0	0
B.1.3.	1	0	1	1	0	0	0	0	0	0	0
B.1.4.	1	0	1	1	0	0	0	0	0	0	0
B.1.5.	0	0	0	1	0	0	0	0	0	0	0
B.2.1.	1	0	1	1	0	1	1	0	0	0	0
B.2.2.	1	0	1	1	0	1	1	0	0	0	0
B.2.3.	1	0	1	1	0	1	1	0	0	0	0
B.2.4.	1	0	1	1	0	1	1	0	0	0	0
B.2.5.	0	0	0	1	0	0	0	0	0	1	0
B.3.1.	0	0	0	1	0	0	0	0	0	0	0
B.3.2.	0	0	0	1	0	0	0	0	0	0	0
B.3.3.	0	0	0	1	0	0	0	0	0	0	0

According to the information obtained from the AFAD and Boğaziçi University Kandilli Observatory and Earthquake Research Institute, approximately 94 thousand people lost their lives as a result of 88 devastating earthquakes that occurred between 1900 and 2021. The January 24 Sivrice and October 30 KuşadasıBay Sasam Island earthquakes, which last occurred in 2020, were recorded as the two deadliest earthquakes in the world for that year, and as a result of these earthquakes, 158 of citizens lost their lives and there was a significant amount of financial loss [67]. The most important tectonic element threatening the Elazığ province is the Eastern Anatolian Fault System (EAF), and many devastating earthquakes have occurred on this fault system in the historical and instrumental period. The only earthquake that caused a surface rupture on the EAF in the last century was the Bingöl (M 6.8) earthquake of 22 May 1971 [67]. Apart from this, the 8 March 2010 Okçular (Elazığ) (M 6.1), 1 May 2003 Bingöl (M 6.4), 27 June 1998 Adana (M 6.2) and 5 May 1986 Malatya (M 6.0) earthquakes. There are many devastating earthquakes on the EAF in historical earthquake records. 995 Palu Sivrice (VI), 1114 Ceyhan Antakya, Maraş (IX), 1268 Kozan Ceyhan and its region (IX), 1737 Antakya (VII), 1789 Palu Elazığ (VIII), 1855 Ceyhan Adana (VI), 1872 AntakyaSamandağ (IX), 1874 MadenElazığ, Diyarbakır (VIII), 1875 Karlıova Bingöl, Palu Elazığ (VIII), 1889 Palu Elazığ (VI) are some of the important earthquakes in historical earthquake records [68].

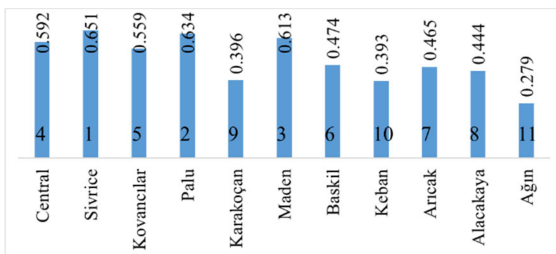


FIGURE 10. **The rank of Elazığ's districts according to earthquake vulnerability.**

TABLE 12. Criteria weights.

CRITERIA	WEIGHT	COST/BENEFIT
A.1.1.	0,0330	BENEFIT
A.1.2.	0,0660	BENEFIT
A.1.3.	0,0660	COST
A.2.1.1.	0,1251	COST
A.2.1.2.	0,1251	BENEFIT
A.2.2.1.	0,0337	COST
A.2.2.2.	0,0337	BENEFIT
A.2.2.3.	0,0674	BENEFIT
B.1.1.	0,0551	BENEFIT
B.1.2.	0,0473	BENEFIT
B.1.3.	0,0315	BENEFIT
B.1.4.	0,0158	BENEFIT
B.1.5.	0,0079	BENEFIT
B.2.1.	0,0551	BENEFIT
B.2.2.	0,0473	BENEFIT
B.2.3.	0,0315	BENEFIT
B.2.4.	0,0158	BENEFIT
B.2.5.	0,0079	BENEFIT
B.3.1.	0,0540	BENEFIT
B.3.2.	0,0270	BENEFIT
B.3.3.	0,0540	BENEFIT

In this study, we assess Elazığ Earthquake vulnerability according to the GIS-based framework as given in Figure 6. This framework consists of three main steps. These stages are 1-Construct Decision Hierarchy, 2-Construct Decision Matrix, and 3-Obtain Rankings. These stages are detailed below.

STAGE 1: Construct Decision Hierarchy:

V. ELAZIĞ GIS-BASED EARTHQUAKE VULNERABILITY ASSESSMENT DECISION HIERARCHY

Evaluation of earthquake vulnerability requires the collaboration of experts from different disciplines and a comprehensive analysis of the literature. Experts from engineering, geography, and other fields can help make these assessments more comprehensive and scientifically based. To carry out these evaluations effectively, it is important to adopt MCDM methods and an integrated approach. Additionally, interdisciplinary collaboration and MCDM problem classification can contribute to the successful conduct of such studies [69]. During this study, experts from diverse disciplines played a crucial role in shaping the decision hierarchy. The collaborative effort included professionals specializing in earthquake engineering, geospatial analysis, and disaster management. Earthquake engineering experts provided key insights into technical aspects such as structural integrity, building attributes, and infrastructure considerations. Geospatial analysis experts contributed to spatial analysis, incorporating geographic information for enhanced accuracy. This interdisciplinary collaboration contributed to the comprehensive and scientifically grounded nature of our earthquake vulnerability assessments. Literature review and expert opinions were considered in constructing the decision hierarchy and matrix.

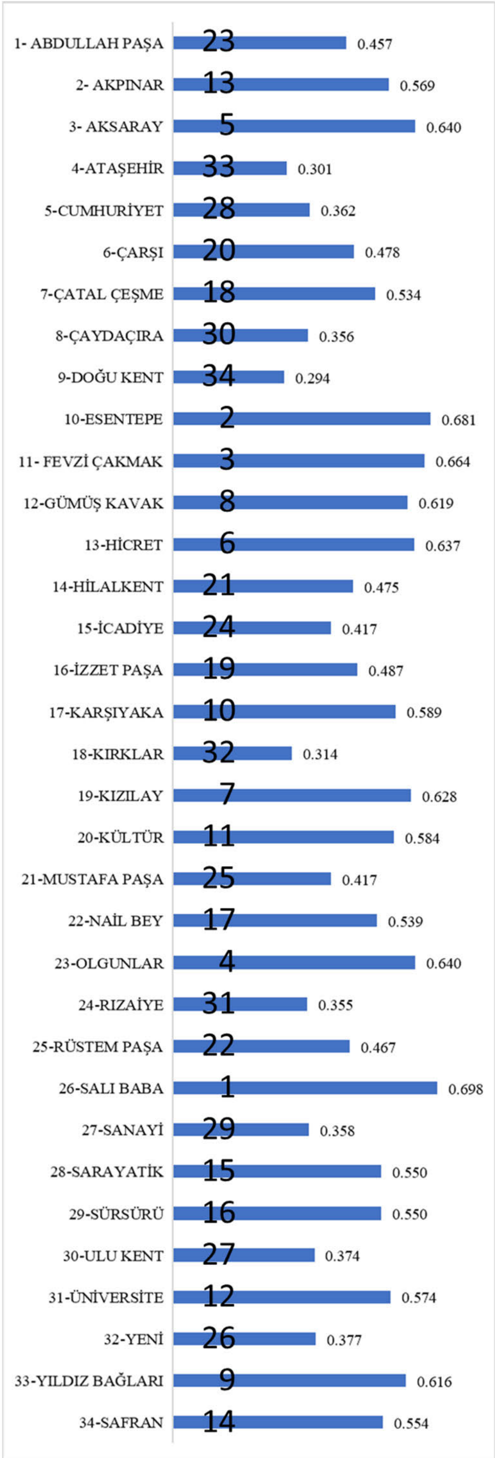


FIGURE 11. The rank of Elazığ's NHs according to earthquake vulnerability.

Several research studies have investigated the definition of distinct indicator categories in the context of seismic resilience and earthquake vulnerability. Bruneau et al. [70] have proposed a framework for quantitatively assessing seismic resilience, which involves four interconnected

TABLE 13. WDoM and WIDoM matrices of alternative district Sivrice.

