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Investigation of GIS-based Analytical Hierarchy Process for Multi-Criteria Earthquake Risk Assessment: The Case Study of Kahramanmaras Province

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Abstract

The risk level that earthquakes pose to the environment depends on different factors. Correctly analyzing the effects of these factors is a crucial step in identifying risky areas before the earthquake. Geographic information systems (GIS) provide essential tools for determining the weights of these factors, analyzing them, and creating risk maps. Two devastating earthquakes occurred in Türkiye in February 2023, centered in Kahramanmaras. In this study, research was carried out to estimate the damage caused by the earthquake in Kahramanmaras by analyzing pre-earthquake data with GIS. The determined factors are seven: fault line risk zone, epicenter risk zone, depth of the magnitude, slope, curvature, population density, and building density. These factors have created different weighting scenarios with the Analytical Hierarchy Process (AHP). As a result of the analyses, risk maps were produced. Evaluations were made by comparing the risk maps produced with DPM. The findings emphasize the importance of considering multiple risk criteria when assessing earthquake risk.

Keywords: Earthquake, Kahramanmaras, Geographic Information System, Analytical Hierarchy Process, Risk Assessment

Introduction

Natural disasters include catastrophic events such as earthquakes, hurricanes, floods, wildfires, landslides, and droughts. These occurrences may have catastrophic effects on human life, the environment, and infrastructure, incurring high social and financial expenses. Countries and non-governmental organizations are increasing their preparation and response efforts to combat natural disasters. It is crucial to accurately estimate the extent of damage to identify sensitive areas, facilitate effective disaster management, and minimize the impact on human life and infrastructure (Erden and Karaman, 2012). This involves creating resilient infrastructure, enhancing emergency response systems, and creating plans for reducing the risk of disaster. Computer-based technology offers wide possibilities against natural disasters. (Alexander, 1991). Computer-based technology, including GIS, remote sensing, and other data analytics tools, has greatly advanced in comprehensively understanding and taking precautions against natural disasters. (Laituri and Kodrich, 2008). A significant amount of multitemporal spatial data is needed to manage natural disasters, and GIS is the perfect instrument for analyzing these spatial data. (Van Westen, 2013). When used in conjunction with remote sensing for disaster management, GIS has grown in significance because it makes it possible to handle and integrate enormous amounts of data from multiple sources (Mihiretie, 2022). GIS also helps identify sensitive areas at risk of earthquakes and other natural disasters, allowing proactive measures to be taken to reduce damage and loss of life. Additionally, GIS significantly contributes to minimizing the impact of future earthquakes by helping to plan earthquake-resistant buildings and infrastructure. (Hashemi and Alesheikh, 2011). GIS can also be used for post-earthquake recovery efforts such as emergency responses. GIS analyzes data on the affected population, demographics, and economic impact to help identify the most critical areas that need reconstruction and recovery efforts. Risk assessment using GIS is the process of using spatial data to identify and analyze potential risks in a given area (Sleeman, 2005). GIS facilitates the better allocation of resources and the prioritization of mitigation and preparedness activities by merging this data with information on the locations of vital infrastructure, population centers, and other assets. To identify and mitigate potential risks, decrease the impact of hazards on the populace and infrastructure, and enable decision-makers to make well-informed decisions, GIS is an essential tool in risk assessment.

Multi-criteria decision-making (MCDM) is an essential GIS-based technique for analyzing and visualizing disaster risks by considering different factors (Malczewski and Liu, 2014; Vaghela et al., 2018; Savun-Hekimoğlu et al., 2021). MCDM is a collection of methods for evaluating, comparing, and choosing alternatives based on quantitative or qualitative standards. There are many studies on the use of MCDM techniques in applications for natural disasters (Yavasoglu and Ozden, 2017; Shadmaan and Popy, 2023). AHP is one of the most popular methods for MCDM. The AHP is a helpful tool for assessing a region's seismic risk (Shadmaan and Popy, 2023). It can perform analysis using different criteria for earthquake risk analysis. AHP's capabilities create an effective tool to manage, analyze, and integrate data.

In this study, a risk analysis was performed using pre-earthquake data in Kahramanmaras province, which experienced a devastating earthquake in 2023. The risk maps created by weighting different criteria were compared with the post-earthquake damage situation. Several criteria have been used in order to determine the earthquake risk completely.

Literature Review

An accurate earthquake risk assessment is important data for planning pre-earthquake preparation and quickly directing emergency management professionals to the right places in case of an earthquake. GIS and open-source data are effective tools for monitoring damaged buildings following an earthquake (Safi and Atik, 2023). Menderes et al. (2015) utilized DTM and DSM data for detecting collapsed buildings in the study region. Pre- and post-event DSMs were created from topographic maps. In the study, nDSM was generated from pre-event and post-event DSMs to identify man-made objects with different heights. This approach proved to be a promising and time-saving solution for automatically detecting damaged buildings and monitoring buildings after an earthquake. Fan et al. (2017) published a study that presents an assessment method for quantifying the damage caused by various hazards in a disaster-affected region to obtain post-earthquake damage. In the technique's scope, pre-disaster background data collected from statistical and high-resolution remote sensing sources are used. GIS analysis is used to get data for the quantification of physical damage assessment. This approach works particularly well for quick assessments of disaster damage. In the study published by Adams et al. (2004), post-earthquake damage assessment was carried out using remote sensing images to evaluate the damage following extreme earthquakes such as the 2003 Boumerdes and Bam events. In order to prioritize relief efforts and determine the location and severity of building collapse, the methodology employs a Tiered Reconnaissance System (TRS). Konukcu et al. (2016) demonstrated that post-earthquake functionality of debris propagation distance and transportation structure damage can be used to develop risk mitigation strategies. The post-earthquake road functionality of Küçükçekmece, which was selected as the study area, was determined. Shadmaan and Islam (2021) evaluate the seismic risk of Chittagong City in Bangladesh. In the study, social and structural vulnerability factors were developed using AHP. Pairwise comparisons were made at each level to determine the weight of the criteria, rank priorities, and evaluate options for each criterion. Another study (Erden and Karaman, 2012) focused on generating earthquake hazard maps for a specific area in Istanbul, Türkiye called Küçükçekmece. The researchers combined GIS and MCDM methods, such as AHP and TOPSIS, to create earthquake hazard maps. The researchers ranked the top five characteristics that affect how much an earthquake affects a region using the Analytic Hierarchy Process (AHP). The resulting risk maps generated by the TOPSIS and AHP models were compared. Lastly, they used building and demographic data to estimate possible losses, highlighting the possibility of combining GIS with AHP and TOPSIS. Nwe and Tun (2016) emphasize how crucial it is to implement reliable seismic zoning in Mandalay City, which is densely populated, urbanized, and earthquake-prone. It also proposes using a combination of seismological, geological, and geotechnical data in GIS to create a micro-zoning technique to evaluate the seismic hazard of the city. In the study, AHP was used to qualitatively map seismic hazard zoning. Aydin et al. (2024) conducted an earthquake risk analysis using the AHP method in Bitlis province by evaluating six risk factors. Disaster risk assessment was carried out with AHP by using data obtained from various sources in the literature. In this study, the evaluations made with the data before the major earthquakes in Kahramanmaras will be compared with the damage situation after the earthquake.

