International Journal of Disaster Risk Reduction 110 (2024) 104647

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

The impact of Kahramanmaraş (2023) earthquakes: A comparative case study for Adıyaman and Malatya

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ARTICLE INFO

Keywords:
Kahramanmaraş (2023) earthquakes
Adıyaman
Malatya
Economic and environmental impact
Environmental pollution
Waste recycling
Waste management
Small enterprise

ABSTRACT

This study examines the effects of two major earthquakes of magnitude 7.7 and 7.6 that struck Kahramanmaraş on February 6th, 2023, followed by a magnitude 6.4 quake in Hatay on February 20th, which caused major damage in 11 Turkish provinces. The study focuses on Adıyaman and Malatya and uses an interdisciplinary approach to analyze the economic and environmental impacts. Primary data sources, including field visits and interviews, reveal clear labor-related challenges in both provinces, characterized by a government-induced labor shortage. In both provinces, physical capital has been severely damaged, particularly affecting small businesses, historic bazaars, and old industrial areas. The impact on businesses varies by size and location, with Adıyaman suffering more severe setbacks than other cities. The shortage of skilled labor related to the earthquake damage affects the quality of production, which can have a serious economic impact. Transportation disruptions continue to hamper supply chains and affect companies' ability to meet their export commitments. The environmental consequences, particularly the large amount of debris, pose a major challenge. The lack of a comprehensive disaster waste plan at the central government level leads to inadequate waste management. The study recommends sorting the debris at temporary sites to obtain reusable items while paying attention to the sustainability and transparency of debris management processes. In summary, this comparative case study highlights the need for tailored approaches to address the different impacts in the 11 provinces. A one-size-fits-all solution is insufficient and an individual needs assessment is needed for each province in order to implement targeted economic and environmental recovery measures.

1. Introduction

On February 6th, 2023, two earthquakes of magnitude (Mw) 7.7 and 7.6 occurred with epicenters in the province of Kahramanmaraş, Türkiye, as shown in Fig. 1. These earthquakes caused significant destruction in 11 provinces and became one of the largest disasters not only in Türkiye but also worldwide in terms of intensity, magnitude, loss of life, and damage. More than 50,000 people

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https://doi.org/10.1016/j.ijdrr.2024.104647
Received 17 February 2024; Received in revised form 25 June 2024; Accepted 28 June 2024
Available online 2 July 2024

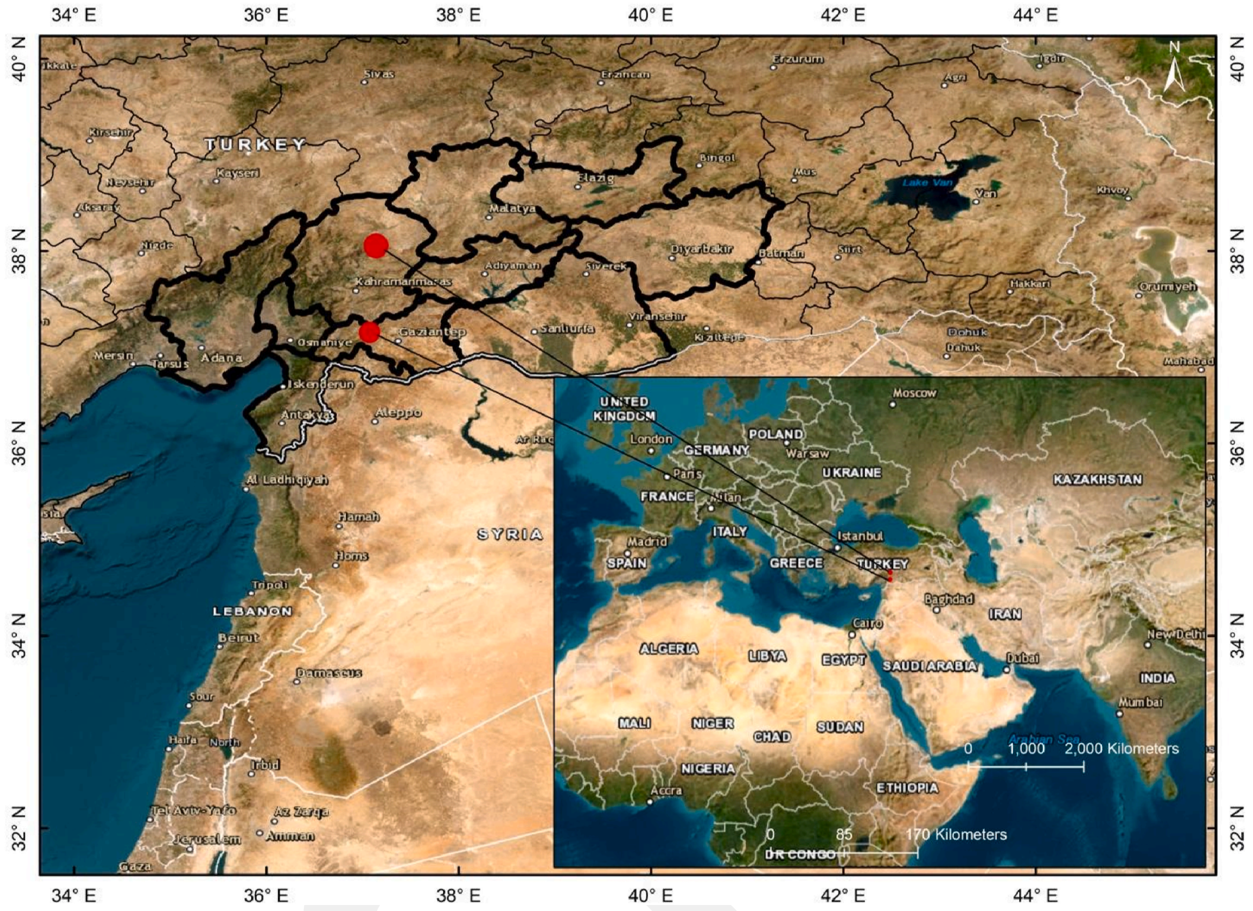

Fig. 1. The Kahramanmaraş earthquakes of February 6th, 2023.

lost their lives. The communications and energy infrastructure and more than half a million buildings were damaged, according to a report by the Strategy and Budget Office of the Presidency of the Republic of Türkiye [1].

Data from 2021 indicates that the earthquake region, which is home to 16.4 percent of Türkiye's population, accounts for 13.3 percent of the country's jobs. Around 79 billion dollars of national income, or 9.8 percent of Türkiye's gross domestic product, is generated in this region [1]. Therefore, the significant economic devastation caused by the earthquakes was predictable from day one. Various predictions were made in the first months after the earthquakes: a report by the World Bank [2] on February 20th, 2023, estimated the direct impact of the earthquakes at 34.2 billion dollars. In a detailed report by SBB on March 6th, 2023, which involved various public institutions in Türkiye, the total impact of the disaster on the Turkish economy was estimated at around ₺2 trillion ($103.6 billion).

Table 1 shows the main socio-economic indicators for 11 provinces affected by the earthquakes on February 6th. It is evident that provinces such as Kilis and Gaziantep stand out with a high proportion of the Syrian population, indicating a greater need for resources and assistance for the refugee communities. Differences in per capita income between provinces indicate varying levels of economic development and vulnerability to shocks, with some areas lagging well behind the national average. In addition, differences in education indicators, particularly in the proportion of K-12 students, point to possible inequalities in educational infrastructure and access to education. This disaster-affected region is home to one-fifth of Türkiye's K-12 students, adding to the post-disaster educational challenges. In the aftermath of the disaster, the significant differences in the share of informal employment across provinces show that the resilience of the labor market varies, possibly indicating regions with limited formal employment opportunities. Overall, these observations underline the importance of targeted measures to address the specific challenges of each province, especially after the major disaster in February 2023.

After the earthquakes on February 6th, 2023, the emergency response in the affected provinces was completed not in weeks but months. The completion of the emergency response phase is followed by the recovery phase. Given the extent of the affected region and the variety of impacts at the provincial level, it is inevitable that the humanitarian, economic, social, cultural, and environmental consequences of the earthquakes will vary from region to region. According to an International Labour Organization Report [3], Malatya, for example, had the highest labor losses (reduction in working hours) at 59 percent. Other provinces with high losses are Adıyaman (48 percent), Hatay (45 percent), and Kahramanmaraş (43 percent). In the remaining seven provinces, the labor loss is below 5 percent.

Table 1
Socio-economic indicators of 11 affected provinces.