	Central	Sivrice	Kovancılar	Palu	Karakoçan	Maden	Baskil	Keban	Arıcak	Alacakaya	Ağın
A.1.1.	0	0	0	0	0	0	0.033	0.033	0	0.033	0.033
A.1.2.	0	0	0	0	0.066	0.066	0.066	0	0	0	0
A.1.3.	0.066	0	0.066	0.066	0.066	0	0	0.066	0.066	0	0.066
A.2.1.1.	0.125	0	0.125	0	0.125	0	0	0	0	0	0
A.2.1.2.	0.125	0	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
A.2.2.1.	0.034	0	0.034	0.034	0.034	0.034	0.034	0	0	0	0.034
A.2.2.2.	0	0	0	0	0.034	0	0	0	0	0	0
A.2.2.3.	0.067	0	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
B.1.1.	0	0	0	0	0.055	0.055	0.055	0.055	0.055	0.055	0.055
B.1.2.	0	0	0	0	0.047	0.047	0.047	0.047	0.047	0.047	0.047
B.1.3.	0	0	0	0	0.032	0.032	0.032	0.032	0.032	0.032	0.032
B.1.4.	0	0	0	0	0.016	0.016	0.016	0.016	0.016	0.016	0.016
B.1.5.	0.008	0	0.008	0	0.008	0.008	0.008	0.008	0.008	0.008	0.008
B.2.1.	0	0	0	0	0.055	0	0	0.055	0.055	0.055	0.055
B.2.2.	0	0	0	0	0.047	0	0	0.047	0.047	0.047	0.047
B.2.3.	0	0	0	0	0.032	0	0	0.032	0.032	0.032	0.032
B.2.4.	0	0	0	0	0.016	0	0	0.016	0.016	0.016	0.016
B.2.5.	0.008	0	0.008	0	0.008	0.008	0.008	0.008	0.008	0	0.008
B.3.1.	0.054	0	0.054	0	0.054	0.054	0.054	0.054	0.054	0.054	0.054
B.3.2.	0.027	0	0.027	0	0.027	0.027	0.027	0.027	0.027	0.027	0.027
B.3.3.	0.054	0	0.054	0	0.054	0.054	0.054	0.054	0.054	0.054	0.054

	Central	Sivrice	Kovancılar	Palu	Karakoçan	Maden	Baskil	Keban	Arıcak	Alacakaya	Ağın
A.1.1.	0.033	0	0.033	0.033	0.033	0.033	0	0	0.033	0	0
A.1.2.	0.066	0	0.066	0.066	0	0	0	0.066	0.066	0.066	0.066
A.1.3.	0	0	0	0	0	0.066	0.066	0	0	0.066	0
A.2.1.1.	0	0	0	0.125	0	0.125	0.125	0.125	0.125	0.125	0.125
A.2.1.2.	0	0	0	0	0	0	0	0	0	0	0
A.2.2.1.	0	0	0	0	0	0	0	0.034	0.034	0.034	0
A.2.2.2.	0.034	0	0.034	0.034	0	0.034	0.034	0.034	0.034	0.034	0.034
A.2.2.3.	0	0	0	0	0	0	0	0	0	0	0
B.1.1.	0.055	0	0.055	0.055	0	0	0	0	0	0	0
B.1.2.	0.047	0	0.047	0.047	0	0	0	0	0	0	0
B.1.3.	0.032	0	0.032	0.032	0	0	0	0	0	0	0
B.1.4.	0.016	0	0.016	0.016	0	0	0	0	0	0	0
B.1.5.	0	0	0	0.008	0	0	0	0	0	0	0
B.2.1.	0.055	0	0.055	0.055	0	0.055	0.055	0	0	0	0
B.2.2.	0.047	0	0.047	0.047	0	0.047	0.047	0	0	0	0
B.2.3.	0.032	0	0.032	0.032	0	0.032	0.032	0	0	0	0
B.2.4.	0.016	0	0.016	0.016	0	0.016	0.016	0	0	0	0
B.2.5.	0	0	0	0.008	0	0	0	0	0	0.008	0
B.3.1.	0	0	0	0.054	0	0	0	0	0	0	0
B.3.2.	0	0	0	0.027	0	0	0	0	0	0	0
B.3.3.	0	0	0	0.054	0	0	0	0	0	0	0

dimensions of community resilience, encompassing technical, organizational, social, and economic aspects. Likewise, Davidson and Shah [71] have emphasized that vulnerability factors are not isolated but exhibit interactions, overlaps, and contradictions among different indicator classes. Ruiter et al. [75] have classified vulnerability indicators into two primary categories, mirroring many flood and earthquake vulnerability assessments: physical indicators (including infrastructure, building attributes, and environmental factors) and social indicators (comprising demographics, awareness, socioeconomics, and institutional aspects). While prior studies typically encompassed around 30 criteria, Ozmen [32]'s study has considered 67 criteria. The integration of GIS and MCDM methods represents a valuable approach with broad applications across various fields. It equips decision-makers with the means to make well-informed, geospatially aware choices. Examples in the literature include Nyimbili et al. [34] for earthquake risk, Kumlu and Tüdeş [35] in Yalova, and Jena et al. [36] for susceptibility. Milad Moradi et al. [38] used GIS for seismic vulnerability, while Delavar et al. [39] focused on hospital safety. This integrated approach enhances decision-making across applications.

In this study, Elazığ all districts and its' central district NHs' were ranked according to 21 criteria, including two main criteria given in Table 9. Decision hierarchy and

TABLE 14. DBDM results of districts.

	TDoM	*TIDoM*	*SDoM*	*RANK*
Central	0.371	0.538	0.592	4
Sivrice	0.318	0.591	0.651	1
Kovancılar	0.401	0.508	0.559	5
Palu	0.333	0.576	0.634	2
Karakoçan	0.549	0.36	0.396	9
Maden	0.351	0.558	0.613	3
Baskil	0.478	0.431	0.474	6
Keban	0.552	0.357	0.393	10
Arıcak	0.487	0.423	0.465	7
Alacakaya	0.505	0.404	0.444	8
Ağın	0.655	0.254	0.279	11

TABLE 15. DBDM results of NHs.

	TDoM	TIDoM	SDoM	RANK
NH-1	0,527	0,444	0,457	23
NH-2	0,349	0,462	0,569	13
NH-3	0,307	0,546	0,640	5
NH-4	0,678	0,292	0,301	33
NH-5	0,444	0,405	0,478	28
NH-6	0,398	0,455	0,534	20
NH-7	0,525	0,290	0,356	18
NH-8	0,619	0,351	0,362	30
NH-9	0,626	0,261	0,294	34
NH-10	0,260	0,555	0,681	2
NH-11	0,325	0,528	0,619	3
NH-12	0,309	0,544	0,637	8
NH-13	0,433	0,392	0,475	6
NH-14	0,497	0,356	0,417	21
NH-15	0,419	0,398	0,487	24
NH-16	0,349	0,500	0,589	19
NH-17	0,585	0,268	0,314	10
NH-18	0,317	0,536	0,628	32
NH-19	0,357	0,502	0,584	7
NH-20	0,500	0,358	0,417	11
NH-21	0,393	0,460	0,539	25
NH-22	0,293	0,522	0,640	17
NH-23	0,623	0,342	0,355	4
NH-24	0,455	0,398	0,467	31
NH-25	0,363	0,451	0,554	22
NH-26	0,259	0,599	0,698	1
NH-27	0,623	0,348	0,358	29
NH-28	0,368	0,450	0,550	15
NH-29	0,391	0,478	0,550	16
NH-30	0,605	0,360	0,374	27
NH-31	0,347	0,467	0,574	12
NH-32	0,604	0,366	0,377	26
NH-33	0,328	0,525	0,616	9
NH-34	0,275	0,543	0,664	14

GIS-based Earthquake Vulnerability Assessment are given below.

STAGE 2. Construct Decision Matrix:

VI. ELAZIĞ GIS-BASED EARTHQUAKE VULNERABILITY ASSESSMENT DECISION MATRIX

In Elazığ, TÜRKİYE GIS-based earthquake vulnerability assessment decision hierarchy, there are 2 main and a total of 21 sub-criteria.

A. A: BUILDINGS

A: Buildings' main criteria values were obtained from two resources. One of them was the Republic of Türkiye Minister of Environment, Urbanization and Climate Change. The other was the 24 January 2020 MW 6.8 Sivrice earthquake Elazig region structural damages investigation and evaluation report prepared by Firat University Construction and Concrete Application Research Center [63].