Materials and Methods
Study Area

The province of Kahramanmaras is situated in Turkey's Mediterranean area. Adıyaman and Malatya to the east, Adana and Kayseri to the west, Osmaniye and Gaziantep to the south, and Sivas to the north form its borders. Its geographical coordinates lie between 37°35′ N latitude and 36°56′ E longitude, encompassing an area of 14,525 km². The Location of the study area of this research is shown in Fig. 1.

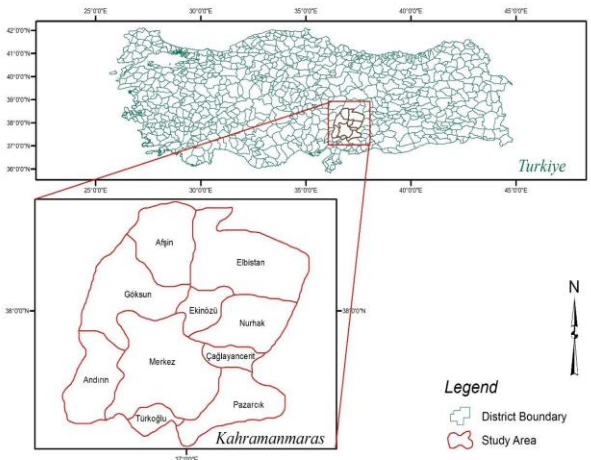

Fig. 1. Location of the study area.

According to the Disaster and Emergency Management Authority of Türkiye (AFAD), two destructive earthquakes with magnitudes of 7.7 and 7.6 struck Kahramanmaras and the surrounding area on February 6, 2023. Two more earthquakes with magnitudes of 6.4 and 5.8 occurred on February 20 after these initial ones (Fig. 2). The impact of these seismic events extended to 11 provinces in Southeast Türkiye, resulting in widespread damage. Subsequently, more than 11020 aftershocks have been detected (AFAD, 2023).

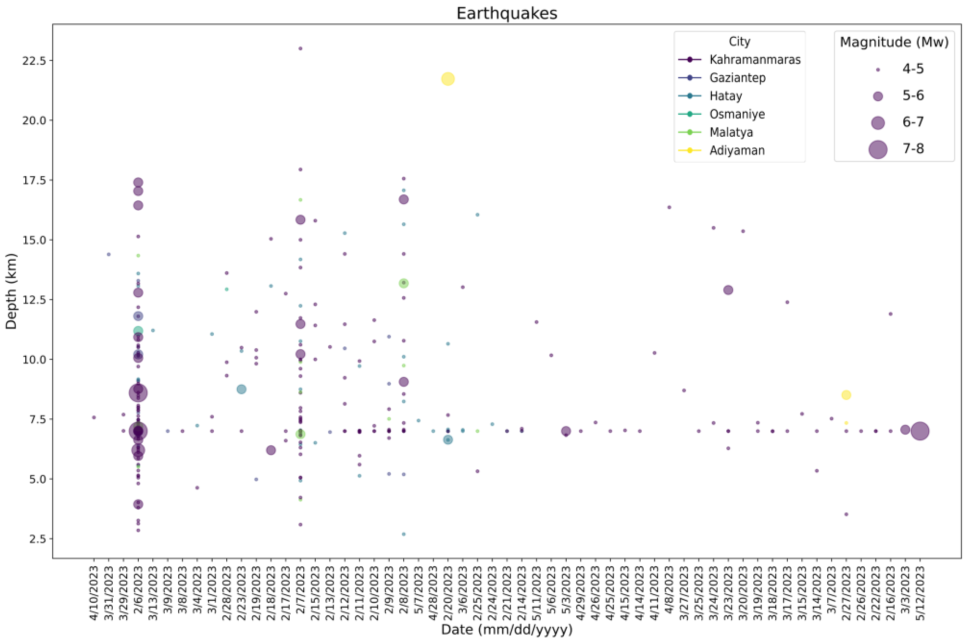

Fig. 2. Scatter plot of magnitudes and depths of earthquakes over time.

Risk Assessment

The systematic assessment of potential risks, weaknesses, and potential effects related to seismic events is known as earthquake risk assessment (Zhang et al., 2021). It is an important procedure that attempts to evaluate the possibility of earthquakes occurring in a certain location and their possible effects on infrastructure, human life, and the environment. The evaluation usually considers variables including past seismic activity, fault lines, curvature, magnitude depth, slope, population density, and building density to calculate the possibility of a hazard and future earthquakes, as well as their possible magnitude. It also assesses how vulnerable and exposed the impacted area's buildings, vital infrastructure, and population density are. This study examined the effects of various geographical, demographic, and topographic factors on risk assessment to conduct a comprehensive risk assessment.