	Population Share in Türkiye (a)	K-12 Student Share in Türkiye (b)	# of Beds per 10,000 (c)	Proportion of Syrian Population in Province (d)	Per capita income (Province/National average) (e)	Employment Share in Türkiye (f)	Share of Informal Employment in Province (g)
Adana	2.7 %	3.0 %	34	11.3 %	76.9 %	2.4 %	38.4 %
Adıyaman	0.7 %	0.9 %	22	3.7 %	44.8 %	0.4 %	33.8 %
Diyarbakır	2.1 %	2.8 %	28	1.4 %	40.5 %	1.5 %	44.3 %
Elazığ	0.7 %	0.7 %	54	2.2 %	58.0 %	0.7 %	41.7 %
Gaziantep	2.5 %	3.7 %	32	21.5 %	81.9 %	2.5 %	33.8 %
Hatay	2.0 %	2.6 %	27	24.1 %	66.2 %	1.7 %	37.9 %
Kahramanmaraş	1.4 %	1.7 %	27	8.2 %	68.7 %	1.2 %	37.9 %
Kilis	0.2 %	0.3 %	44	61.3 %	67.1 %	0.1 %	33.8 %
Malatya	1.0 %	1.0 %	44	4.0 %	53.0 %	0.9 %	41.7 %
Osmaniye	0.7 %	0.8 %	23	7.7 %	60.0 %	0.5 %	37.9 %
Şanlıurfa	2.5 %	3.9 %	20	17.7 %	36.5 %	1.4 %	44.3 %
Region	16.4 %	21.4 %	32	13.1 %	–	13.3 %	–

Source: All the data is taken from SBB [1].

A key characteristic of the affected region is its below-average per capita income compared to the country average. While the country average is $9,592, the average in the 11 affected provinces is $5,924, according to Turkish Statistical Institute[1] (TURKSTAT). In addition, the rate of informal employment in this region is higher than the Turkish average. Finally, about 50 percent of Syrians residing in Türkiye live in these 11 provinces. These indicators point to an increase in relative poverty in the region, which has increased as a result of the earthquake-related migration. Milan et al. [4] present an analysis of skilled labor shortages in the region following the earthquakes. The report discusses how skilled workers who often earn higher incomes migrate to other cities, exacerbating the shortage.

As indicated by this data, the resumption of normalcy has not been anticipated to adhere to a consistent geographical trajectory from the outset. Thus, it is imperative to closely monitor the progress of various regions in the recovery process. Doing so is crucial for devising strategies to expedite recovery, as delays in normalization may result in diverse economic, environmental, and social challenges.

The objective of the study is to comprehensively investigate and analyze the economic and environmental recovery efforts in Adıyaman and Malatya after the Kahramanmaraş earthquakes of February 6th*, 2023.* Through extensive field research and a multi-layered methodology, the study aims to achieve the following: (i) Understand the evolving dynamics and challenges affected communities and businesses face during the transition from the early to the medium-term recovery phase. (ii) Engage with relevant decision-makers and institutions involved in the economic and environmental recovery to monitor progress, share lessons learned, and identify early and medium-term recovery needs. (iii) Provide information and insights for the policy development process, particularly concerning the region's specific needs, by capturing the perspectives of different stakeholders. (iv) Examine the impact of the earthquakes and the reconstruction process on economic and environmental dimensions, including capital stock, labor, supply chain, infrastructure, entrepreneurial ecosystem, distribution, marketing, financial needs, financial vulnerability, air and water pollution, and waste management. (v) Evaluate the effectiveness of existing recovery strategies and plans and identify strengths, weaknesses, and areas for improvement. (vi) Ensure that spatial and contextual data are included to substantiate findings and increase the credibility and validity of the research.

By accomplishing these objectives, the study aims to contribute to a comprehensive understanding of economic and environmental recovery efforts in Adıyaman and Malatya and provide valuable insights for future disaster mitigation and recovery initiatives.

Recovery, which includes decisions and activities aimed at systematically incentivizing and regulating to reduce potential disaster risks, is the totality of efforts aimed at restoring the living conditions of a community affected by a disaster. After fulfilling the tasks related to coping with the emergency resulting from disasters, the most critical aspect is the rapid return of local communities and individuals to pre-disaster living conditions. The main goal of recovery efforts is to minimize the time needed to return to normalcy [5]. According to Gülkan et al. [6], in addition to the immediate goal of alleviating the consequences of a disaster, the top priority is to support affected individuals and communities to restore local economic vitality, improve infrastructure, support industry and commerce, provide educational opportunities for the community and offer social and psychological support services to strengthen the community's resilience to potential future disasters.

According to UNDP [7], recovery includes three phases: (i) *Early Recovery:* In this phase, the affected population is in a relatively stable transition phase. They have access to resources to obtain food and water, albeit only to temporary shelters that can withstand weather conditions to a certain extent. Disaster victims are continuing their daily lives to a certain extent. Children can return to school, even if the classrooms are in tents or other temporary shelters. The injured may not have fully recovered, but adjusting to the "new normal" has begun. Early recovery may take weeks or even months. (ii) *Medium-term recovery:* During medium-term reconstruction, permanent physical structures will begin to be erected to replace tents, containers, or plywood houses, and social structures will also be rebuilt. Rebuilding permanent shelters will strengthen the social fabric of the communities. Children are returning to school,

[1] https://data.tuik.gov.tr/Bulten/Index?p=Gross-Domestic-Product-by-Provinces-2021-45619.

and adults are starting to earn a living and rebuild the family economy. Life largely returns to normal. (iii) *Community development:* It serves to improve the "normal". This phase, not traditionally considered part of emergency response, begins to address some of the root causes of the conditions that pose a significant challenge for communities. Community development focuses on improving daily life for vulnerable or underserved populations who have survived but are not doing well. Priorities in this phase include livelihoods, quality of life, and access to education and health services. This phase can extend over several years.

As part of the current research, the field study team has set itself the goal of investigating the effects of earthquakes and the early and medium-term recovery process in the areas visited based on economic and environmental dimensions.

The economic dimension includes capital stock (buildings, machinery, equipment, etc.), labor, supply chain, infrastructure, entrepreneurial ecosystem, distribution, marketing, financial needs, and financial vulnerability.

The environmental dimension includes air and water pollution as well as solid waste problems that arose after the earthquakes [8]. The Disaster and Emergency Management Presidency (Afet ve Acil Durum Yönetimi Başkanlığı in Turkish) has set up various tent sites and containers in the disaster area to meet people's shelter needs during the initial recovery period. The correct placement of these tent sites and containers is crucial, as explained below.

Within this framework, the research team conducted on-site visits in Malatya and Adıyaman provinces in April 2023. Three methods were used in the fieldwork: (i) Observation, (ii) Semi-structured interviews, and (iii) Geographic Information System (GIS) analysis to corroborate the findings obtained through observation and semi-structured interviews by providing spatial context and visual representation of on-site data.

The recovery practices were first studied through the observation method to understand the economic and environmental developments in the provinces of Adıyaman and Malatya. Secondly, semi-structured interviews were conducted with municipalities, chambers of commerce and industry, Organized Industrial Zones, and businesses. The participants in the semi-structured interviews were informed about the research and signed consent forms. Thirdly, GIS is used to determine whether the locations where these provinces were built based on satellite data could adversely affect residents. For example, emergency shelters built close to the urban areas are expected to be exposed to significant air pollution during debris removal. Shelters built in riverbeds could also be at risk of flooding. During the field visit to validate the GIS work, observations were made to assess whether the factors recommended in the literature for shelter selection were considered. These factors include accessibility, distance from affected people's homes, infrastructural conditions, soil drainage, spatial layout, environmental design, distance from hazardous areas, ground slope, availability of water sources, access to medical facilities and emergency services, previous land use, vegetation, and proximity to the road network.

The information collected during the project fieldwork was analyzed by combining it with the information obtained through desk studies. Due to the limited number of observations, descriptive analyses were used instead of statistical ones. The results and the related discussions are presented in the following sections of the paper.

2. .Theoretical framework and literature review

The devastating earthquakes that struck southeastern Turkey on February 6, 2023, have had profound and multifaceted impacts on the region's economic, social, and environmental landscapes. This study aims to analyze these impacts through the lens of economic resilience, drawing on both established theoretical frameworks and recent empirical research. This section presents the theoretical underpinnings of our study and reviews relevant literature to contextualize our research within the broader disaster impact assessment and recovery field.

2.1. Theoretical framework: economic resilience

The foundation of our research is the economic resilience framework proposed by Rose and Krausmann [9]. This comprehensive approach provides a structured method for assessing and enhancing the capacity of economic systems to withstand and recover from disasters. The framework operates on three distinct levels of economic analysis: microeconomic (individual firms or households), macroeconomic (industries or markets), and macroeconomic (overall economy) [10,11].

Central to this framework is the distinction between two types of economic resilience: 1) Static economic resilience: This refers to the ability of an economic system to maintain functionality during a shock by efficiently utilizing existing resources. 2) Dynamic economic resilience: This encompasses the speed and effectiveness of recovery efforts to restore and improve productive capacity over time.

Rose and Krausmann [9] further delineate between inherent resilience, which includes pre-existing adaptive capacities such as inventory and excess capacity, and adaptive resilience, which arises from innovative responses to stress, such as altering production methods or implementing contingency measures. The framework emphasizes the importance of focusing on flows of goods and services, rather than merely stockpiling assets, to capture the actual impact on economic well-being [12].

Our study applies this framework to analyze the impacts of the February 2023 earthquakes in Turkey, with a particular focus on microeconomic and macroeconomic analyses. We examine the extent of damage and recovery capacity at various levels of aggregation, including impacts on physical capital and the labor force. By identifying critical areas for resilience-building interventions, we aim to contribute to the development of targeted and effective recovery strategies.