B. B:GIS-BASED RISK AND HAZARD

B: GIS-based risk and hazard main criteria values were obtained from European Seismic Hazard Model maps and AFAD [19], [72].

The European Facilities for Earthquake Hazard and Risk (EFEHR) is a nonprofit network of organizations and community resources that aims to advance earthquake hazard and risk assessment in the Euro-Mediterranean region [73]. It promotes good practice and the exchange of knowledge within the research community. Integrates with the engineering community to ensure a seamless transition from hazard to risk (exposure, vulnerability). It enables national and local hazard and risk assessment by providing access to the software and expertise required for contemporary hazard and risk assessment. It provides open access to state-of-the-art, reliable, and reproducible data, models, and information on earthquake hazard and risk, harmonized across Europe. Boğaziçi University and Kandilli Observatory from Türkiye are also present in the general assembly of the EFEHR Consortium.

The 2020 update of the European Seismic Hazard Model ESHM20: Model Overview report published by the EFEHR Consortium in 2021 includes the 2020 update of the European Seismic Hazard Model. The 2020 European Seismic Hazard Model (ESHM20) is an update of the earthquake hazard assessment of the Euro Mediterranean region. ESHM20 follows the same principles as ESHM13, with state-of-the-art procedures applied homogeneously for the entire European region without country border issues. The model is built on recently compiled data sets (i.e., earthquake catalogs, active faults, ground shaking records), information (tectonic and geological), and models (seismogenic sources, ground shaking).

While obtaining criteria values from EFEHR several image processing steps were implemented. In literature, there are many GIS-based decision-making approaches. The steps are detailed below.

Hazard maps for specific types of density measurements (PGA, spectrum acceleration with 5% damping in dominant periods in the range of 0.05 seconds to 5 seconds) and five mean return periods (i.e., 50, 475, 975, 2500, and 5000 years) are available on the scientific website EFEHR.

C. B. 1. FAULT

Active fault model compiled for ESHM20. Active faults are included in the Generic ground acceleration hazard map in Figure 7. From this map, 5 criteria expressing the active fault density within the radius of 0.5km, 0.1km, 0.2km, 0.4km, and 5km of the coordinates of each damaged building were calculated by following the image processing steps in the flow diagram given in Figure 9.

D. B. 2. EARTHQUAKES

Between AD 1000 and 2014: ESHM20 European Earthquake Catalogue. Figure 8 shows earthquakes between 1000 AD and 2014 on the Generic ground acceleration hazard map. From this map, 8 attributes expressing the earthquake intensity within the radius of 5km, 10km, 20km, 25km, 40km, 50km, 100km, and 200km of the coordinates of each damaged building were calculated by following the image processing steps in the flow diagram given in Figure 9.

TABLE 16. Decision matrix of ELAZIĞ's central district NHs.

	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6	NH-7	NH-8	NH-9	NH-10	NH-11	NH-12	NH-13	NH-14	NH-15	NH-16	NH-17
A.1.1.	5,45	5,99	1,74	5,68	7,31	0,87	2,27	12,05	3,76	1,41	3,40	1,45	2,09	6,98	4,99	6,87	1,67
A.1.2.	3,53	5,65	1,85	4,13	4,88	5,08	2,10	8,05	3,54	1,65	3,13	1,70	1,94	6,89	5,61	5,53	1,44
A.1.3.	1992,48	1991,00	1990,16	1994,41	1995,10	1991,00	1990,85	1994,33	1994,44	1989,99	1989,61	1988,59	1991,15	1996,17	1988,54	1991,65	1991,00
A.2.1.1.	0,54	0,87	0,25	0,95	0,87	0,73	0,68	0,97	0,96	0,24	0,40	0,27	0,39	0,89	0,94	0,92	0,18
A.2.1.2.	0,46	0,13	0,75	0,05	0,13	0,27	0,32	0,03	0,04	0,76	0,60	0,73	0,61	0,11	0,06	0,08	0,82
A.2.2.1.	0,33	0,43	0,04	0,88	0,66	0,28	0,62	0,92	0,30	0,06	0,26	0,18	0,33	0,83	0,34	0,35	0,08
A.2.2.2.	0,20	0,39	0,17	0,06	0,16	0,67	0,07	0,04	0,65	0,17	0,14	0,10	0,04	0,03	0,58	0,54	0,09
A.2.2.3.	0,48	0,18	0,79	0,06	0,18	0,05	0,31	0,04	0,05	0,76	0,61	0,72	0,63	0,14	0,08	0,11	0,83
B.1.1.	1,00	1,00	0,48	1,00	0,95	0,50	0,60	1,00	0,10	1,00	1,00	0,19	1,00	1,00	0,44	1,00	0,04
B.1.2.	1,00	1,00	0,48	1,00	0,95	0,50	0,60	1,00	0,10	1,00	1,00	0,19	1,00	1,00	0,44	1,00	0,04
B.1.3.	2,99	3,00	1,79	3,00	2,85	2,33	1,45	3,00	0,36	3,00	3,00	0,56	3,00	3,00	2,03	3,00	0,20
B.1.4.	8,98	9,00	5,66	8,99	8,55	7,75	3,82	9,00	0,94	9,00	9,00	1,46	8,99	9,00	7,75	8,60	0,48
B.1.5.	0,17	0,00	0,00	0,13	1,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B.2.1.	1,00	1,00	1,00	1,00	0,98	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
B.2.2.	1,00	1,00	1,00	1,00	0,98	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
B.2.3.	3,00	3,00	3,00	3,00	2,94	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00
B.2.4.	8,99	9,00	9,00	8,99	8,80	9,00	9,00	9,00	9,00	9,00	9,00	9,00	9,00	8,99	9,00	9,00	9,00
B.2.5.	517,39	593,55	587,87	532,48	575,32	594,00	598,73	596,97	600,69	601,13	597,92	578,91	584,89	431,59	594,03	594,05	598,16
B.3.1.	0,38	0,39	0,40	0,39	0,38	0,39	0,40	0,37	0,39	0,37	0,38	0,42	0,39	0,38	0,39	0,38	0,41
B.3.2.	0,71	0,72	0,74	0,72	0,71	0,72	0,74	0,69	0,73	0,70	0,71	0,77	0,73	0,71	0,72	0,71	0,75
B.3.3.	19632,90	811,53	21376,25	21201,12	21164,56	2057,47	22329,64	21376,72	22324,78	21258,67	21526,73	21392,30	21720,96	21423,79	21045,83	20979,98	12273,41
	NH-18	**NH-19**	**NH-20**	**NH-21**	**NH-22**	**NH-23**	**NH-24**	**NH-25**	**NH-26**	**NH-27**	**NH-28**	**NH-29**	**NH-30**	**NH-31**	**NH-32**	**NH-33**	**NH-34**
A.1.1.	5,11	1,63	6,09	5,67	5,83	4,71	6,32	5,53	1,78	2,66	5,21	5,72	3,92	7,04	4,59	2,46	4,13
A.1.2.	4,34	1,90	4,61	4,43	5,29	3,90	5,08	4,74	1,82	3,12	4,59	4,07	3,12	5,12	3,60	2,53	1,24
A.1.3.	1992,81	1989,35	1992,55	1991,43	1990,89	1990,93	1990,82	1989,53	1989,21	1989,61	1989,95	1992,99	1993,50	1992,33	1991,43	1991,65	1971,88
A.2.1.1.	0,93	0,27	0,79	0,96	0,87	0,67	0,96	0,91	0,22	0,94	0,88	0,63	0,58	0,79	0,85	0,21	0,90
A.2.1.2.	0,07	0,73	0,21	0,04	0,13	0,33	0,04	0,09	0,78	0,06	0,12	0,37	0,42	0,21	0,15	0,79	0,10
A.2.2.1.	0,54	0,09	0,03	0,12	0,26	0,30	0,11	0,16	0,03	0,33	0,26	0,35	0,26	0,26	0,58	0,13	0,04
A.2.2.2.	0,45	0,18	0,70	0,82	0,42	0,27	0,37	0,81	0,22	0,39	0,69	0,22	0,33	0,54	0,28	0,33	0,35
A.2.2.3.	0,01	0,73	0,27	0,06	0,33	0,43	0,51	0,03	0,75	0,28	0,05	0,44	0,40	0,19	0,14	0,54	0,61
B.1.1.	0,00	0,04	0,96	0,70	0,99	1,00	0,86	0,80	0,50	0,40	1,00	1,00	0,12	1,00	1,00	0,81	1,00
B.1.2.	0,00	0,04	0,96	0,70	0,99	1,00	0,86	0,80	0,50	0,40	1,00	1,00	0,12	1,00	1,00	0,81	1,00
B.1.3.	0,55	0,13	2,88	2,07	2,97	3,00	2,30	1,42	1,43	0,74	3,00	3,00	0,57	3,00	2,99	2,24	3,00
B.1.4.	2,53	0,77	8,64	4,85	8,92	9,00	7,15	5,25	4,13	2,85	7,04	9,00	1,78	9,00	8,98	6,55	9,00
B.1.5.	0,00	0,00	1,32	0,40	0,00	0,00	0,00	0,00	0,60	3,12	0,00	0,01	0,00	0,00	0,05	0,00	0,00
B.2.1.	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,94	1,00	1,00	1,00	1,00
B.2.2.	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,94	1,00	1,00	1,00	1,00
B.2.3.	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	2,99	3,00	3,00	2,87	3,00	2,99	3,00	3,00
B.2.4.	9,00	9,00	9,00	9,00	9,00	9,00	8,99	9,00	9,00	8,98	9,00	9,00	8,68	9,00	8,98	9,00	9,00
B.2.5.	599,61	596,79	593,53	595,12	594,03	593,82	594,18	593,48	600,50	595,99	593,35	582,08	601,86	595,30	596,49	599,11	602,68
B.3.1.	0,39	0,40	0,39	0,39	0,39	0,39	0,38	0,39	0,40	0,40	0,39	0,39	0,39	0,38	0,38	0,38	0,37
B.3.2.	0,72	0,75	0,72	0,73	0,72	0,72	0,72	0,73	0,74	0,74	0,73	0,72	0,72	0,71	0,71	0,71	0,69
B.3.3.	21194,26	22489,21	21238,20	21256,07	20589,78	21275,40	20577,38	20535,75	21443,54	21379,64	19222,48	20455,51	21106,81	20076,96	20667,82	21716,27	22333,54