Fault line. Earthquakes are caused by fault lines, which are fractures in the crust where rocks move in relation to one another (Chen et al., 2013). The fault's length, depth, and type all affect how an earthquake moves in terms of size and style (Elnashai and Sarno, 2015). If fault lines are close to populated areas, they pose higher risks and have the potential to damage buildings and infrastructure. In order to identify active faults, comprehend their behavior, and create safety precautions like building codes and early warning systems, fault lines are scientifically investigated and observed (Swetapadma and Yadav, 2015). The General Directorate of Mineral Research and Exploration provided the fault line layouts used in this study (MTA). The Türkiye Active Fault Map was updated by the MTA and published at a scale of 1:250,000. It was first published in 1992 and printed at a 1:1,000,000 scale on October 6, 2012. QGIS (QGIS Development Team, 2021) is used to view and analyze the fault line data. This made it possible to thoroughly grasp the traits, distribution, and possible dangers connected to these fault lines. The overlay of the research area onto the fault line structure is shown in Fig. 3a, which gives an overview of the fault lines in the area.

Kahramanmaras's fault line map shows regions' classification into high-risk, medium-risk, and low-risk zones. High-risk regions are regions that are close to active fault lines and have a higher potential for more severe and more frequent earthquakes. To reduce the potential impact of earthquakes, these places need special consideration when it comes to building, land-use planning, and emergency preparedness measures. Despite their potential for fewer seismic events and their moderate distance from fault lines, the medium-risk locations nevertheless need to take the necessary precautions. The low-risk areas are less likely to be directly affected by earthquakes and are located further away from fault lines. Fig. 3b shows the fault line risk zones within the study area.

Epicenter. The location on Earth's surface immediately above the point at which seismic energy is produced during an earthquake is known as the epicenter. (Sha'ameri et al., 2021). The epicenter is determined by observing seismic data from several stations that record wave arrival times (Cleveland and Ammon, 2013). The earthquake magnitude and epicenter data in this study were obtained from the reputable AFAD website. While epicenter data provide the precise location above the seismic source, magnitude data provide information regarding energy released. The spatial distribution of earthquake magnitudes in the research area is shown in Fig. 3c. It gives an overview of the distribution of magnitudes throughout the area.

On the other hand, Fig. 2 illustrates a scatter representation of earthquake magnitudes over a specific period. Though not all point values are displayed due to visualization limitations, the figure provides a visual depiction of how magnitudes are distributed during the study period. Based on the intensity of seismic events, areas are categorized into high, medium, and low-risk zones on the earthquake magnitude map. This map is visually represented in Fig. 3d, where colors are used to denote various magnitudes.

Depth of the magnitude. The depth of the magnitude of an earthquake plays an essential role in understanding earthquake hazards and potential impacts. When evaluating earthquake dangers, Fig. 3e—a map showing the depth of the magnitude in the research area—provides important information. The distance between an earthquake's hypocenter—the location on Earth where seismic energy is released—and the surface is referred to as the earthquake's depth. It directly affects both the potential of damage and the degree of shaking sensed at the surface. Significant depths in the Earth's crust or upper mantle cause high-depth earthquakes, which often have less of an effect on the surface. Because there is a greater space for the seismic energy to dissipate, there is less shaking and possibly less danger. High-depth earthquakes, however, can still pose a threat to some infrastructure types since they are susceptible to ground vibrations with extended periods. At intermediate depths in the Earth's crust, medium-depth earthquakes take place. The fact that the seismic energy is discharged closer to the surface makes these earthquakes potentially more dangerous. Compared to high-depth earthquakes. In general, compared to deep earthquakes, there is an increased probability of damage and stronger shaking, especially for buildings and nearby towns. Earthquakes that occur close to the surface, or at low depths, can have the most effects on seismic hazards. Because of their shorter seismic wave propagation distance, there is a greater chance of damage and heavier shaking. Low-depth earthquakes can be extremely dangerous for infrastructure, people, and buildings, particularly in places with high population density.

Slope. The ground's stability during seismic occurrences is greatly impacted by the slope of the land surface. (Lu et al, 2015). Unstable geological formations of rock and steep slopes can cause the initiation or intensification of earthquakes. A slope map of the research region is shown in Fig. 3f, where various color schemes or shading methods represent various gradients. Lighter shades imply softer inclinations, whereas redder tints suggest steeper slopes. The region's topography and terrain morphology can be well understood thanks to this visualization. Slope gradient affects earthquakes differently in different ranges. Slightly sloping areas (0–10%) typically have less of an effect, scattering seismic energy and producing less ground shaking. Slopes between 10 and 20 percent have a moderate effect and can cause localized seismic wave amplification. Slope failure risk is increased and ground shaking is exacerbated by steeper slopes (20–30%). Slopes higher than thirty percent have a significant effect, concentrating seismic energy and seriously damaging structures.

Curvature. Curvature is a crucial factor in understanding earthquake hazards as it provides valuable insights into the geological structures and potential for seismic activity (Yilmaz and Yucemen, 2011). Curvature in geology is the term used to describe how the Earth's crust bends or deforms (Yu et al., 2022). Areas with high curvature are indicative of tectonic activity and complex structures, which raise the risk of earthquakes (Stupazzini et al., 2020). High curvature regions are frequently found along active fault systems, where the rocks are under a lot of stress and strain. Because fault movement is a more likely means of releasing the accumulated strain, these places are more vulnerable to earthquakes. An important source of information about the potential risk of earthquakes is the study area's curvature map (Fig. 3g). The map provides insights into the tectonic activity and structural complexity within the region by highlighting variations in the Earth's crust's curvature. High curvature areas, which indicate zones where considerable stress and strain accumulate, suggest a higher risk potential for earthquakes. To prioritize appropriate mitigation solutions and guarantee the safety and resilience of the impacted communities and infrastructure, these regions should be carefully considered in earthquake risk assessments.

Population density. The impact of earthquakes is significantly influenced by population density. The concentration of infrastructure in populated regions raises the possibility of earthquake damage and destruction. Because of the large number of people, emergency response and rescue operations can be difficult. Social vulnerability is a worry as well because disadvantaged populations might find it more difficult to deal with the fallout. The resilience of infrastructure becomes essential because interruptions can have a domino effect. In highly populated areas, building rules and urban planning are essential for reducing the effects of earthquakes. To improve community resilience, comprehensive disaster preparedness strategies are required. Fig. 3h presents the population density map of the study area.