2.2. Literature review

Recent studies on the 2023 Kahramanmaraş earthquakes in Turkey provide valuable insights into various aspects of earthquake impacts and recovery processes. These studies can be categorized into several key themes.

2.2.1. Economic impact assessment

In their current study, Tatar et al. [13] aim to develop a novel approach to assess the negative impact of earthquakes on economic activity by detecting physical damage in commercial areas. It uses geographic information systems (GIS) and remote sensing techniques to identify impacted commercial enterprises using point of interest (POI) data in Antakya and Defne districts in Hatay, which are among the 11 provinces severely affected by the Kahramanmaraş earthquakes. The study's results provide valuable insights into the extent of earthquake-related economic losses in these districts of Hatay.

Alam and Ali [14] investigate the resilience of the Turkish real estate sector in the face of earthquakes using the Dynamic Inoperability Input-Output Model (DIIM) together with a nonlinear optimization technique. According to the DIIM results, specific sectors such as electricity and gas supply, chemical production, non-metallic mineral production, and financial and insurance services suffer significant financial losses. Among these sectors, mining and quarrying have the highest degree of inoperability, followed by chemical and non-metallic minerals manufacturing and mining support activities.

In the study by Akdemir et al. [15], a research survey was conducted to evaluate the socio-economic impact on agricultural production after the earthquakes that shook Türkiye on February 6th, 2023, and the collected data was analyzed. The survey covered 15 villages, with three villages selected from each of the five districts where the earthquake was felt the most, ensuring representativeness across all affected areas. The results show that the earthquakes not only cost lives and property in the rural areas, but also had a significant impact on factors of production, particularly stocks, availability of tractors and labor, and caused disruptions in supply chains and delays in agriculture.

2.2.2. Infrastructure and built environment

Kocaman et al. [16] conducted a detailed examination of the collapse mechanism of the Malatya Yeni Mosque, which had undergone strengthening measures before the earthquakes. This case study provides valuable insights into the efficacy of pre-disaster rehabilitation strategies for similar structures.

In their study, Unal et al. [17] assess the impact of geohazards, including landslides, high ground acceleration (PGA), liquefaction, and surface rupture, on natural gas pipelines. These hazards led to numerous incidents affecting the pipelines during the devastating Kahramanmaraş earthquakes that occurred on February 6th, 2023 (Mw 7.7 and Mw 7.6) in southeastern Türkiye. A total of 21 incidents were documented through field observations and visual analysis of aerial photographs with a nominal spatial resolution of 25 cm taken shortly after the earthquakes. In addition to the inventory, maps of landslide and liquefaction susceptibility in the area with a resolution of 25 m were created using supervised machine learning methods and evaluated at the locations of the incidents.

2.2.3. Environmental concerns

In their study, Mavroulis et al. [8] carried out field investigations after the event. Several landfills established in the most affected provinces were identified and tested for their suitability. Based on field observations of the site characteristics and surrounding areas, as well as the assessment of debris management activities, it was found that none of the sites met the criteria for safe seismic debris management. In conclusion, the authors proposed measures for effective debris management based on existing scientific knowledge and operational experience aimed at overcoming the challenges encountered in managing earthquake debris and mitigating the associated public health and environmental hazards, thus avoiding similar failures in future destructive events.

Vural [18] aims to evaluate two types of particulate matter pollution during debris removal at 25 different locations in Adıyaman city using a CEM DT 9880 particle monitor in May and August 2023. Field measurements of PM2.5 and PM10, which are known for their significant impact on human health, were conducted. The collected data was analyzed using the Inverse Distance Weighting (IDW) method in ArcGIS 10.7 software. The results showed that neighborhoods with extensive demolition work had the highest levels of particulate matter. In particular, the highest PM2.5 pollution levels were measured in the neighborhoods of Barbaros Hayrettin, Hoca Omer, Yeşilyurt, and Varlık. In terms of PM10 pollution, the highest levels were recorded in the Alıtaşı, Barbaros Hayrettin, Sümerevler, and Hoca Omer neighborhoods.

2.2.4. Social and psychological impacts

In a departure from the previous seven studies, we conducted field visits to the earthquake-affected areas, particularly Malatya and Maras, to collect primary data for our analysis. While the author of the following study collects data through semi-structured, in-depth interviews, focusing primarily on examining the experiences of rescue teams and victims, our aim is to analyze the economic and environmental losses through interviews in the earthquake region.

Sert et al. [19] aim to investigate the experiences of people affected by the Kahramanmaraş earthquakes and those who were actively involved in search and rescue operations in the affected areas. Using a qualitative approach, data was collected through semi-structured in-depth interviews and focus group discussions (FGDs) with 47 earthquake victims living in different tent cities and 46 members of search and rescue teams in Kahramanmaraş and Hatay provinces. Data analysis was conducted using the content analysis method. The results showed that the search and rescue teams faced challenges in the areas of coordination, transportation, communication, debris safety, and team reinforcement, especially during the operational phase. Conversely, earthquake victims struggled with psychosocial impacts and encountered difficulties in accessing resources and distributing relief supplies, as well as a lack of information before, during, and after the earthquakes.

2.3. Global perspectives on earthquake impacts and recovery

Other regions of the world have also suffered economic and environmental losses following the earthquakes. The following four studies are cited as examples of the other regions of the world.

Joseph [20] examines the average causal impact of the 2010 earthquake in Haiti on economic growth and recovery through a detailed empirical analysis at the subnational level. To this end, the author uses a difference-in-differences model with fixed effects and impulse response functions, with the intensity of the earthquake serving as the primary exogenous variable and nighttime illumination data serving as a proxy for economic activity from 1992 to 2019. The results show clear evidence that the earthquake led to a significant short-term decline in the country's economic growth.

Chen and Zhang [21] present an automated machine learning (AutoML) system that can be used to predict both casualty rates and direct economic losses due to earthquakes. The AutoML framework incorporates automated combined algorithm selection and hyperparameter tuning (CASH), which streamlines the manual tasks involved in model development. The proposed AutoML system consists of five modules — data acquisition, data pre-processing, CASH, damage prediction, and model analysis— - and uses earthquake data and social indicators to train the models. The CASH module identifies the optimal algorithm and hyperparameter settings for the models.

Shibusawa [22] evaluates the economic impact of a major earthquake on regional economies in China. Using a dynamic spatial computable general equilibrium model, the author divides China into 30 regions/cities using a multiregional input-output table. This model depicts a decentralized economy characterized by utility-maximizing households and profit-maximizing firms. Based on historical data, the author simulates both unforeseen and predicted earthquakes hitting the Bohai economic area of China and then measures the dynamic and spatial impact before and after each event. The analysis focuses on two aspects: Pre-earthquake investment, which is aimed at mitigating the impact of the earthquake, and post-earthquake expenditure, which is aimed at recovery measures.

Gu et al. [23] present an earthquake-induced cascading disaster mitigation–Bayesian Decision Network (ECDM-BDN) model that aims to evaluate strategies to mitigate the impact of earthquakes within limited budgets, using a systematic approach. Furthermore, cost-benefit analysis is performed by integrating Bayesian decision network utility nodes and dynamic programming to balance costs and benefits within budget constraints. As a case study, earthquake-induced liquefaction is tested to demonstrate the effectiveness of the proposed model. The experimental results show that the ECDM-BDN model can effectively balance the costs and impacts of each pre-disaster mitigation strategy and finally select the optimal strategy based on the benefits.

This review of literature and theoretical frameworks demonstrates the multifaceted nature of earthquake impacts and the complexity of recovery processes. By integrating the economic resilience framework proposed by Rose and Krausmann [9] with insights from recent empirical studies, our research aims to comprehensively analyze the 2023 Kahramanmaraş earthquakes' impacts. We focus on assessing static and dynamic resilience at micro and macroeconomic levels, identifying inherent and adaptive resilience factors in affected regions, analyzing impacts on physical capital and labor force, and evaluating the effectiveness of current recovery efforts.

Through this integrated approach, our study seeks to contribute to a deeper understanding of earthquake impacts and inform the development of effective, sustainable recovery strategies for the affected regions in Turkey. By bridging theoretical concepts with empirical findings, we aim to provide valuable insights for policymakers, disaster management professionals, and researchers working to enhance community resilience in the face of natural disasters.

3. Methodology

For this study, the research team visited the provinces of Malatya and Adıyaman in April 2023. Three methods were used in the fieldwork: (i) direct observation, (ii) semi-structured interviews, and (iii) Geographical Information System (GIS) analysis. GIS analysis was used to validate the observations and findings from the field visits and interviews by providing a spatial context and visual representation of the data collected in the field. The following sections describe the recovery framework, study timeline, research team expertise, observation methodology, participant selection and roles, environmental recovery, consent and semi-structured interview questions, GIS work, secondary data sources, and interview data analysis.