6 steps are followed when calculating B.1. Fault and B.2. Earthquake criteria values from EFEHR Maps. The steps in the flow diagram were repeated.

Step 1: Obtaining the relevant map image from the EFEHR web service

Step 2: Obtaining an image of the area including Türkiye and its immediate surroundings from the image. The coordinate information of the four corners of the images was obtained in this step.

Step 3: Converting Color Image to Gray Image: Images are obtained in color from most devices. While some algorithms can work on color images, some images need to be converted to Gray images. The first thing to do before counting is to convert the color image into a black-and-white image [74]. Gray images are images that show the intensity of light. These images are stored in 8-bit format on the computer. This means that each pixel is stored with 8 bits of binary code. It takes values between 0255. 0 will indicate black color, while 255 will indicate white color. However, the color with a value of 128 will be an intermediate color that is a mixture of black and white. Gray image is a color between 0 and 255, that is, between black and white. Color images consist of mixtures of red, green, and blue colors in varying proportions. Red, green, or blue ratios (wavelengths) vary depending on the medium represented by these colored images. The wavelength of the blue color is longer in a sea image, the wavelength of the green color is longer in a forest image, and the wavelength of the red color is longer in a fire image [74].

Step 4: Calculating the number of pixels corresponding to a latitude/longitude: By proportioning the pixel numbers between the coordinates specified in the previous step, the number of pixels corresponding to each latitude and each longitude was calculated. This information will be used to calculate the radius in the following steps.

Steps 5 and 6 are repeated for each building and each radius of 0.5km, 0.1km, 0.2km, 0.4km, and 5km.

Step 5: Obtaining images of each building and each radius. The relevant image is obtained by using the pixel numbers calculated in Step 4.

Step 6: Calculating density from the images: The sum of the values in each pixel in the image obtained in the previous step is calculated. These calculated values will also constitute the attribute value.

E. B. 3. GROUND ACCELERATION AND VELOCITY

According to the Earthquake Hazard Map, the earthquake ground motion parameter values of a place can be accessed on a coordinated basis with the Türkiye Earthquake Hazard Maps Interactive Web Application. PGA values were calculated based on the site's coordinates and considered for

TABLE 17. ***DoM*** **and** ***IDoM*** **matrices of alternative NH-3: AKSARA.**

NHs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
A.1.1.	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.1.2.	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
A.1.3.	1	1	0	1	1	1	1	1	1	0	0	0	1	1	0	1	1	1	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0
A.2.1.1.	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1
A.2.1.2.	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1
A.2.2.1.	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0
A.2.2.2.	0	0	0	1	1	0	1	1	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.2.2.3.	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B.1.1.	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
B.1.2.	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
B.1.3.	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0
B.1.4.	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	0	1	0	0	0	1	1	1	0	0	1	0	0	0	0
B.1.5.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B.2.1.	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0
B.2.2.	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0
B.2.3.	1	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0
B.2.4.	1	0	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	0	1	0	0
B.2.5.	1	0	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
B.3.1.	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1
B.3.2.	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1
B.3.3.	1	1	0	1	1	1	0	0	0	1	0	0	0	0	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0

NHs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
A.1.1.	1	1	0	1	1	0	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
A.1.2.	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0
A.1.3.	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1
A.2.1.1.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
A.2.1.2.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
A.2.2.1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1
A.2.2.2.	1	1	0	0	0	1	0	0	1	1	0	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
A.2.2.3.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B.1.1.	1	1	0	1	1	1	1	1	0	1	1	0	1	1	0	1	0	0	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1
B.1.2.	1	1	0	1	1	1	1	1	0	1	1	0	1	1	0	1	0	0	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1
B.1.3.	1	1	0	1	1	1	0	1	0	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	1	1	0	1	1	1	1
B.1.4.	1	1	0	1	1	1	0	1	0	1	1	0	1	1	1	1	0	0	0	1	0	1	1	1	0	0	0	1	1	0	1	1	1	1
B.1.5.	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	1	0	0	1	0	0
B.2.1.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B.2.2.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B.2.3.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B.2.4.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B.2.5.	0	1	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
B.3.1.	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
B.3.2.	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
B.3.3.	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1

return periods of 475 and 2475 years. PGV values are also available in the Türkiye Earthquake Hazard Maps, tailored to the construction site's coordinates and the selected recurrence interval, particularly for a return period of 475 years.

STAGE 3. Obtain Rankings With DBDM:

VII. ELAZIĞ DISTRICTS AND ITS' CENTRAL DISTRICT NHs RANKING FOR EARTHQUAKE VULNERABILITY ASSESSMENT

DBDM method presents several advantages when assessing earthquake vulnerability in Elazığ, Türkiye, compared to other MCDM methods. DBDM is known for its simplicity and transparency in decision-making processes. This can be advantageous in earthquake vulnerability assessments, especially in complex urban environments like Elazığ. The straightforward nature of DBDM allows for a clear understanding of the decision-making criteria, aiding in effective communication and interpretation of the results.

One notable advantage of DBDM is its immunity to the rank reversal phenomenon. In earthquake vulnerability assessments, where the importance of criteria might change based on the context or expert opinions, the immunity to rank reversal ensures that sudden changes in the relative importance of criteria do not significantly impact the results.

DBDM, when integrated with GIS, offers a powerful tool for earthquake vulnerability assessment. The combination of DBDM's decision-making capabilities with GIS's spatial data management allows for a comprehensive analysis considering factors such as building conditions, population density, accessibility, and other geographic elements. This integration enhances the accuracy and reliability of the vulnerability assessment.

DBDM provides an objective approach to decision-making by combining expert judgments with mathematical foundations. In earthquake vulnerability assessments, where input from experts and stakeholders is crucial, DBDM allows for

TABLE 18. WDoM and WIDoM matrices of alternative NH-3: AKSARAY.