Building density. Building density significantly impacts earthquakes. During seismic events, there is an increased risk of structural damage and collapse in locations with a high building density. The close proximity of buildings can result in a phenomenon called "pounding," where adjacent structures collide and exacerbate structural damage. Furthermore, complex and interconnected infrastructure systems, like transportation and utility networks, are frequently found in densely populated areas and can be severely damaged by earthquakes. Densely populated areas have higher population densities and higher economic activity, intensifying the effects of building damage and creating obstacles for emergency response, evacuation, and post-earthquake recovery. The most effective ways to reduce the seismic risk to densely populated places are to enforce building rules, encourage earthquake-resistant construction techniques, and implement strict building standards. Fig. 3i presents a building density map of the study area.

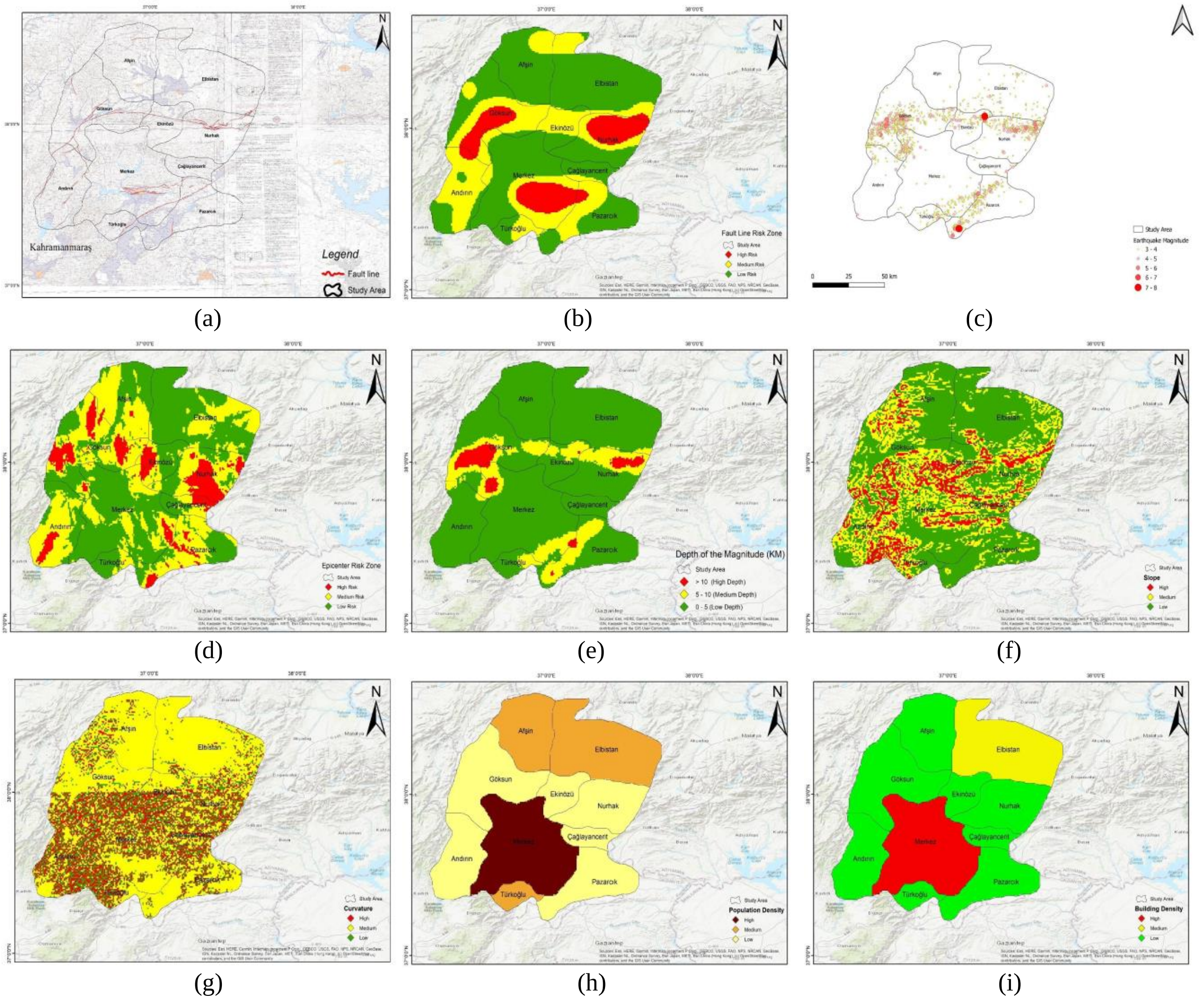

Fig. 3. Criteria maps of the study area. (a) Fault line map; (b) Fault line risk zone; (c) Earthquake magnitude; (d) Epicenter risk zone; (e) Depth of the magnitude; (f) Slope; (g) Curvature; (h) Population density; (i) Building density.

Analytic Hierarchy Process (AHP)

The methodology utilized in the study was the AHP (Saaty, 1987), which is widely accepted and commonly applied in multi-criteria decision-making based on GIS applications (Jena et al., 2020). The reasons behind the success of AHP include its ease of use, comprehension, and simplicity. This study follows a systematic process for implementing AHP. First, the study's objective is determined, and the factors affecting the selection procedure are precisely noted. Then, a hierarchical structure is built and other alternatives are determined according to these predetermined criteria. The criteria and alternatives from the first phase were evaluated in the following step using Saaty's importance scale (1987). To achieve a consistency ratio (CR) below 10%, the method typically includes the following steps:

Step 1. Both the criteria and the problem are stated. The problem and its associated criteria are well-defined and are employed in the weight evaluation process.

Step 2. The matrix of pairwise comparisons is created. To figure out each criterion's relative value or preference, a matrix is utilized in this stage to compare it with all other criteria that were developed. The matrix's elements indicate how much one criterion is preferred over another. We use a scale from 1 to 9 to indicate this desire. A number of 1 denotes that the criteria are equally important, while a value of 9 denotes that they are extremely important.

Step 3. The assessments of the pairwise comparisons are compiled. In this step, decision-makers are asked to evaluate the relative importance of the criteria in pairs using our expertise. Each expert compares the criteria, and values representing their respective assessments of the relative weight of the criteria are allocated to the appropriate cells in the matrix.

Step 4. It is computed to obtain the weight vector. This phase involves finding the primary eigenvector of the pairwise comparison matrix in order to determine the weight vector. Next, the eigenvector is normalized so that the total of its elements is equal to 1. The relative weight of each criterion is represented by this normalized weight vector.