3.1. Recovery framing

As mentioned earlier in the introduction section, recovery includes three phases: early recovery, medium-term recovery, and community development. In this study, the field study team aims to examine the impacts of earthquakes and the early to medium-term recovery processes in the visited areas, focusing on economic and environmental aspects. We observed the recovery process in Malatya and Adiyaman during our visit. In addition, we also met with representatives of local municipalities, a development agency, a chamber of commerce, and representatives of organized industrial zones, including five business owners/managers from various industries and local representatives from municipalities, to figure out the recovery framework of both cities. The outcomes are embedded in sections four and five.

3.2. Study timing

The field research was conducted between April 11 and 14, 2023, about nine weeks after the earthquakes. This period coincides with the transition from the early to the mid-term recovery phase and provides a unique opportunity to capture the evolving dynamics and challenges faced by affected communities and businesses.

3.3. Research team expertise

The research team consists of experts from various disciplines, including economics, finance, civil engineering, environmental science, and disaster management. The team members are experienced in conducting field studies and analyzing complex socioeconomic and environmental issues using quantitative and qualitative research methods.

3.4. Observation method

The observation method included direct on-site observations of the affected areas in Adıyaman and Malatya. The research team systematically documented physical and environmental conditions, such as the condition of buildings, infrastructure, emergency shelters, and waste disposal. Observations were recorded through field notes, photographs, and video recordings, capturing both the spatial and temporal dimensions. The exact locations and time stamps of the observations were carefully recorded.

3.5. Participant selection and their roles

The research team identified and recruited key stakeholders who played or will play an active role in the economic and environmental recovery efforts in Adıyaman and Malatya. These stakeholders included representatives from local municipalities, chambers of commerce and industry, development agencies, organized industrial zones, and the private sector. The recruitment process included initial outreach through formal channels via email and phone calls, followed by a snowballing process based on referrals from initial participants.

A total of 13 semi-structured interviews were conducted, involving participants from different sectors and organizations. The roles of the participants are described below.

Economic Recovery: Four representatives of local municipalities, one representative of a development agency, one representative of a chamber of commerce, and seven representatives of organized industrial zones, including five business owners/managers from various industries (textile, glass, etc.).

Environmental Recovery: Two representatives from local municipalities responsible for waste management and environmental monitoring.

3.6. Consent and semi-structured interview questions

Before the interviews were conducted, the research team obtained the consent of all participants. The consent form outlined the purpose of the study, the voluntary nature of participation, and the measures taken to ensure confidentiality and data protection. The semi-structured interview questions were designed to provide insights into the economic and environmental impact of the earthquakes, the challenges faced by businesses and local authorities, and the recovery strategies and plans in place. The questions were tailored to each participant's specific roles and responsibilities to understand the recovery efforts from different perspectives comprehensively. The semi-structured interview questions are provided in the Appendix.

3.7. GIS works

The identification of temporary landfills after an earthquake requires the use of GIS to integrate spatial data from different sources. This process includes assessing the impact of the earthquake, analyzing satellite imagery to identify areas of significant debris accumulation, and incorporating topographic data to assess terrain features such as slope and susceptibility to landslides. In addition, infrastructure data helps determine accessibility for cleanup crews, while land use/land cover datasets help identify suitable parcels for waste disposal sites, considering factors such as environmental sensitivity and population density.

In addition, hydrological data is critical to prevent pollution of water sources, and population density analysis ensures that landfills are not located near residential areas to minimize health risks. Soil surveys confirm the GIS analysis, while risk assessments evaluate the potential hazards associated with selected sites [24].

In contrast to the approach of Demir and Dinçer [24], where potential temporary waste sites in Kahramanmaraş were identified based on various criteria, the GIS component of this study focuses on observing the location of the temporary waste sites and verifying whether they are consistent with the observed debris distribution due to the earthquake. The GIS applications in this study primarily use ArcGIS software to input the observed locations where earthquake-related debris is concentrated, with Sentinel-2 serving as the primary source of satellite imagery data used to identify land cover patterns.

3.8. Secondary data sources

In addition to the primary data collected through observations, interviews, and GIS analysis, the research team relied on secondary data sources to provide contextual information and validate findings. These sources included official reports from government agencies, such as the Strategy and Budget Office of the Presidency of the Republic of Türkiye, the Turkish Statistical Institute, and the Ministry of Environment, Urbanization, and Climate Change. Additionally, data from international organizations, such as the World Bank and the International Labor Organization, were utilized to triangulate and contextualize the findings.

By employing this multifaceted methodology, the research team aimed to gain a comprehensive understanding of the economic and environmental recovery efforts in Adıyaman and Malatya, capturing the perspectives of diverse stakeholders and incorporating spatial and contextual data to support the findings.

3.9. Interview data analysis

The semi-structured interviews were audio-recorded with the consent of the participants. The recordings were subsequently transcribed. The transcripts were analyzed using thematic analysis, a widely used qualitative data analysis method [25], to identify recurring themes, patterns, and insights related to the economic and environmental recovery efforts. Two researchers first familiarized themselves with the data and then generated initial codes. The next step was collating codes into potential themes, reviewing them, and defining them to ensure they accurately reflect the narratives. Triangulation was achieved by cross-referencing and corroborating the findings from the interview data with the observations, GIS analysis, and secondary data sources. The triangulation process enhanced the credibility and validity of the research findings by drawing upon multiple sources of evidence and different methodological approaches [26].

4. .Economic impact

The objective of this section is to briefly explain the results of the field study from an economic perspective after presenting the relative importance of the economies of Adıyaman and Malatya compared to Türkiye. Table 2 shows the economic indicators of Adıyaman and Malatya compared to Türkiye in order to familiarize the reader with the economic subtleties of the two cities.

The combined share of Adıyaman and Malatya in Türkiye's population and employment is 1.7 percent and 1.3 percent, respectively, while their share in GDP is limited to 0.9 percent (Table 2). There are direct and indirect costs to the economy from earthquakes. However, it is difficult to estimate the costs of earthquakes due to a lack of transparent data sharing. A few institutions provide initial rough estimates, ranging from 77 to 146.8 billion dollars, as shown in Table 3.

This significant difference between cost estimates was also observed after the 1999 Kocaeli and Düzce Earthquakes. For example, the estimates of OECD [31], World Bank [32] and Özmen [33], Selçuk and Yeldan [34] differed significantly. One of the reasons for this is that each researcher had access to different data sources with varying degrees of depth and reliability following a major disaster. Over time, the reliability of the data increases due to updates, resulting in different estimates throughout the years. The same is expected to be valid for the estimates in Table 3.

Unlike recent economic studies and work on the 1999 earthquakes, our goal is not to provide estimates of economic costs but to report what was observed on the ground and the results of interviews with those affected on the ground. In other words, our work is based on primary data sources, while the literature cited above relies on secondary data sources. Both methods have advantages and disadvantages, but they complement each other.

4.1. Impact on Aggregate production

Against this background, we now discuss the findings of the field study conducted for Adıyaman and Malatya from an economic angle by mainly concentrating on the losses in production factors in the period the field visits are conducted (April 2023), which are expected to result in declines in economic activity in at least 6–12 months period following the earthquakes.

4.1.1. Physical capital

As far as the damage or destruction of physical capital is concerned, both provinces are severely affected. It can be observed that the small stores and historical bazaars in the city centers, as well as the old and small industrial areas, are the most affected. The organized industrial areas were in a relatively better condition.

There are two organized industrial zones in Malatya, where 394 companies are located. Of these, 39 were moderately and severely damaged, while 355 were slightly damaged or not damaged at all. In these 355 enterprises, the losses of machinery and equipment are minimal; the biggest problem is the adjustments and calibrations of the machines.

In Adıyaman, there is an Organized Industrial Zone where 201 companies (80 percent in the textile and garment industry) with 22,000 employees are located, according to the zone's higher administration. Of these factories, 15 percent have collapsed or been severely damaged, and 40 percent are moderately to slightly damaged. In 6 factories, machinery and equipment were also severely damaged.

In summary, Adıyaman Province and Malatya Province suffered significant property damage, particularly affecting small stores, historical bazaars, and old industrial areas, while the Organized Industrial Zones fared relatively better. The two organized industrial zones in Malatya suffered varying degrees of damage, with minimal losses to machinery but requiring adjustments. In the Adıyaman Organized Industrial Zone, mainly home to textile and garment companies, 15 factories suffered collapse or severe damage, and 40 % suffered moderate to light damage, with some machinery also severely affected.

4.1.2. Labor force

Both provinces show certain similarities in terms of the impact of the earthquakes on the labor force. *First*, according to local authorities,[2] there were nearly 6000 deaths in Adıyaman and 1410 in Malatya, accounting for 15 percent of the total deaths in the earthquake region. The sheer scale of the loss of life and the number of injured not only affected the ability to work and motivation of the people who were victims of this disaster but also prevented their families from working due to psychological trauma or caregiving responsibilities.

Secondly, there is extensive damage to the building stock in both provinces.[3] Fig. 2 shows the composition of damage to independent units and shows that 68 percent are damaged in Adıyaman and 55 percent in Malatya. The figure summarizes heavy, medium, and light damages, as the interviews conducted during the field study showed that people do not want to live even in the lightly damaged units. Although the buildings have not collapsed as much as in Hatay or Kahramanmaraş, many independent units in Adıyaman and Malatya are damaged, making it impossible to live or work in them. In other words, the labor force in both cities is struggling with the difficulties of not having a permanent residence and/or workplace.