NHs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A.1.1.	0,000	0,000	0,000	0,000	0,000	0,033	0,000	0,000	0,000	0,033	0,000	0,033	0,000	0,000	0,000	0,000	0,033
A.1.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,066	0,000	0,066	0,000	0,000	0,000	0,000	0,066
A.1.3.	0,066	0,066	0,000	0,066	0,066	0,066	0,066	0,066	0,066	0,000	0,000	0,000	0,066	0,066	0,000	0,066	0,066
A.2.1.1.	0,125	0,125	0,000	0,125	0,125	0,125	0,125	0,125	0,125	0,000	0,125	0,125	0,125	0,125	0,125	0,125	0,000
A.2.1.2.	0,125	0,125	0,000	0,125	0,125	0,125	0,125	0,125	0,125	0,000	0,125	0,125	0,125	0,125	0,125	0,125	0,000
A.2.2.1.	0,034	0,034	0,000	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034
A.2.2.2.	0,000	0,000	0,000	0,034	0,034	0,000	0,034	0,034	0,000	0,000	0,034	0,034	0,034	0,034	0,000	0,000	0,034
A.2.2.3.	0,067	0,067	0,000	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,000
B.1.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,055	0,000	0,000	0,055	0,000	0,000	0,055	0,000	0,055
B.1.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,047	0,000	0,000	0,047	0,000	0,000	0,047	0,000	0,047
B.1.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,032	0,000	0,032	0,000	0,000	0,032	0,000	0,000	0,000	0,000	0,032
B.1.4.	0,000	0,000	0,000	0,000	0,000	0,000	0,016	0,000	0,016	0,000	0,000	0,016	0,000	0,000	0,000	0,000	0,016
B.1.5.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.1.	0,055	0,000	0,000	0,055	0,055	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.2.	0,047	0,000	0,000	0,047	0,047	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.3.	0,032	0,000	0,000	0,032	0,032	0,000	0,000	0,000	0,032	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.4.	0,016	0,000	0,000	0,016	0,016	0,000	0,000	0,000	0,016	0,000	0,000	0,000	0,000	0,016	0,000	0,000	0,000
B.2.5.	0,008	0,000	0,000	0,008	0,008	0,000	0,000	0,000	0,000	0,000	0,000	0,008	0,008	0,008	0,000	0,000	0,000
B.3.1.	0,054	0,054	0,000	0,054	0,054	0,054	0,000	0,054	0,054	0,054	0,054	0,000	0,054	0,054	0,054	0,054	0,000
B.3.2.	0,027	0,027	0,000	0,027	0,027	0,027	0,000	0,027	0,027	0,027	0,027	0,000	0,027	0,027	0,027	0,027	0,000
B.3.3.	0,054	0,054	0,000	0,054	0,054	0,054	0,000	0,000	0,000	0,054	0,000	0,000	0,000	0,000	0,054	0,054	0,054
NHs	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
A.1.1.	0,000	0,033	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
A.1.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,066	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,066
A.1.3.	0,066	0,000	0,066	0,066	0,066	0,066	0,066	0,000	0,000	0,000	0,000	0,066	0,066	0,066	0,066	0,066	0,000
A.2.1.1.	0,125	0,125	0,125	0,125	0,125	0,125	0,125	0,125	0,000	0,125	0,125	0,125	0,125	0,125	0,125	0,000	0,125
A.2.1.2.	0,125	0,125	0,125	0,125	0,125	0,125	0,125	0,125	0,000	0,125	0,125	0,125	0,125	0,125	0,125	0,000	0,125
A.2.2.1.	0,034	0,034	0,000	0,034	0,034	0,034	0,034	0,034	0,000	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,000
A.2.2.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
A.2.2.3.	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067	0,067
B.1.1.	0,055	0,055	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,055	0,000	0,000	0,055	0,000	0,000	0,000	0,000
B.1.2.	0,047	0,047	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,047	0,000	0,000	0,047	0,000	0,000	0,000	0,000
B.1.3.	0,032	0,032	0,000	0,000	0,000	0,000	0,000	0,032	0,032	0,032	0,000	0,000	0,032	0,000	0,000	0,000	0,000
B.1.4.	0,016	0,016	0,000	0,016	0,000	0,000	0,000	0,016	0,016	0,016	0,000	0,000	0,016	0,000	0,000	0,000	0,000
B.1.5.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,055	0,000	0,000	0,055	0,000	0,000	0,055	0,000	0,055	0,000	0,000
B.2.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,047	0,000	0,000	0,047	0,000	0,000	0,047	0,000	0,047	0,000	0,000
B.2.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,032	0,000	0,000	0,032	0,000	0,000	0,032	0,000	0,032	0,000	0,000
B.2.4.	0,000	0,000	0,000	0,000	0,000	0,000	0,016	0,000	0,000	0,016	0,000	0,016	0,016	0,000	0,016	0,000	0,000
B.2.5.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,008	0,000	0,000	0,000	0,000	0,000
B.3.1.	0,054	0,000	0,054	0,054	0,054	0,054	0,054	0,054	0,000	0,000	0,054	0,054	0,054	0,054	0,054	0,054	0,054
B.3.2.	0,027	0,000	0,027	0,027	0,027	0,027	0,027	0,027	0,000	0,000	0,027	0,027	0,027	0,027	0,027	0,027	0,027
B.3.3.	0,054	0,000	0,054	0,054	0,054	0,054	0,054	0,054	0,000	0,000	0,054	0,054	0,054	0,054	0,054	0,000	0,000

NHs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A.1.1.	0,033	0,033	0,000	0,033	0,033	0,000	0,033	0,033	0,033	0,000	0,033	0,000	0,033	0,033	0,033	0,033	0,000
A.1.2.	0,066	0,066	0,000	0,066	0,066	0,066	0,066	0,066	0,066	0,000	0,066	0,000	0,066	0,066	0,066	0,066	0,000
A.1.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,066	0,066	0,066	0,000	0,000	0,066	0,000	0,000
A.2.1.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,125	0,000	0,000	0,000	0,000	0,000	0,000	0,125
A.2.1.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,125	0,000	0,000	0,000	0,000	0,000	0,000	0,125
A.2.2.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
A.2.2.2.	0,034	0,034	0,000	0,000	0,000	0,034	0,000	0,000	0,034	0,034	0,000	0,000	0,000	0,000	0,034	0,034	0,000
A.2.2.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,067
B.1.1.	0,055	0,055	0,000	0,055	0,055	0,055	0,055	0,055	0,000	0,055	0,055	0,000	0,055	0,055	0,000	0,055	0,000
B.1.2.	0,047	0,047	0,000	0,047	0,047	0,047	0,047	0,047	0,000	0,047	0,047	0,000	0,047	0,047	0,000	0,047	0,000
B.1.3.	0,032	0,032	0,000	0,032	0,032	0,032	0,000	0,032	0,000	0,032	0,032	0,000	0,032	0,032	0,032	0,032	0,000
B.1.4.	0,016	0,016	0,000	0,016	0,016	0,016	0,000	0,016	0,000	0,016	0,016	0,000	0,016	0,016	0,016	0,016	0,000
B.1.5.	0,008	0,000	0,000	0,008	0,008	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.4.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.5.	0,000	0,008	0,000	0,000	0,000	0,008	0,008	0,008	0,008	0,008	0,008	0,000	0,000	0,000	0,008	0,008	0,008
B.3.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,054	0,000	0,000	0,000	0,000	0,054	0,000	0,000	0,000	0,000	0,054
B.3.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,027	0,000	0,000	0,000	0,000	0,027	0,000	0,000	0,000	0,000	0,027
B.3.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,054	0,054	0,054	0,000	0,054	0,054	0,054	0,054	0,000	0,000	0,000
NHs	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
A.1.1.	0,033	0,000	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033	0,033
A.1.2.	0,066	0,066	0,066	0,066	0,066	0,066	0,066	0,066	0,000	0,066	0,066	0,066	0,066	0,066	0,066	0,066	0,000
A.1.3.	0,000	0,066	0,000	0,000	0,000	0,000	0,000	0,066	0,066	0,066	0,066	0,000	0,000	0,000	0,000	0,000	0,066
A.2.1.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,125	0,000	0,000	0,000	0,000	0,000	0,000	0,125	0,000
A.2.1.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,125	0,000	0,000	0,000	0,000	0,000	0,000	0,125	0,000
A.2.2.1.	0,000	0,000	0,034	0,000	0,000	0,000	0,000	0,000	0,034	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,034
A.2.2.2.	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034
A.2.2.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.1.1.	0,000	0,000	0,055	0,055	0,055	0,055	0,055	0,055	0,055	0,000	0,055	0,055	0,000	0,055	0,055	0,055	0,055

TABLE 18. *(Continued.)* **WDoM and WIDoM matrices of alternative NH-3: AKSARAY.**