Step 5. It is calculated to get the consistency ratio (CR) and consistency index (CI). This step involves computing the CI by dividing the corresponding element in the weight vector by the average of the weighted sum of each column in the pairwise comparison matrix. Equation 2, where n is the number of criteria and λmax is the ratio of the weighted sum value per criteria weight, is used. Depending on the size of the matrix, the random index (RI) is computed using the values in Table 1. For a random matrix, the expected degree of inconsistency is represented by the RI (Shadmaan and Popy, 2023). Eq. 1 calculates the CR.

$$CR = \frac{CI}{RI} \qquad (Eq. 1)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad (Eq. 2)$$

Table 1. Random consistency index value (Saaty, 1987).

Matrix Size	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Step 6. This stage involves looking at the CR to determine the consistency. The consistency is considered adequate if the CR is less than 10%. On the other hand, a CR greater than 10% suggests that pairwise comparison judgements are inconsistent (Sahin, 2021). In such cases, it is necessary to revisit Step 2 and re-evaluate the pairwise comparison judgments or make the required modifications to the criteria to satisfy the consistency criterion.

Weights are calculated for every criterion after the AHP procedures are finished. Different combinations are created by increasing the weight of a criterion by obtaining low consistency. The weights given to each criterion are shown in Fig 4. The fault-line criterion is shown to be more weighted than the other criteria, suggesting that it plays a major role in determining the likelihood of damage. The weight distribution of the epicenter dominance has a consistency ratio of 0.099. The epicenter criterion is particularly significant because it has a higher weight than the other criteria, indicating that it plays a major role in determining the potential of damage. This weight distribution demonstrates how important the epicenter criterion was to the entire assessment. The pairwise comparison judgments demonstrate an acceptable level of consistency with a consistency ratio, which strengthens the validity of the weight distribution allotted to each criterion. The depth of magnitude-dominant weights allocated to each criterion has a consistency ratio of 0.1. The depth of magnitude criterion is particularly important as it has a higher weight in comparison to the other criteria, suggesting that it plays a significant role in determining the potential of damage. This weight distribution demonstrates how important the depth of magnitude criterion was to the entire assessment. The slope-dominant weights have a consistency ratio of 0.097. The slope criterion shows a greater weight than the other criteria, indicating that it plays a more significant role in determining the potential of damage. This weight distribution highlights the slope criterion's substantial impact on the evaluation as a whole. The consistency ratio of curvature-dominant weights is 0.076. It is evident that the curvature criterion has a greater weight than the other criteria. In building density-dominant weights, the building density criterion stands out as having a higher weight than the others, suggesting that it plays a major role in determining the potential of damage. The consistency ratio of population density-dominant weight distribution is 0.099. It is evident from the data that the population density criterion is given more weight than the other factors. However, a distribution was also created in which balanced weights were given to the criteria, with a low consistency rate. The consistency ratio of the AHP process is measured to be 0.044, which represents a remarkably low value. This suggests that the framework for making decisions has a high degree of coherence and consistency. A low consistency ratio indicates that the overall priorities assigned to the criteria are tightly aligned with the pairwise comparisons done during the AHP process. It suggests that the weights are very reliable and in accord. Establishing weights for every criterion and computing consistency ratios provides a methodical and logical assessment procedure.

The weight distributions have low consistency ratios which are indicative of the decision-making framework's validity and dependability. This implies that the assessments and pairwise comparisons made by the decision-makers are coherent and well-aligned with the overall priorities given to the criteria. AHP makes decision-making transparent and well-founded by enabling a thorough evaluation of several criteria and their relative importance. The AHP process yields results that make it easier to make decisions by making it clear how important each criterion is and how it affects the evaluation as a whole.

Results

All processes were carried out via open-source QGIS software. Making earthquake damage risk maps has been extremely helpful with planning and has given important information about what might happen after an earthquake. This study shows that the Kahramanmaras province is typically exposed to a high risk of earthquake damage, which places restrictions on the suitability of settlement. The study demonstrates the applicability of the GIS-supported AHP method in earthquake damage risk analyses. The consistent outcomes and compatibility of the study with earlier applications highlight the importance of GIS techniques in earthquake analysis and demonstrate to their potential as a preferred method in related fields.

Spatial analysis in a GIS environment is the next step after all risk parameters and weight distribution have been established, mapped, and finished with a consistency ratio of less than 10%. Creating the risk zone map requires performing a weighted overlay process for every weight distribution. The weighted overlay procedure is used to combine the distinct criteria layers according to their weights. After combining the weighted values from each criterion, a composite layer is created that illustrates the risk zones according to the established parameters and their relative significance. This spatial analysis yielded a risk zone map that offers a thorough visual representation of the areas with different risk levels. It is an important tool for planning, allocating resources, and making decisions about how to address and lessen possible risks in the areas that have been designated. To compare the potentiality of risk parameters to the Damage Proxy Map (DPM), a risk zone map is created for every weight distribution. Fig. 5a displays the study area's DPM.