Thirdly, there is damage to the water infrastructure, energy networks, roads, railroads, and airports in both provinces, all of which worsen living conditions. For example, on April 11th, 2023, there was no clean drinking water in either Adıyaman or

[2] When this article was written, the official death toll at province level was not yet available.

[3] Yılmaz [30] reports that among all other provinces affected by the earthquakes, Malatya has the highest percentage (8.9 percent) of buildings that collapsed or had to be demolished due to severe damage, followed by Adıyaman (6.9 percent).

Table 2
Pre-earthquake economic indicators of Malatya and Adıyaman.

	Adıyaman	Malatya	Türkiye
Gross Domestic Product			
GDP (million $), 2021	2587	4324	807,106
Per capita GDP ($), 2021	4092	5355	9592
Share of agriculture in GDP (percent), 2021	15	11	6
Share of manufacturing in GDP (percent), 2021	27	26	29
Share of services in GDP (percent), 2021	59	63	65
Population			
Total population (person), 2022	635,169	812,580	85,279,553
Share of population in Türkiye (percent), 2022	0.74	0.95	100
Population density (per square km), 2022	90.31	69	110.81
Employment			
Total employment (Thousand person), 2022	122	257	28,797
Share of total employment in Türkiye (percent), 2022	0.42	0.89	100
Formal employment (Thousand person), 2022	81	149	20,441
Share of formal employment in Türkiye (percent), 2022	0.40	0.73	100
Trade			
Exports (thousand dollars), 2022	82,968	449, 636	235,269,494
Share of exports in Türkiye (percent), 2022	0.04	0.19	
Imports (thousand dollars), 2022	77,216	171,650	349,209,838
Share of imports in Türkiye (percent), 2022	0.02	0.05	
Energy			
Electric consumption per person (kWh), 2022	2099	2231	3386
Health			
#hospital beds (per thousand people), 2020	222	369	300
Agriculture			
Total cultivated agricultural area (hectares), 2021	166,757	175,572	20,169,569
Share of cultivated agricultural area (percent), 2021	0.83	0.87	100
Value of crop production (million $), 2021	335	448	40,125
Share of crop production (percent), 2021	0.84	1.12	100
Value of live animal stock (million $), 2021	140	256	26,575
Share of live animal stock (percent), 2021	0.53	0.96	100
Government Revenue			
Central budget revenue (million $), 2022	111	272	169,095
Share in central budget revenue (percent), 2022	0.07	0.16	100
Tax revenue, 2022 (million $), 2022	95	214	141,997
Share in tax revenue (percent), 2022	0.07	0.15	100
Residence Stock			
# residences, 2021	216,744	345,536	40,200,000
Share of post-2001 residences in building stock (percent)	52.3	58.1	47.4

Source: All the data is taken from TURKSTAT (https://www.tuik.gov.tr) except employment and building stock data, which are taken from SBB [1].

Table 3
Total cost estimates of the earthquakes.

	Total Cost (Billion $)	GDP Loss (percent)
SBB (March 2023) [1]	103.6	6.9
TEPAV (March 2023) [27]	146,8	–
World Bank (February 2023) [28]	100+	–
Turkonfed (February 2023) [29]	84	11.1
Yılmaz (February 2023) [30]	77–105	11.4–19.2

Malatya, as the aftershocks had contaminated the main water supply of both provinces (natural reservoirs) with ground sediments. In addition, the tents and containers have been set up sporadically in many different places. According to the Malatya Municipality, the number of neighborhoods has increased from 718 to 1718 after the earthquakes, which increases the strain on public transportation in the city and means that there are fewer and less frequent bus routes, making commuting very difficult.

Finally, the lost working hours in the two provinces are similar. The ILO (2023) estimates that Adıyaman and Malatya lost 48.1 percent and 58.8 percent, respectively, of their pre-earthquake labor hours compared to 2021, putting them ahead of all other provinces affected by the earthquakes. This result is even bleaker when looking at the average income level in Adıyaman and Malatya before the earthquakes (Table 4). The two provinces have the lowest income levels in the group. Taking the lead in terms of lost labor hours means an increased risk of future poverty and inequality if immediate action is not taken to address these challenges.

Regarding the reasons for the loss of working hours in Adıyaman and Malatya, differences were not only observed during the field study but also revealed through interviews with civil servants. One of the most striking observations is the exodus that took place in

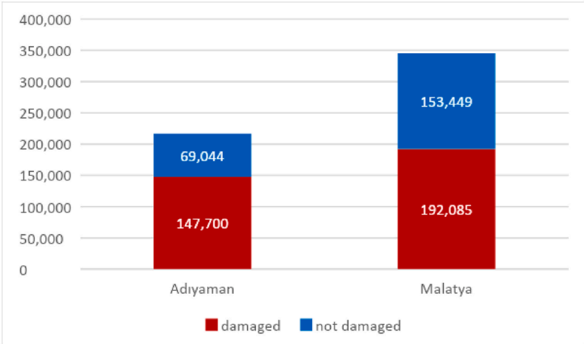

Fig. 2. Number of independent units: Damaged and undamaged. **Source:** SBB [1]. Independent units with any damage are taken as damaged.

Table 4
Labor market indicators for the provinces affected by the earthquakes.

Provinces	Average Daily Earnings[a] (TL) in 2021	% workhours Lost[b] as of March 5th, 2023
Adana	150	0.1
Adıyaman	135	48.1
Diyarbakır	141	0.7
Elazığ	146	2.0
Gaziantep	158	5.5
Hatay	157	45.1
Kahramanmaraş	150	43.1
Kilis	152	6.7
Malatya	139	58.8
Osmaniye	145	6.4
Şanlıurfa	148	0.4

Source: [a] Cılasun et al. [35]; [b] ILO [36].

Malatya. The streets were empty, and the city looked like a ghost town. The interviews with the officials of the municipalities, the Chamber of Commerce and Industry, the organized industrial zones, and the development agency in Malatya revealed the following information: (i) In the first three days after the earthquakes, the evacuation of 320,000 people was organized by the municipalities. About 200,000 left the province on their own. All in all, therefore, more than half of the people living in Malatya left the province, and the return has been protracted and sporadic ever since. (ii) People with higher levels of education and income are not expected to return soon.

The labor-related problems in Adıyaman are different from those in Malatya. Outmigration from Adıyaman is limited compared to Malatya for three reasons: (i) Adıyaman's GDP per capita is lower compared to Malatya, resulting in fewer opportunities for successful migration. (ii) The residents of Adıyaman tend to have a strong attachment to their villages, where the damages are not as pronounced as in the city center. This has indeed reduced the need to migrate to other provinces. (iii) Shops in the city center of Adıyaman have resumed operations after a month on a mobile basis, e.g., selling goods on the street or in tent stores, which has led to some recovery.

Interviews with the heads of the Chamber of Commerce and Industry and the Organized Industrial Zone revealed that the main problem related to the labor market in Adıyaman is the labor shortage caused by the government's policies, which have an unintended effect on the labor supply in the province. The short-time work allowance policy introduced by İŞKUR (Turkish Employment Agency) was intended for workers who lost their jobs due to the earthquakes. The amount of the payment is approximately ¾ of the minimum wage. Considering the composition of Adıyaman's labor force, which consists mainly of minimum wage earners, this policy has created a reverse incentive for workers: they have chosen to stay in their villages and not work.

In summary, the effects of the earthquakes on the labor force dynamics in the provinces of Adıyaman and Malatya are similar. In both cases, there were numerous fatalities, widespread damage to buildings, and disruption to infrastructure, which affected living and working conditions. The loss of labor was significant, with Adıyaman and Malatya leading the affected provinces in this aspect. However, each province faced unique challenges. Malatya experienced significant outmigration, particularly among people with higher education and income, while Adıyaman faced a labor shortage due to government policies that unintentionally discouraged work.

The economic effects of the earthquakes documented so far have focused on the losses in production factors and, therefore, do not reflect the short to medium-term challenges individual companies face. Therefore, The following sub-section describes the experiences of company representatives interviewed during the field study.

4.2. Impact on businesses

This section presents a comparative analysis of the earthquakes' impact on businesses in Adıyaman and Malatya based on field studies conducted in both provinces. The analysis encompasses physical damage, infrastructure disruptions, labor force impacts, operational challenges, market changes, and financial consequences.

4.2.1. Physical damage and infrastructure disruptions

The extent of physical damage varied significantly between Adıyaman and Malatya, influenced by factors such as company size, geographical location, and economic structure. Malatya benefited from the presence of larger, more prepared companies, particularly in the textile industry. For instance, a major textile company with 1650 employees stated in the interview that it had risk committees. They conducted pre-earthquake safety analyses and reinforced the company's facilities, enabling it to resume operations three weeks after the earthquakes. The company reports that it has suffered less from the loss of machinery and equipment than other companies and could also assess the damage caused by earthquakes more quickly. They modified the buildings, set up emergency communication lines, and implemented effective emergency and recovery plans. However, many micro-enterprises in Malatya's city center remained non-operational due to building damage.