B.1.2.	0,000	0,000	0,047	0,047	0,047	0,047	0,047	0,047	0,047	0,000	0,047	0,047	0,000	0,047	0,047	0,047	0,047
B.1.3.	0,000	0,000	0,032	0,032	0,032	0,032	0,032	0,000	0,000	0,000	0,032	0,032	0,000	0,032	0,032	0,032	0,032
B.1.4.	0,000	0,000	0,016	0,000	0,016	0,016	0,016	0,000	0,000	0,000	0,016	0,016	0,000	0,016	0,016	0,016	0,016
B.1.5.	0,000	0,000	0,008	0,008	0,000	0,000	0,000	0,000	0,008	0,008	0,000	0,008	0,000	0,000	0,008	0,000	0,000
B.2.1.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.2.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.3.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.4.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.2.5.	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,008	0,000	0,008	0,008	0,008	0,008	0,008
B.3.1.	0,000	0,054	0,000	0,000	0,000	0,000	0,000	0,000	0,054	0,054	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.3.2.	0,000	0,027	0,000	0,000	0,000	0,000	0,000	0,000	0,027	0,027	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.3.3.	0,000	0,054	0,000	0,000	0,000	0,000	0,000	0,000	0,054	0,054	0,000	0,000	0,000	0,000	0,000	0,054	0,054

the incorporation of expert opinions in a structured and objective manner. DBDM is known for producing consistent and stable results, which is essential in earthquake vulnerability assessments where the reliability of the outcomes is paramount. The stability of results ensures that small variations in the input criteria or expert opinions do not lead to significant fluctuations in the vulnerability rankings. DBDM offers a systematic and structured approach to decision-making. In earthquake vulnerability assessments for Elazığ, this systematic approach allows for the comprehensive evaluation of districts and neighborhoods, considering various criteria systematically and providing a holistic understanding of vulnerability.

In summary, the advantages of DBDM, including its simplicity, rank reversal immunity, integration with GIS, objectivity, consistency, and systematic approach, make it a valuable method for earthquake vulnerability assessments in Elazığ. Its ability to handle complex decision-making scenarios and provide reliable, transparent results positions DBDM as a favorable choice for informing disaster preparedness and risk mitigation strategies in the region.

Now we explain how Elazığ's districts and their' central district NHs get ranked when the DBDM method is implemented on the previous section's given dataset.

Step 1: Construct a Decision Matrix

The ELAZIĞ districts decision matrix is given in Table 10 and the decision matrix of ELAZIĞ's central district NHs is given in Appendix Table 16.

Decision Matrix $= X = \left[x_{ij}\right]_{m\times n}$

Step 2: Construct Is Dominated Matrix (*IDoM*) and Dominated Matrix (*DoM*)

All alternatives were compared with each other according to all criteria. In the below, alternative district Sivrice's *DoM* and *IDoM* matrices are given in Table 11. Besides, alternative NH-3: AKSARAY's *DoM* and *IDoM* matrices are given in Appendix Table 17.

Step 3: Construct Weighted Is Dominated Matrix (*WIDoM*) and Weighted Dominated Matrix (*WDoM*)

Criteria weights $\boldsymbol{W} = \left[w_j\right]_{1\times n}$ are given in Table 12.

All *WDoM* and *WIDoM* matrices were calculated according to equations (5) and (6). In the below, alternative district Sivrice's *WDoM* and *WIDoM* matrices are given in Table 13. Besides, alternative NH-3: AKSARAY's *WDoM* and *WIDoM* matrices are given in Appendix Table 18.

Step 4: Calculate the Total Is Dominated and Dominated Matrix values of each alternative and

Step 5. Calculate the dominance coefficient and rank the order of alternatives.

Each alternative *TDoM* and *TIDoM* values were calculated according to equations (7) and (8). *SDoM* and rank the order of alternatives were calculated according to equation (9).

Elazığ's district results are given in Table 14 and Elazığ's central district NHs results are given in Table 15.

According to the results given in Table 14 and Figure 10, the most earthquake-vulnerable district is Sivrice.

According to the results given in Table 15 and Figure 11, the most five earthquake-vulnerable NHs are 26-Sali Baba, 10-Esentepe, 11- Fevzi Çakmak, 23-Olgunlar And 3- Aksaray.

VIII. CONCLUSION

In this study, a comprehensive assessment of earthquake vulnerability in the central district NHs of Elazığ, Türkiye was conducted by integrating MCDM methods with GIS. Two main criteria, namely building conditions and GIS-based risk and hazard factors were utilized in the assessment.

The newly introduced MCDM method, DBDM was employed to rank earthquake vulnerability. DBDM is based on one-to-one comparisons of alternatives and dominance information. This method allows for a nuanced assessment, ensuring that an alternative's superior performance in one criterion does not overshadow its performance in others. It provides a balanced evaluation of the alternatives.

The results of the earthquake vulnerability assessment revealed that several NHs in Elazığ, including Sali Baba, Esentepe, Fevzi Çakmak, Olgunlar, and Aksaray, are among the most earthquake-vulnerable areas. These findings are crucial for disaster preparedness and risk mitigation strategies in the region.

Future research may explore the refinement of the DBDM method, as well as its application in other fields and regions. Different extensions of MCDM methods (i.e., fuzzy and stochastic) can be used to evaluate according to the criteria of the new data to be included in the study (i.e., the uncertainty in the data). Additionally, ongoing collaboration between experts from various disciplines, including engineering, geography, and social sciences, is vital to continually improve earthquake vulnerability assessments and disaster preparedness efforts.

APPENDIX

See Tables 16–18.

Conflict of Interest Statement: The authors declare that they do not have any conflict of interest.

REFERENCES

[1] J. Ananda and G. Herath, ''A critical review of multi-criteria decision making methods with special reference to forest management and planning,'' *Ecol. Econ.*, vol. 68, no. 10, pp. 2535–2548, Aug. 2009.

[2] J. Więckowski, B. Kizielewicz, A. Shekhovtsov, and W. Sałabun, ''RANCOM: A novel approach to identifying criteria relevance based on inaccuracy expert judgments,'' *Eng. Appl. Artif. Intell.*, vol. 122, Jun. 2023, Art. no. 106114.

[3] N. Munier, ''A new approach to the rank reversal phenomenon in MCDM with the SIMUS method,'' *Multiple Criteria Decis. Making*, vol. 11, pp. 137–152, 2016.

[4] W. Sałabun and A. Piegat, ''Comparative analysis of MCDM methods for the assessment of mortality in patients with acute coronary syndrome,'' *Artif. Intell. Rev.*, vol. 48, no. 4, pp. 557–571, Dec. 2017.

[5] J. Dezert, A. Tchamova, D. Han, and J.-M. Tacnet, ''The SPOTIS rank reversal free method for multi-criteria decision-making support,'' in *Proc. IEEE 23rd Int. Conf. Inf. Fusion (FUSION)*, Jul. 2020, pp. 1–8.

[6] P. A. Alvarez, A. Ishizaka, and L. Martínez, ''Multiple-criteria decision-making sorting methods: A survey,'' *Expert Syst. Appl.*, vol. 183, Nov. 2021, Art. no. 115368.

[7] S. A. R. Khan, Z. Yu, H. Golpira, A. Sharif, and A. Mardani, ''A state-of-the-art review and meta-analysis on sustainable supply chain management: Future research directions,'' *J. Cleaner Prod.*, vol. 278, Jan. 2021, Art. no. 123357.

[8] M. G. Hasan, Z. Ashraf, and M. F. Khan, ''Multi-choice best-worst multi-criteria decision-making method and its applications,'' *Int. J. Intell. Syst.*, vol. 37, no. 2, pp. 1129–1156, Feb. 2022.

[9] T. Li, A. Li, and X. Guo, ''The sustainable development-oriented development and utilization of renewable energy industry—A comprehensive analysis of MCDM methods,'' *Energy*, vol. 212, Dec. 2020, Art. no. 118694.

[10] S. K. Sahoo and S. S. Goswami, ''Theoretical framework for assessing the economic and environmental impact of water pollution: A detailed study on sustainable development of India,'' *J. Future Sustainability*, vol. 4, no. 1, pp. 23–34, 2024.

[11] S. L. Gebre, D. Cattrysse, E. Alemayehu, and J. Van Orshoven, ''Multi-criteria decision making methods to address rural land allocation problems: A systematic review,'' *Int. Soil Water Conservation Res.*, vol. 9, no. 4, pp. 490–501, Dec. 2021.