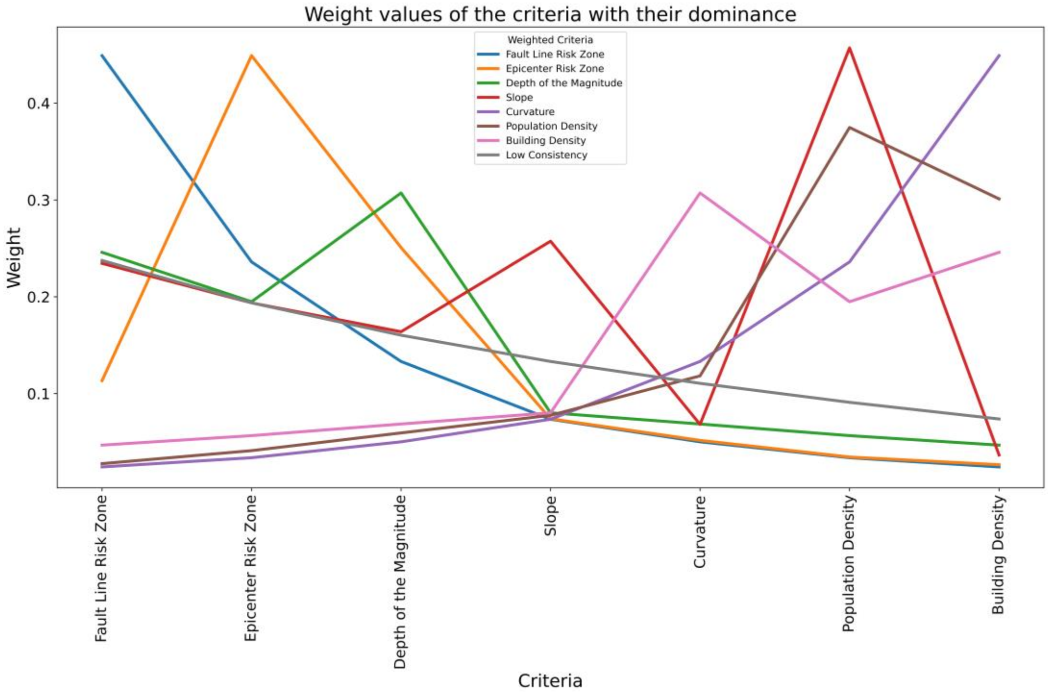

Fig. 4. Different weight distributions created for each criterion.

The DPM is a significant tool developed by the Earth Observatory of Singapore – Remote Sensing Lab (2023) to evaluate and visualize the potential damage caused by earthquakes. The DPM finds and highlights areas that are probably damaged after an earthquake by examining synthetic aperture radar (SAR) images taken by the ALOS-2 satellite. On this map, pre-earthquake SAR images from April 2021–April 2022 are combined with post-earthquake images from February 8, 2023. The DPM offers important insights into the degree of damage in affected areas by comparing these images. By means of cutting-edge satellite technology and data analysis, the DPM provides an all-encompassing evaluation of the affected areas, supporting efforts related to disaster response and recovery.

By performing the weighted overlay, the fault line dominance map is generated (Fig. 5b). The fault line criterion has a higher weight than the other criteria. The epicenter's dominance map is presented in Fig. 5c. This map illustrates the locations where the epicenter criterion significantly affects the potential of damage. Using different colors or symbols, the map highlights the areas most vulnerable to damage by showing the various degrees of dominance connected to the epicenter criterion. The depth of magnitude dominance map is generated. The areas where the depth of magnitude criterion significantly influences the potentiality of damage are visually represented in Fig. 5d. A slope dominance map is created using the weighted overlay process. This map shows the areas where the slope criterion has a significant impact on the possibility of damage (Fig. 5e). The population density dominance map (Fig. 5g) and the building density dominance map (Fig. 5f) are produced, respectively, by applying the weighted overlay process with the parameters. These maps visually represent the areas where the population density criteria and curvature show a strong influence on the possibility of damage. The curvature dominance map is generated (Fig 5h). The regions on this map where the curvature criterion significantly affects the potential of damage are shown visually. The damage map's final potentiality is produced, but the consistency ratio throughout the process is remarkably low. A detailed breakdown of the areas that could sustain damage based on the weights assigned to each combined criterion is shown in Fig. 5i. Through the integration of various factors, including fault line dominance, epicenter dominance, depth of magnitude dominance, and other relevant parameters, the damage map's potentiality provides a comprehensive depiction of the possible hazards in various areas. The resulting risk assessment maps were analyzed by comparing them with DPM (Fig 4).

Discussion

The province of Kahramanmaras is highly vulnerable to earthquake damage. The study illustrates how earthquake damage risk assessments can benefit from the application of the GIS-supported AHP method.