In Adıyaman, the Organized Industrial Zone reported severe machinery damage in six factories, highlighting the vulnerability of smaller companies that lacked proactive disaster preparedness measures. The city's geographical isolation further exacerbated the impact, limiting recovery options. An interviewee from the administration of the Adıyaman Organized Industrial Zone states the geographical isolation of Adıyaman:

> "*Other cities can thrive due to their connectivity. Hatay, for example, has a port. Adıyaman, however, is somewhat isolated. Limited transportation options and increased transportation costs reduce our competitiveness. Even attending a meeting in the capital Ankara takes two days because flights are limited.*"

Both cities experienced similar infrastructure challenges, particularly in transportation and logistics. Severe damage to local roads hampered truck traffic, causing significant logistical challenges. The halt in operations at the port of Iskenderun, a key export hub, affected businesses in both regions. Additionally, both cities reported interruptions to drinking water supplies, further complicating business operations.

4.2.2. Labor force impacts

The earthquakes severely impacted the labor force in both Adıyaman and Malatya, albeit with some distinctions. In Adıyaman, businesses reported a significant drop in worker morale and motivation, with production in mid-April 2023 reaching only 25 % of pre-earthquake levels. While facing similar morale issues, Malatya also grappled with a shortage of skilled labor due to outmigration. For example, a leading glass company in Malatya lost 100 out of 350 employees, with 30 % being white-collar workers. The manager of this company expressed concerns about government policies encouraging skilled worker relocation, potentially exacerbating the labor shortage.

> "The deputies come, the local officials come. They say: "I have placed so many people in jobs, and I have also placed people in jobs in another city." Although this action is well-intentioned, it hurts us a lot. They are taking a qualified workforce away from us. I said: "Take the disadvantaged groups first. They are doing it wrong. They are sending people who will be useful in the market as young and active workers. They are not sending people with disabilities or older people." Do you know the demographic structure of social security in Malatya? Malatya has 60,000 SSI (Social Security Institution) members, 26,000 independent contributors, 40,000 civil servants, and 117,000 pensioners. Instead of sending 117,000 pensioners, they sent 40,000 out of the 60,000. If they do that, they will be playing with the dynamics of the city. We are moving towards a commercial earthquake."

This quote highlights the unintended consequences of well-meaning policies and the complex challenges facing businesses in the aftermath of the disaster.

4.2.3. Business operational challenges

Operational challenges in both cities stemmed from labor shortages, infrastructure damage, and employee well-being concerns, with varying degrees of impact on different sectors. In Adıyaman, the Organized Industrial Zone operated below capacity due to employee shortages, with the textile industry, the city's most important sector, facing significant challenges.

Malatya's businesses, particularly those in organized industrial zones, resumed operations more quickly but faced significant ongoing issues. Companies struggled with employee commuting and accommodation problems. According to an interviewee from the Malatya Organized Industrial Zone administration, although employees' homes were only slightly damaged, they could not return to their homes because there were no repair facilities. A manager from a well-known textile company in Malatya described their proactive approach:

> "Without waiting for help from the government, we took proactive measures by setting up containers and tents outside the factory to provide immediate shelter for our workers. We also set up beds in the offices for ourselves and the managers."

However, productivity remained affected by employee trauma and ongoing earthquake fears, as the same manager noted:

> "Numerous employees had to accept the tragic loss of their loved ones, while others sent their relatives to other cities to cope with the separation and longing. In addition, the ongoing earthquakes are delaying the recovery from the initial shock."

The administration of the Malatya Organized Industrial Zone noted that the fear of another devastating earthquake is exacerbating the problem of a shortage of skilled labor.

> "*Skilled workers and employees can find work in other cities, and they have no intention of returning because of the constant danger of earthquakes.*"

In Adıyaman, the situation is similar. As reported by the Adıyaman Chamber of Commerce and Industry, although production in mid-April 2023 has reached 25 percent of pre-earthquake levels, the morale and motivation of workers and administrative staff have dropped significantly.

Therefore, after an earthquake, companies must not only focus on maintaining operational facilities but also prioritize the well-being and accessibility of their employees after such a natural disaster.

4.2.4. Market disruptions

The earthquakes caused significant market disruptions in both cities, affecting local demand and export relationships. In Adıyaman, some buyers shifted production to other regions, while others provided upfront payments and sourcing assistance to support local businesses. The tourism sector in Adıyaman was particularly hard hit, with widespread damage to hotels and cultural monuments expected to create a lasting stigma against the province. Some important cultural monuments, such as Ulu Cami and Mor Peter Church, have collapsed completely or partially. Of the 32 existing tourist accommodations, 12 have been destroyed, killing hundreds of people. One is severely damaged, one has moderate damage, and there is minor damage in 9 [1]. This destruction is expected to create a stigma against the province and will inevitably undo years of efforts to build Adıyaman's tourism potential.

Malatya experienced a significant decline in local demand due to population exodus and shifts in consumption patterns. As reported by the Malatya Chamber of Commerce:

> "Local demand has fallen significantly. Many inhabitants have moved away, and those who have remained in the region no longer consume as much as they did before the earthquake. They have become accustomed to receiving food and other goods from the government and various organizations."

Moreover, some Malatya-based companies lost important European customers due to their inability to fulfill contractual obligations. The long-term economic impact of this loss could be substantial, as these relationships were pivotal for the region's economic stability and growth.

A major concern among managers of textile companies in both Adıyaman and Malatya is the shortage of skilled labor, which is crucial for maintaining production quality. The earthquakes exacerbated this shortage, leading to a potential decline in product quality that jeopardizes important customer relationships.

4.2.5. Financial struggles

Financial resilience emerged as a critical concern in both cities, with businesses facing immediate liquidity issues and long-term uncertainties about recovery and growth. In Adıyaman, the tourism sector is expected to suffer severe financial losses due to infrastructure damage and potential stigma. Malatya's businesses reported struggles with paying utility bills and operating expenses and skepticism about the effectiveness of government loan deferrals.

The increased uncertainty led many companies to postpone investment decisions. However, companies linked to parent companies demonstrated greater financial resilience, highlighting the importance of broader corporate support structures in disaster recovery.

This comparative analysis reveals similarities and differences in the earthquakes' impact on businesses in Adıyaman and Malatya. While both cities face significant challenges in infrastructure, labor force, operations, market disruptions, and financial stability, the specific nature and extent of these impacts vary due to each region's unique economic structures and geographical factors.

Adıyaman's geographical isolation and reliance on tourism may make its recovery more challenging, while Malatya benefits from the presence of larger, more prepared companies, particularly in the textile sector. The nature of market disruptions differs, with Adıyaman facing production shifts and Malatya experiencing more local demand changes.

Understanding these nuanced impacts is crucial for developing targeted and effective recovery strategies for each city. Future research could focus on long-term recovery trajectories and the effectiveness of various support mechanisms in addressing the specific challenges businesses face in each region.

5. .Environmental impact

One of the most remarkable consequences of an earthquake is the creation of a considerable amount of debris. If the debris generated by the disaster is not properly disposed of, it can lead to significant environmental damage, economic setbacks, and psychological effects for the affected population [37]. Therefore, after a brief explanation of the GIS work, this section examines the efforts to manage disaster debris after the Kahramanmaraş earthquakes.

5.1. Calculations of disaster waste

Field research was conducted in the earthquake regions of Adıyaman and Malatya to investigate the debris removal and disposal process by the government and local authorities. It was found that the amount of debris generated by the demolition of buildings is one of the largest in the world [8].

According to SBB [1], 14.1 percent of Türkiye's total housing stock is located in the 11 earthquake-affected provinces. According to a report by the Ministry of Environment, Urbanization, and Climate Change in the Turkish Ministry of Environment Urbanization and Climate Change [38], a significant number of buildings collapsed in the Adıyaman and Malatya regions. The report shows that 1485 buildings have completely collapsed in Adıyaman, while there are 3899 such buildings in Malatya. The total number of households living in these destroyed buildings is approximately 6311 and 16,570 in Adıyaman and Malatya, respectively. In addition, the report states that the number of households living in severely damaged buildings is 20,400 and 22,302 for Adıyaman and Malatya, respectively.

Based on the number of demolished and severely damaged buildings, the total amount of construction and demolition waste in Adıyaman and Malatya is calculated to be 4.0 million tons and 5.8 million tons respectively, based on an estimated household area of 150 m^2 and a unit density of waste of 1.0 t/m^2 [39].

In addition, waste from household items such as appliances, electronic waste, furniture, and animal carcasses contribute to total waste. According to Villoria-Sáez et al. [39], each household produces a total mass of 424.2 kg of such waste. Therefore, about 11,330 tons and 16,490 tons of household waste were generated in Adıyaman and Malatya, respectively.