[12] R. Pelissari, S. A. Khan, and S. Ben-Amor, ''Application of multi-criteria decision-making methods in sustainable manufacturing management: A systematic literature review and analysis of the prospects,'' *Int. J. Inf. Technol. Decis. Making*, vol. 21, no. 2, pp. 493–515, Mar. 2022.

[13] M. Yenugula, S. K. Sahoo, and S. S. Goswami, ''Cloud computing for sustainable development: An analysis of environmental, economic and social benefits,'' *J. Future Sustainability*, vol. 4, no. 1, pp. 59–66, 2024.

[14] Y. Supriya and T. R. Gadekallu, ''A survey on soft computing techniques for federated learning- applications, challenges and future directions,'' *J. Data Inf. Qual.*, vol. 15, no. 2, pp. 1–28, Jun. 2023.

[15] S. Vatankhah, M. Darvishmotevali, R. Rahimi, S. M. Jamali, and N. A. Ebrahim, ''Assessing the application of multi-criteria decision making techniques in hospitality and tourism research: A bibliometric study,'' *Int. J. Contemp. Hospitality Manage.*, vol. 35, no. 7, pp. 2590–2623, Jun. 2023.

[16] M. H. Kurth, S. Larkin, J. M. Keisler, and I. Linkov, ''Trends and applications of multi-criteria decision analysis: Use in government agencies,'' *Environ. Syst. Decisions*, vol. 37, no. 2, pp. 134–143, Jun. 2017.

[17] M. C. Comerio, ''Public policy for reducing earthquake risks: A U.S. perspective,'' *Building Res. Inf.*, vol. 32, no. 5, pp. 403–413, Sep. 2004.

[18] C. Gurbuz, M. Aktar, H. Eyidogan, and A. Cisternas, ''The seismotectonics of the Marmara region (Turkey): Results from a microseismic experiment,'' *Tectonophysics*, vol. 316, nos. 1–2, pp. 1–17, Jan. 2000.

[19] *T. C. İçişleri Bakanlığı Afet ve Acil Durum Yönetimi Başkanlığı*. Accessed: Jan. 11, 2024. [Online]. Available: https://www.afad.gov.tr

[20] A. Dwyer, C. Zoppou, O. Nielsen, S. Day, and S. Roberts, ''Quantifying social vulnerability: A methodology for identifying those at risk to natural hazards,'' Geosci. Aust. Record, Tech. Rep. 2004/14, 2004.

[21] T. Rashed and J. Weeks, ''Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas,'' *Int. J. Geographical Inf. Sci.*, vol. 17, no. 6, pp. 547–576, Sep. 2003.

[22] S. Erdogan, *İstanbul Tarihi Yarimada'da Kentsel Ölçekte Deprem Odakli Kentsel Zarar Görebilirlik Değerlendirmesi*. Istanbul, Türkiye: İstanbul Teknik Üniversitesi, istanbul türkiye, 2021.

[23] J. M. Diaz-Sarachaga and D. Jato-Espino, ''Analysis of vulnerability assessment frameworks and methodologies in urban areas,'' *Natural Hazards*, vol. 100, no. 1, pp. 437–457, Jan. 2020.

[24] A. Shayannejad and B. A. Angerabi, ''Earthquake vulnerability assessment in urban areas using MCDM case study,'' *Central Part 6 District Tehran Municipality*, vol. 2, no. 2, pp. 39–51, 2014.

[25] Y. Peng, ''Regional earthquake vulnerability assessment using a combination of MCDM methods,'' *Ann. Operations Res.*, vol. 234, no. 1, pp. 95–110, Nov. 2015.

[26] N. Chen, L. Chen, C. Tang, Z. Wu, and A. Chen, ''Disaster risk evaluation using factor analysis: A case study of Chinese regions,'' *Natural Hazards*, vol. 99, no. 1, pp. 321–335, Oct. 2019.

[27] P. Yariyan, H. Zabihi, I. D. Wolf, M. Karami, and S. Amiriyan, ''Earthquake risk assessment using an integrated fuzzy analytic hierarchy process with artificial neural networks based on GIS: A case study of sanandaj in Iran,'' *Int. J. Disaster Risk Reduction*, vol. 50, Nov. 2020, Art. no. 101705.

[28] R. Jena, B. Pradhan, G. Beydoun, H. Sofyan, and M. Affan, ''Integrated model for earthquake risk assessment using neural network and analytic hierarchy process: Aceh province, Indonesia,'' *Geosci. Frontiers*, vol. 11, no. 2, pp. 613–634, Mar. 2020.

[29] E. Güler, S. Avci, and Z. İ. Aladağ, ''Türkiye'de İllerİn deprem hasar görebílírlík siralamasinda çok kríterlí karar verme tekníklerínín başarisinin copeland yöntemí íle değerlendírílmesí,'' *J. Ind. Eng.*, vol. 32 no. 3, pp. 1–24, Sep. 2021.

[30] G. Yücel, ''Earthquake and evacuation area assessment for Istanbul Avcılar district,'' *Disaster Sci. Eng.*, vol. 4, no. 2, pp. 65–79, 2018.

[31] S. Balyemez and L. Berköz, ''Hasar görebilirlik ve kentsel deprem davranıçı,'' *İTÜDERGİSİ/a*, vol. 4, no. 1, pp. 1–12, Aug. 2010.

[32] M. Özmen, ''Evaluating earthquake vulnerability of 2023 Kayseri, Türkiye via BWM-ABAC method,'' *Sādhanā*, vol. 48, no. 3, p. 179, Aug. 2023.

[33] S. Kundak, *İstanbul'da Deprem Risk Parametrelerinin değerlendirilmesine yönelik Bir Model Önerisi. (Doktora tezi)*. Maslak, Istanbul, Türkiye: İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, 2006.

[34] P. H. Nyimbili, T. Erden, and H. Karaman, ''Integration of GIS, AHP and TOPSIS for earthquake hazard analysis,'' *Natural Hazards*, vol. 92, no. 3, pp. 1523–1546, Jul. 2018.

[35] K. B. Yavuz Kumlu and Ş. Tüdeş, ''Determination of earthquake-risky areas in Yalova city center (Marmara region, Turkey) using GIS-based multicriteria decision-making techniques (analytical hierarchy process and technique for order preference by similarity to ideal solution),'' *Natural Hazards*, vol. 96, no. 3, pp. 999–1018, Apr. 2019.

[36] R. Jena, B. Pradhan, and G. Beydoun, ''Earthquake vulnerability assessment in northern Sumatra province by using a multi-criteria decision-making model,'' *Int. J. Disaster Risk Reduction*, vol. 46, Jun. 2020, Art. no. 101518.

[37] R. Jena, B. Pradhan, G. Beydoun, A. Alamri, and A. Shanableh, ''Spatial earthquake vulnerability assessment by using multi-criteria decision making and probabilistic neural network techniques in odisha, India,'' *Geocarto. Int.*, vol. 37, no. 25, pp. 8080–8099, Dec. 2022.

[38] M. Moradi, M. R. Delavar, and B. Moshiri, ''Sensitivity analysis of ordered weighted averaging operator in earthquake vulnerability assessment,'' *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, vols. XL–1/W3, pp. 277–282, Sep. 2013.

[39] M. R. Delavar, M. Moradi, and B. Moshiri, ''Earthquake vulnerability assessment for hospital buildings using a gis-based group multi criteria decision making approach: A case study of tehran, Iran,'' *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, vol. XL-1/W5, pp. 153–157, Dec. 2015.

[40] Y. Wind and T. L. Saaty, "Marketing applications of the analytic hierarchy process," *Manage. Sci.*, vol. 26, no. 7, pp. 641–658, Jul. 1980.

[41] C. L. Hwang and K. S. Yoon, *Multiple Attributes Decision Making Methods* (Lecture Notes in Economics & Mathematical Systems), vol. 404, no. 4, 1981, pp. 287–288.

[42] J. P. Brans, P. Vincke, and B. Mareschal, "How to select and how to rank projects: The promethee method," *Eur. J. Oper. Res.*, vol. 24, no. 2, pp. 228–238, Feb. 1986.

[43] L. Duckstein and S. Opricovic, "Multiobjective optimization in river basin development," *Water Resour. Res.*, vol. 16, no. 1, pp. 14–20, Feb. 1980.

[44] B. Roy, "The outranking approach and the foundations of electre methods," *Theory Decis.*, vol. 31, no. 1, pp. 49–73, Jul. 1991.