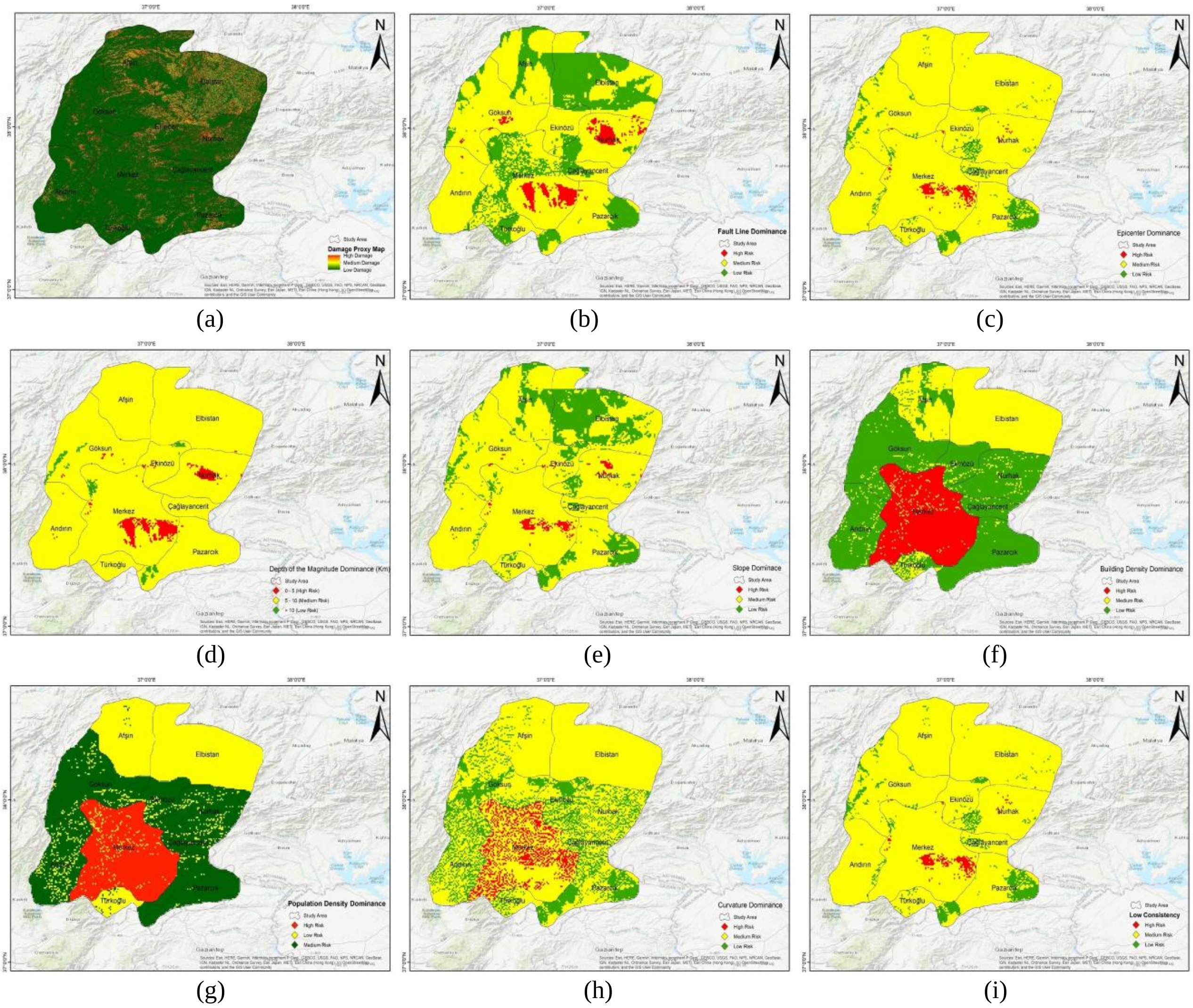

Fig. 5. Result maps of the study area. (a) DPM of the study area; (b) Fault line dominance map; (c) Epicenter dominance map; (d) Depth of the magnitude dominance map; (e) Slope dominance map; (f) Building density dominance map; (g) Population density dominance map; (h) Curvature dominance map; (i) Low consistency ratio map of risk parameters.

Interesting insights into the dominant factors influencing the potentiality of damage in our study region can be gained by comparing the Damage Proxy Map with the dominance maps of different risk criteria, such as fault line, slope, curvature, population density, building density, depth of the earthquake magnitude, and epicenter. Firstly, AHP analysis was performed with a high weight given to the epicenter criterion. It has been accepted that greater damage will be more likely to occur in areas close to the epicenter of seismic events. This emphasizes how crucial it is to precisely locate and evaluate epicenters to assess potential risks and make emergency response plans. Second, determining the potential for damage also heavily depends on the depth of magnitude criterion. Because of their greater capacity to release and propagate energy, regions with deeper magnitudes may sustain more severe damage. Understanding the distribution of magnitude depth within the study area is crucial for efficient risk handling and resource distribution. In another scenario, when identifying possible risk areas, the fault line criterion shows notable dominance. This implies that areas near fault lines are more vulnerable to damage than other types of areas. Fault lines can raise the probability of seismic activity and the damage that follows, which highlights the significance of taking fault line information into account when assessing risks and developing mitigation plans.

Moreover, the slope criterion is strongly influenced, suggesting that regions with steeper slopes are more vulnerable to damage. In addition to increasing the risk of soil erosion, landslides, and structural instability, steep slopes can also increase the potential impact of natural disasters like earthquakes and heavy rains. Minimizing damage and ensuring the safety of the communities living in these areas depend heavily on assessing and reducing slope-related risks.

Taking everything into account, these results highlight how important it is to consider a range of risk criteria when determining the possibility of damage in Kahramanmaras. It has been shown that the risk map produced when each criterion is weighted to have low consistency gives the most appropriate results for the damage situation after the earthquake. We prioritize risk mitigation efforts by thoroughly understanding the risk landscape by analyzing various factors' dominance. Decision-makers and governments engaged in disaster management can benefit greatly from these findings, which give them the knowledge they need to develop targeted strategies, allocate resources effectively, and enhance the overall resilience of the study region. In Kahramanmaras province, it is crucial to avoid building new structures that could increase the already-present earthquake risk to reduce the possibility of future earthquake damage. This emphasizes the need for large-scale, comprehensive studies as well as more organized and methodical implementation efforts. The value of GIS and AHP techniques in earthquake analysis is highlighted by the consistent results of this study and its compatibility with previous applications, establishing it as a preferred method in similar areas.

Conclusions

In conclusion, this study has demonstrated the practical utility of AHP methodology in earthquake damage and risk assessment. The study's findings have shown how useful AHP is for precisely determining the kind and extent of earthquake damage, allowing for a thorough visualization of the regions that were affected. Proper evaluation of multiple factors, rather than just one factor, is essential for accurate risk assessment. The research has included a risk assessment component by mapping numerous variables, including fault lines, epicenters, earthquake zones, slope, curvature, population, and building density. The study's use of the AHP methodology has improved the accuracy of risk assessments, enabled informed decision-making, and furthered our understanding of risk distribution by methodically assessing and prioritizing these factors. Further research will enhance analytical methodologies, such as spatial modeling approaches, data fusion techniques, and image processing algorithms. This will improve the precision and relevance of the findings from analyses based on GIS. To mitigate potential earthquake damages in Kahramanmaras province, it is crucial to prevent the construction of new buildings that would exacerbate the existing earthquake risk in high-risk areas. This necessitates more thorough studies in addition to more organized and systematic implementation efforts.

References

Adams, B. J., Huyck, C. K., Mansouri, B., Eguchi, R. T., Shinozuka, M. (2004). Application of high-resolution optical satellite imagery for post-earthquake damage assessment: The 2003 boumerdes (algeria) and bam (iran) earthquakes. *Research Progress and Accomplishments 2003-2004, Buffalo: MCEER*.

AFAD (2023). PRESS BULLETIN-36 about the Earthquake in Kahramanmaraş.

Alexander, D. (1991). Information technology in real-time for monitoring and managing natural disasters. *Progress in Physical Geography*, *15*(3), 238-260.

Chen, K. H., Bürgmann, R., Nadeau, R. M. (2013). Do earthquakes talk to each other? Triggering and interaction of repeating sequences at Parkfield. *Journal of Geophysical Research: Solid Earth*, *118*(1), 165-182.

Earth Observatory of Singapore – Remote Sensing Lab (2023).

Elnashai, A. S., Di Sarno, L. (2015). *Fundamentals of earthquake engineering: from source to fragility*. John Wiley & Sons.

Erden, T., Karaman, H. (2012). Analysis of earthquake parameters to generate hazard maps by integrating AHP and GIS for Küçükçekmece region. *Natural Hazards and Earth System Sciences*, *12*(2), 475-483.