Based on the findings of the Federal Emergency Management Agency [40], it was found in past disasters, approximately 0.52 km^2 of temporary disaster waste area is required to dispose of 1 million m3 of waste. For this study, the total amount of waste for Adıyaman and Malatya was calculated to be 2.4 million m3 and 3.5 million m^3 respectively, including construction and demolition waste and household waste. The land area required for the disposal of the disaster waste was calculated to be 1.25 km2 and 1.82 km2 for Adıyaman and Malatya, respectively, which is consistent with previous studies [24]. To illustrate the size of the required land, the area of 1.82 km2 is equivalent to approximately 32 soccer fields. Table 5 gives a clear overview of the disaster debris and the corresponding area of the disaster area for both Adıyaman and Malatya.

5.2. Sustainability of disaster waste management

The calculations show that extensive debris was created in Adıyaman and Malatya after the Kahramanmaraş earthquakes. Therefore, it is imperative to prioritize the sustainable management of disaster waste. It is proposed to implement four major approaches for effective debris management: Reuse, recycling, energy recovery and disposal [41,42].

To ensure sustainable debris management, a detailed disaster waste management plan should be in place [43]. This plan should consider the following points.

- *Pre-determining temporary waste management locations*

The choice of location for temporary disaster waste is a crucial aspect that should be decided in advance of a natural disaster. In a recent study by Demir and Dinçer [24], temporary disaster waste sites were proposed for Kahramanmaraş considering land use, distance to the severely damaged area, slope, elevation, distance to populated area, distance to roads, distance to rivers, emissions from transportation from temporary disaster site to recycling facilities and time for waste transportation using GIS techniques. The criteria can be varied depending on the characteristics of the hazard sites.

- *Designating specific on-site zones for collecting debris of various types*

This approach ensures the organized and efficient handling of waste generated by a disaster and facilitates the separation of materials according to their nature and potential for recycling or reuse. By designating specific zones for different categories of waste, authorities can streamline sorting and processing procedures, enabling the recovery of valuable resources while minimizing environmental impact. This practice contributes to long-term sustainability by reducing the burden on landfills and promoting responsible waste management practices in disaster-affected areas.

- *Identifying the final destination for the collected and sorted debris*

This process involves determining appropriate disposal or recycling facilities suitable for the different types of waste generated by a disaster. By designating well-defined destinations, authorities can ensure that debris is disposed of in an environmentally sound manner, minimizing potential risks to public health and the ecosystem. In addition, this practice helps to optimize resource use and reduce transport-related emissions by selecting destinations close to the disaster site.

It is worth noting that sustainable waste management is a challenge even for highly developed nations such as Japan, which is known for its disaster preparedness, as demonstrated by the Great East Japan Earthquake. As the Japan Ministry of Environment [44] reported, around 81 percent of the disaster waste generated by the 2011 earthquake was successfully recycled. However, it took about four years to remove almost all of the disaster debris [45]. This experience underlines that while the rapid removal of disaster debris

Table 5
The disaster debris generated after Kahramanmaraş earthquakes.

City	# of households		C&D waste (million t)	Household waste (t)	Total waste (million m^3)	Disaster site area (km^2)
	collapsed	severely damaged				
Malatya	6311	22302	5.8	16490	3.5	1.82
Adıyaman	16570	20400	4.0	11330	2.4	1.25

is essential, ensuring that debris is dealt with sustainably is equally important, as the example of the aftermath of the 2011 Great East Japan Earthquake shows.

5.3. Disaster waste management in Adıyaman and Malatya

In Türkiye, no detailed disaster waste management plan has been prepared by the central government. A few municipalities prepare their waste management plans for disasters. The field research, interviews, and personal communication with local authorities in Adıyaman and Malatya indicate that there are no detailed disaster waste plans for these cities.

The disaster waste management steps followed by these two municipalities are as follows.

a. Selection of temporary sites for the collection of all types of debris.
b. Arrangements with relevant companies for the collection and transportation of debris.
c. Transportation of debris from demolished buildings/structures to the temporary sites as a first and ongoing step.
d. Demolition of other severely affected buildings and transportation of debris to temporary sites as the next step.
e. Recycling activities are primarily concerned with the separation of steel from the debris created by the disaster. Local authorities have indicated that the remaining debris from the disaster will be reused as material for landfills. This reuse involves using the debris to backfill specific areas within the landfills to create a stable base or cover layer that will effectively contain and manage the waste.

Our field visit indicates that there are serious deficits in the disposal of disaster waste in Adıyaman and Malatya. For example, it was found that some of the temporary sites for disaster waste were not selected according to sustainability criteria. Fig. 2 shows the current sites that were identified as temporary disaster waste sites during the interviews.

Fig. 3 (a) shows the temporary disaster sites in Malatya. This shows that the temporary disaster waste site is located near a cemetery in Malatya, which also has a newly constructed apricot exchange nearby. Although there are no households in the immediate vicinity of this site, the segregation and classification processes leading to air pollution would adversely affect the quality of life of workers in the new apricot exchange and cemetery. Fig. 3 (b), which shows the temporary disaster sites in Gölbaşı, represents a more worrying scenario as the temporary disaster site in Gölbaşı is located close to residential areas. In addition, a container city is located directly opposite the temporary disaster site. There is also a lake in close proximity to these temporary disaster areas.

Fig. 3 (c) and (d) show the temporary landfills for disaster waste in Adıyaman. The first one is located near the Adıyaman Organized Industrial Zone, and the air pollution from this landfill has a negative impact on the people working in the area. The second site was built on an old landfill, which may raise concerns due to its proximity to the Euphrates River. However, it can be assumed that the necessary tests were carried out beforehand to ensure that the waste in the old landfill would not affect the water quality of the nearby Euphrates branch.

Fig. 3. Temporary disaster waste sites in (a) Malatya, (b) Gölbaşı, (c) Adıyaman near the organized industrial zone, and (d) Adıyaman on the old waste dump site.

Fig. 4 also shows images of the temporary disaster waste dumps of Malatya, Gölbaşı, and Adıyaman. It is evident that the temporary sites are turning into rubble mounds due to the massive amount of debris that has been transported to these areas.

Once the waste has been transported to the temporary disaster sites and the necessary separation work has been completed, it is important to initiate the recycling process. Recycling serves as an environmentally conscious solution to waste management and provides benefits such as recovering the economic value of materials, utilizing energy recovery, creating employment opportunities, and reducing the need for landfill space [49]. In addition, recycling can lead to cost savings [50]. In the work of Faleschini et al. [51] and Regattieri et al. [52], examples of successful material recycling of solid waste from disasters were presented. On the other hand, Zhang et al. [53] found that significant amounts of reusable and recyclable materials are still disposed of in landfills or incinerated, primarily due to insufficient expertise [54] and insufficient financial resources [55] in developing countries. Similarly, the field research found that there are undamaged or partially damaged household items (including electronic appliances, furniture, etc.) that are candidates for reuse in debris.

When these items are transported to temporary landfills, they are treated as normal construction waste and must be disposed of. In addition, low-income people, often immigrants, go to these areas to collect recyclable waste. To ensure that recyclable items are not treated as waste, it is strongly recommended that debris removal authorities consider sorting and segregating debris either at the source prior to transportation or at the temporary disaster waste sites. While this may take additional time, it is critical to identify reusable items and keep them from being disposed of as waste.

In addition, an authorized person from a local authority has informed us that the debris (except for steel) can be used as a landfill in the earthquake region.

6. Conclusion

The study aims to comprehensively examine the economic and environmental impacts of the earthquakes in Adıyaman and Malatya, two of the most affected provinces in Türkiye. Utilizing an interdisciplinary perspective, the research collects first-hand observations through field visits and interviews with directly affected individuals, deviating from the predominant reliance on secondary data sources in the existing literature. The study focuses on the comparative analysis of the two provinces, labor market dynamics, assessment of damage to physical capital, impact on businesses, waste management, and assessment of individual needs. **A novel contribution of the study is the emphasis on individual needs assessment for targeted recovery measures, the promotion of recycling as environmentally sound waste management, and the advocacy of transparency and sustainability in debris removal.** By highlighting the variability of earthquake impacts within the affected provinces and proposing strategies for sustainable reconstruction, the study provides valuable insights for disaster management and policy development.

Based on the results of our study, the labor-related problems in Adıyaman differ from those in Malatya. Outmigration from Adıyaman is limited compared to Malatya. The main problem related to the labor market in Adıyaman is the labor shortage caused by government policies that have created a reverse incentive for workers: they have chosen to return to their villages and not to work. It is, therefore, imperative that governments and local authorities adopt policies to incentivize workers to return to work. This situation hampers local businesses, leading to reduced productivity and economic challenges. To address these issues, policies need to balance financial aid with incentives to work, potentially through gradual reduction of allowances and targeted support programs. In terms of damage or destruction of physical capital, both provinces are severely affected. It can be observed that the small stores and historical bazaars in the city centers, as well as the old and small industrial areas, are the most affected. The organized industrial areas were in a relatively better condition.

Fig. 4. Photographs captured at temporary disaster waste sites [46–48].