[45] P. C. Fishburn, "Letter to the editor—Additive utilities with incomplete product sets: Application to priorities and assignments," *Oper. Res.*, vol. 15, no. 3, pp. 537–542, Jun. 1967.

[46] M. H. Azimi, H. Taghizadeh, N. F.-H. Farahmand, and J. Pourmahmoud, "Selection of industrial robots using the polygons area method," *Int. J. Ind. Eng. Computations*, vol. 5, no. 4, pp. 631–646, 2014.

[47] E. K. Zavadskas, Z. Turskis, and J. Antucheviciene, "Optimization of weighted aggregated sum product assessment," *Electron. Electr. Eng.*, vol. 122, no. 6, pp. 3–6, Jun. 2012.

[48] W. Serrai, A. Abdelli, L. Mokdad, and Y. Hammal, "Towards an efficient and a more accurate web service selection using MCDM methods," *J. Comput. Sci.*, vol. 22, pp. 253–267, Sep. 2017.

[49] A. Hussain, J. Chun, and M. Khan, "A novel customer-centric methodology for optimal service selection (MOSS) in a cloud environment," *Future Gener. Comput. Syst.*, vol. 105, pp. 562–580, Apr. 2020.

[50] S. Singh and J. Sidhu, "Compliance-based multi-dimensional trust evaluation system for determining trustworthiness of cloud service providers," *Future Gener. Comput. Syst.*, vol. 67, pp. 109–132, Feb. 2017.

[51] U. Hacioglu, D. Chlyeh, M. K. Yilmaz, E. Tatoglu, and D. Delen, "Crafting performance-based cryptocurrency mining strategies using a hybrid analytics approach," *Decis. Support Syst.*, vol. 142, Mar. 2021, Art. no. 113473.

[52] G. Baranwal and D. P. Vidyarthi, "FONS: A fog orchestrator node selection model to improve application placement in fog computing," *J. Supercomput.*, vol. 77, no. 9, pp. 10562–10589, Sep. 2021.

[53] S. Keyuraphan, P. Thanarak, N. Ketjoy, and W. Rakwichian, "Subsidy schemes of renewable energy policy for electricity generation in Thailand," *Proc. Eng.*, vol. 32, pp. 440–448, Jan. 2012.

[54] A. J. C. Trappey, C. V. Trappey, G. Y. P. Lin, and Y.-S. Chang, "The analysis of renewable energy policies for the Taiwan penghu island administrative region," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 958–965, Jan. 2012.

[55] Y.-C. Shen, C. J. Chou, and G. T. R. Lin, "The portfolio of renewable energy sources for achieving the three e policy goals," *Energy*, vol. 36, no. 5, pp. 2589–2598, May 2011.

[56] M. C. Chuang and H. W. Ma, "An assessment of Taiwan's energy policy using multi-dimensional energy security indicators," *Renew. Sustain. Energy Rev.*, vol. 17, pp. 301–311, Jan. 2013.

[57] H.-C. Lee and C.-T. Chang, "Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan," *Renew. Sustain. Energy Rev.*, vol. 92, pp. 883–896, Sep. 2018.

[58] A. Shekhovtsov, J. Więckowski, B. Kizielewicz, and W. Sałabun, "Towards reliable decision-making in the green urban transport domain," *Facta Universitatis, Series Mech. Eng.*, vol. 20, no. 2, p. 381, Jul. 2022.

[59] R. Taylor, "Interpretation of the correlation coefficient: A basic review," *J. Diagnostic Med. Sonography*, vol. 6, no. 1, pp. 35–39, Jan. 1990.

[60] R. Fagin, R. Kumar, and D. Sivakumar, "Comparing top *k* lists," *SIAM J. Discrete Math.*, vol. 17, no. 1, pp. 134–160, Jan. 2003.

[61] G. S. Shieh, "A weighted Kendall's tau statistic," *Statist. Probab. Lett.*, vol. 39, no. 1, pp. 17–24, Jul. 1998.

[62] W. Sałabun and K. Urbaniak, "A new coefficient of rankings similarity in decision-making problems," *Renew. Sustain. Energy Rev.*, vol. 92, pp. 632–645, Sep. 2018.

[63] H. Şahin, K. E. Alyamaç, A. R. Durucan, B. Demirel, M. Ulaş Açikgenç, A. T. Bildik, C. Durucan, T. Demir, M. Ulucan, and N. ve Demirbaş, "24 Ocak 2020 Mw 6.8 Sivrice/Elazığ Depremi Elazığ Bölgesi Yapısal Hasarlar İnceleme ve Analiz Raporu," in Yapı ve Beton Uygulama ve Araştırma, Elazığ, Türkiye: FıratÜniversitesi.

[64] *Maden Tetkik ve Arama Genel Müdürlüğü*. Accessed: Jan. 11, 2024. [Online]. Available: http://yerbilimleri.mta.gov.tr

[65] E. Karakaş, "Elazığ şehrinin gelişmesi," *Fırat Üniversitesi Sosyal Bilimler Dergisi*, vol. 9, no. 1, pp. 129–154, 1999.

[66] *Mevzuat Bilgi Sistemi*. Accessed: Jan. 11, 2024. [Online]. Available: https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=634&MevzuatTur=1&MevzuatTertip=5

[67] T. C İçleri Bakanlığı Afet ve Acil Yönetimi Başkanlığı. *Elazığ İl Afet ve Acil Durum Müdürlüğü*. Accessed: Jan. 11, 2024. [Online]. Available: https://elazig.afad.gov.tr/kurumlar/elazig.afad/E-Kutuphane/Il-Planlari/Elazig_irap__3103.pdf

[68] H. Soysal, S. Sipahioğlu, D. Kolçak, and Y. Altnok, "Türkiye ve çevresinin Tarihsel Deprem kataloğu," Sci. Technol. Res. Council Türkiye, Ankara/Türkiye, TüBiTAK Proje no. TBAG-341-124, 1981.

[69] K. Aldrin Wiguna, R. Sarno, and N. F. Ariyani, "Optimization solar farm site selection using multi-criteria decision making fuzzy AHP and PROMETHEE: Case study in Bali," in *Proc. Int. Conf. Inf. Commun. Technol. Syst. (ICTS)*, Oct. 2016, pp. 237–243.

[70] M. Bruneau, S. E. Chang, R. T. Eguchi, G. C. Lee, T. D. O'Rourke, A. M. Reinhorn, M. Shinozuka, K. Tierney, W. A. Wallace, and D. von Winterfeldt, "A framework to quantitatively assess and enhance the seismic resilience of communities," *Earthq. Spectra*, vol. 19, no. 4, pp. 733–752, Nov. 2003.

[71] R. Davidson, "EERI annual student paper award a multidisciplinary urban earthquake disaster risk index," *Earthq. Spectra*, vol. 13, no. 2, pp. 211–223, May 1997.

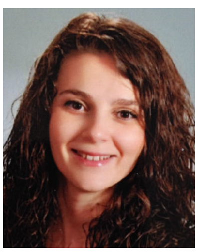
[72] D. Biswas, "Novel gray scale conversion techniques based on pixel depth," *J. Global Res. Comput. Sci. J. Global Res. Comput. Sci.*, vol. 2, no. 6, pp. 118–121, 2011.

[73] L. Danciu, S. Nandan, C. Reyes, R. Basili, G. Weatherill, C. Beauval, A. Rovida, S. Vilanova, K. Sesetyan, P. Y. Bard, F. Cotton, S. Wiemer, and D. Giardini, "The 2020 update of the European seismic hazard model: Model overview," *EFEHR Tech. Rep.*, vol. 1, 2021.

[74] *EFEHR*. Accessed: Jan. 11, 2024. [Online]. Available: http://www.efehr.org

[75] D. Ruiter, M. C. Ward, P. J. Daniell, and J. E. Aerts, "A comparison of flood and earthquake vulnerability assessment indicators," *Natural Hazards Earth Syst. Sci.*, vol. 17, no. 7, pp. 1231–1251, 2017.

[76] *HGM ATLAS*. Accessed: Jan. 11, 2024. [Online]. Available: https://www.harita.gov.tr/



MIHRIMAH ÖZMEN received the B.S., M.S., and Ph.D. degrees in industrial engineering from Erciyes University, Kayseri, Turkey, in 2004, 2013, and 2017, respectively. She is currently an Associate Professor with the Industrial Engineering Department, Erciyes University. Her research interests include decision support systems, multi criteria decision making, machine learning, and disaster management.