Fan, Y., Wen, Q., Wang, W., Wang, P., Li, L., Zhang, P. (2017). Quantifying disaster physical damage using remote sensing data—A technical work flow and case study of the 2014 Ludian earthquake in China. *International Journal of Disaster Risk Science, 8*, 471-488.

Hashemi, M., Alesheikh, A. A. (2011). A GIS-based earthquake damage assessment and settlement methodology. *Soil dynamics and earthquake engineering*, *31*(11), 1607-1617.

Jena, R., Pradhan, B., Beydoun, G. (2020). Earthquake vulnerability assessment in Northern Sumatra province by using a multi-criteria decision-making model. *International journal of disaster risk reduction*, *46*, 101518.

Konukcu, B. E., Karaman, H., Şahin, (2016). M. Determination of Road Functionality for Küçükçekmece District Following a Scenario Earthquake for Istanbul. *International Journal of Environment and Geoinformatics*, *3*(1), 29-43.

Laituri, M., Kodrich, K. (2008). On line disaster response community: People as sensors of high magnitude disasters using internet GIS. *Sensors*, *8*(5), 3037-3055.

Lu, L., Wang, Z. J., Song, M. L., Arai, K. (2015). Stability analysis of slopes with ground water during earthquakes. *Engineering Geology*, *193*, 288-296.

Malczewski, J., Liu, X. (2014). Local ordered weighted averaging in GIS-based multicriteria analysis. *Annals of GIS*, *20*(2), 117-129.

Menderes, A., Erener, A., Sarp, G. (2015). Automatic detection of damaged buildings after earthquake hazard by using remote sensing and information technologies. *Procedia Earth and Planetary Science*, *15*, 257-262.

Michael Cleveland, K., Ammon, C. J. (2013). Precise relative earthquake location using surface waves. *Journal of Geophysical Research: Solid Earth*, *118*(6), 2893-2904.

Mihiretie, A. (2022). Assessment of Malaria Risk Using GIS and Multi Criteria: The Case Study of East Gojjam Zone, Ethiopia. *International Journal of Environment and Geoinformatics (IJEGEO)*, 9(1), 74-78. doi.org/10.30897/ijegeo.781219

Nwe, Z. Z., Tun, K. T. (2016). Seismic hazard Analysis using AHP-GIS. *Int. J. Res. Chem. Metallurg. Civ. Eng*, *3*, 1442-1450.

QGIS Development Team. QGIS Geographic Information System (version 3.18). Open Source Geospatial Foundation; 2021. https://qgis.org/.

Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. *Mathematical modelling*, *9*(3-5), 161-176.

Safi, O., Atik, M. E. (2023). Analyzing optimal routes to safe areas using OpenStreetMap and very high-resolution remote sensing imagery. *Intercontinental Geoinformation Days*, *6*, 117-120.

Şahin, M. (2021). A comprehensive analysis of weighting and multicriteria methods in the context of sustainable energy. *International Journal of Environmental Science and Technology*, *18*(6), 1591-1616.

Savun-hekimoğlu, B., Erbay, B., Burak, Z. S., Gazioğlu, C. (2021). A Comparative MCDM Analysis of Potential Short-Term Measures for Dealing with Mucilage Problem in the Sea of Marmara. *International Journal of Environment and Geoinformatics* (IJEGEO), 8(4), 572-580. doi.org/10.30897/ijegeo.1026107

Sha'ameri, A. Z., Aris, W. W., Sadiah, S., Musa, T. A. (2021). GPS Derived Seismic Signals for Far Field Earthquake Epicenter Location Estimation: Manuscript Received: 19 Dec 2020, Accepted: 23 Dec 2020, Published: 15 June 2021. *Journal of Engineering Technology and Applied Physics*, *3*(1), 7-12.

Shadmaan, M. S., Popy, S. (2023). An assessment of earthquake vulnerability by multi-criteria decision-making method. *Geohazard Mechanics*, *1*(1), 94-102.

Shadmaan, S., Islam, A. I. (2021). Estimation of earthquake vulnerability by using analytical hierarchy process. *Natural Hazards Research*, *1*(4), 153-160.

Sleeman, J. M. (2005). Disease risk assessment in African great apes using geographic information systems. *EcoHealth*, *2*(3), 222-227.

Stupazzini, M., Infantino, M., Allmann, A., Paolucci, R. (2021). Physics-based probabilistic seismic hazard and loss assessment in large urban areas: A simplified application to Istanbul. *Earthquake Engineering & Structural Dynamics*, *50*(1), 99-115.

Swetapadma, A., Yadav, A. (2015). All shunt fault location including cross-country and evolving faults in transmission lines without fault type classification. *Electric Power Systems Research*, *123*, 1-12.

Vaghela, B. N., Parmar, M. G., Solanki, H. A., Kansara, B. B., et al. (2018). Multi Criteria Decision Making (MCDM) Approach for Mangrove Health Assessment using Geo-informatics Technology. *International Journal of Environment and Geoinformatics (IJEGEO)*, 5(2), 114-131, doi.org/10.30897 /ijegeo.412511

Van Westen, C. J. (2013). Remote sensing and GIS for natural hazards assessment and disaster risk management. *Treatise on geomorphology*, *3*(15), 259-298.

Yavasoglu, F., Ozden, C. V. (2017). Using geographic information systems (GIS) BASED analytic hierarchy process (AHP) earthquake damage risk analysis: Kadikoy case. *TÜBAV J Sci*, *10*, 28-38.

Yilmaz, N., Yucemen, M. S. (2011). Spatial sensitivity of seismic hazard results to different background seismic activity and temporal earthquake occurrence models. *Soil Dynamics and Earthquake Engineering*, *31*(7), 1027-1039.

Yu, S., Bo, J., Vandeginste, V., Mathews, J. P. (2022). Deformation-related coalification: Significance for deformation within shallow crust. *International Journal of Coal Geology*, *256*, 103999.

Zhang, Y., Romanelli, F., Vaccari, F., Peresan, A., Jiang, C., Wu, Z., ... Panza, G. F. (2021). Seismic hazard maps based on Neo-deterministic Seismic Hazard Assessment for China Seismic Experimental Site and adjacent areas. *Engineering Geology*, *291*, 106208.