The impact of earthquakes on businesses varies by store and city. Consistent with the literature, size appears to be a good predictor of business preparedness. Location appears to be another important determinant of disaster impact. Businesses in Adıyaman seemed to be more affected than businesses in other cities. Micro businesses in Malatya, located in the city center, are not operating due to the damage to their shops/buildings. Municipalities have set up temporary container warehouses starting in mid-April. Small businesses operating in the organized industrial zones resumed operations in early April. However, they are operating below capacity due to a lack of employees. The situation is similar in Adıyaman.

Several managers from both small and large textile companies emphasized the risk posed by the shortage of skilled workers. This factor, in addition to earthquake damage, reduces production quality. A possible reduction in product quality can lead to the loss of important customers, which significantly increases the economic consequences of the earthquakes for the companies.

With the exception of the drinking water supply, the companies did not experience any disruption to supply services. However, supply chain disruption is a major challenge for companies. The earthquakes caused severe road damage and brought truck traffic in the region to a standstill. Operations at the port of Iskenderun, the central export hub, were suspended after the earthquakes and reconstruction of the port is underway. Reconstruction of the port is underway. Production has been halted, and the disruption of the transportation system has caused delays in the delivery of goods and raw materials.

In terms of foreign demand, several companies in Malatya were unable to meet their production commitments for export. As soon as they started operations, foreign companies demanded fulfillment of their contracts and imposed penalties for unfulfilled contracts.

The effects of the earthquakes in terms of property damage and consumer losses have caused significant financial losses for companies. As most regional companies are small businesses, there are no significant inventory losses, but many are not financially resilient.

Based on the findings presented in the sections above and in the economic impact subsection, the earthquakes had multiple impacts on businesses, with size and location emerging as important determinants of preparedness and resilience. To mitigate the economic impact, we recommend a multi-pronged approach. First, support for micro-enterprises in hard-hit areas such as Malatya city center is critical. Immediate assistance in rebuilding infrastructure and facilitating access to resources can help these businesses to resume operations quickly. In addition, the shortage of skilled labor needs to be addressed, especially in the textile sector, to maintain the quality of production and retain key customers. Collaboration with educational institutions and vocational training programs could be explored to alleviate this problem. In addition, given the supply chain disruption, efforts should be focused on restoring transportation infrastructure, including accelerating the rebuilding of key hubs such as the port of Iskenderun. Finally, financial assistance programs tailored to the needs of small businesses should be introduced to increase their resilience to future crises. The proposed measures all aim to mitigate the immediate challenges faced by businesses while promoting long-term sustainability and recovery.

In terms of *environmental impact*, one of the most notable consequences of an earthquake is the creation of a significant amount of debris. Field research was conducted in the Adıyaman and Malatya earthquake regions to investigate the debris removal and disposal process carried out by the state and local authorities. It was found that the amount of debris generated by the demolition of buildings is one of the largest in the world.

In this study, the total amount of waste for Adıyaman and Malatya was calculated to be 2.4 million m3 and 3.5 million m3, respectively, including construction and household waste. The area required to dispose of the disaster waste was calculated to be 1.25 km2 and 1.82 km2 for Adıyaman and Malatya, respectively, equivalent to approximately 32 soccer pitches.

A detailed waste management plan should be in place for the disasters to ensure sustainable debris management. However, in Türkiye, no detailed disaster waste plan is prepared by the central government. A few municipalities prepare their disaster waste management plans. The field research and interviews with local authorities in Adıyaman and Malatya indicate that there are no detailed disaster waste plans for these cities.

Our field visits suggest severe shortcomings in the disposal of disaster waste in Adıyaman and Malatya. In particular, it was found that some of the temporary sites for disaster waste were not selected according to sustainability criteria. To remedy this, the authorities responsible for debris removal are recommended to start sorting and separating the debris at the source or the temporary waste sites, despite the additional time required. This strategy is crucial to prevent the loss of reusable items. The steps outlined for recycling debris emphasize the importance of sound practices. Finally, promoting transparency during this process while committing to sustainability can mitigate future health and environmental issues.

Geographical aspects significantly impact debris management after disasters. Factors like isolation vulnerability, transportation needs, shelter locations, and debris management site selection are crucial. Isolated areas face challenges in accessing resources, requiring specialized transportation. Shelters and containers should be strategically located for easy access and safety. Debris management sites need to be located focusing on minimizing environmental impact. Integrated planning considering these factors ensures more efficient and resilient recovery efforts. By addressing these geographical considerations carefully, disaster response can be more effective in meeting the needs of affected communities and reducing the overall impact of the disaster on both people and the environment.

One of the key findings of this comparative case study is that the effects of the earthquakes in Kahramanmaraş are different in each of the 11 provinces. One prescription for all is not appropriate in this case. They need to be assessed individually. A needs assessment must be carried out for each province. After that, the necessary steps should be taken to heal their economy and environment.

One of the most critical findings from this comparative case study is the variability of earthquake impacts within the 11 provinces after the Kahramanmaraş earthquakes. A one-size-fits-all solution is not applicable in this context; rather, individualized assessments for each province are essential. Comprehensive needs assessments must be carried out for each province, which will then result in targeted measures to improve the respective economic and environmental conditions. Although 11 proviences are in the same region of Turkey, their social, economical and geographical structures differ. Each province requires comprehensive needs assessments to address its specific economic and environmental conditions. Targeted measures should be implemented based on these assessments, such as rebuilding infrastructure in urban areas, supporting industrial revitalization, aiding agricultural recovery, supporting local tourism, and promoting eco-friendly reconstruction. This tailored approach ensures more effective and sustainable recovery efforts, enhancing resilience against future disasters.

The discussions presented highlight the significant potential of recycling as an environmentally sound waste management concept. Benefits include recovery of the economic value of materials, energy recovery, job creation, reduction in landfill use [49], and cost savings [50]. Field research highlights the potential for the reuse of undamaged or partially damaged household items, which are often treated as waste when transported to temporary sites. To address this, debris management authorities are strongly advised to arrange for sorting and segregation of debris either at source or at temporary disposal sites, despite the additional time required. This strategy is crucial to prevent the loss of reusable items. The steps outlined for recycling debris emphasize the importance of sound practices. Finally, promoting transparency during this process while maintaining a commitment to sustainability can mitigate future health and environmental issues.

The management of debris after earthquakes involves interconnected economic and environmental considerations. Recovering valuable materials from debris not only reduces environmental impact but also generates economic value, specifically through the recycling of materials like steel. This process creates job opportunities and promotes economic growth, especially in disaster-affected areas. Simultaneously, proper debris management minimizes environmental damage by reducing landfill use and preventing pollution. An integrated approach that combines economic recovery with environmental sustainability ensures efficient and responsible management of debris, driving both short-term recovery and long-term resilience.

6.1. Limitations

Although the study has attempted to provide a comprehensive assessment of the economic and environmental reconstruction efforts in Adıyaman and Malatya, certain limitations must be acknowledged. First, the qualitative nature of the study, relying mainly on observations and interviews, may introduce biases and subjectivity inherent in such methods. Although measures were taken to increase trustworthiness through triangulation and agreement between authors, the interpretation of the data may still be influenced by the perspectives and backgrounds of the researchers. Second, the study was conducted within a specific time frame, approximately two months after the earthquakes, so only a snapshot of the recovery process could be captured. Longitudinal studies spanning a longer period of time could provide a more comprehensive understanding of the evolving challenges and strategies. Third, the scope of the study was limited to two provinces, Adıyaman and Malatya, and the findings may not be fully transferable to other affected regions that may have unique socio-economic and environmental contexts. Finally, while the research team attempted to include various stakeholders, some perspectives may have been overlooked or underrepresented, which may lead to data gaps or incomplete interpretations.

6.2. Future research

To address the limitations of this study and further advance our understanding of post-disaster recovery processes, we propose several areas for future research. Longitudinal studies should be conducted to track the evolution of recovery processes and the effectiveness of interventions over time. The research should be extended to other affected provinces to better understand regional variations in earthquake impacts and recovery patterns.

A critical area for future investigation is the differential impacts of the earthquakes on women, men, and vulnerable groups, including analysis of gender-specific economic challenges and opportunities in post-disaster contexts. This research can inform more inclusive and equitable recovery strategies.

Evaluating the implementation and outcomes of post-disaster policies, focusing on their effectiveness in addressing the specific challenges identified in Adıyaman and Malatya, will be crucial for refining future policy interventions. Finally, exploring the potential of emerging technologies (e.g., AI, blockchain) in enhancing disaster preparedness, response, and recovery processes presents an exciting frontier for research in this field.

In conclusion, this study underscores post-earthquake recovery's complex and multifaceted nature, highlighting the need for nuanced, context-specific approaches. By integrating economic, environmental, and social considerations and acknowledging the diverse needs of different demographic groups, policymakers and stakeholders can develop more effective, sustainable, and inclusive recovery strategies. The findings and recommendations presented here serve as a foundation for future research and policy development, aiming to enhance the resilience of communities in the face of natural disasters.

CRediT authorship contribution statement

Ali Ersin Dinçer: Writing – original draft, Visualization, Investigation, Data curation, Conceptualization. **N. Nergiz Dincer:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Ayça Tekin-Koru:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Burze Yaşar:** Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Zafer Yılmaz:** Writing – original draft, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2024.104647.

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