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ORIGINAL ARTICLE

Scenario-based optimization of humanitarian supply chain distribution channels for a possible earthquake: a case study in Türkiye

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Abstract

Earthquakes represent a serious risk to societies, economies, and critical infrastructure, highlighting the need for effective disaster preparedness and resilient humanitarian supply chains (HSCs). In seismically active regions such as Erzincan Province, Türkiye, HSC distribution networks must remain functional despite significant disruptions. This study proposes a five-stage mixed-method framework to design and optimize HSC distribution channels for a potential major earthquake in the central district of Erzincan. First, buildings and transportation links were evaluated in terms of seismic suitability to pre-select candidate main distribution centers (MDCs), local distribution points (LDPs), and low-risk routes. Proximity analyses were then conducted using Quantum GIS (QGIS) to identify potential LDPs within a 1–5 km service radius for 69 neighborhoods. These locations were further validated and optimized using Greenfield analyses in anyLogistix under a distance–demand cost minimization criterion. Four distribution channel scenarios were subsequently simulated over a two-month post-earthquake period in line with national and international disaster standards. Finally, the Shortest Path Method was applied to assign primary, secondary, and tertiary LDPs to each neighborhood. The results indicate that supplying nine LDPs (comprising schools and healthcare centers) through four MDCs, including a newly designated sports facility, minimizes transportation cost, travel distance, and lead time, while enabling 63.8% of neighborhoods to access their primary LDP within 3 km. The proposed framework offers a holistic approach by explicitly incorporating seismic compliance into the design of HSC distribution channels in earthquake-prone regions.

Keywords Humanitarian supply chain · Distribution network design · Geographic information system · Post-earthquake logistics · Seismic suitability

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1 Introduction

Disasters, both natural and man-made, profoundly impact societies, economies, and environments, serving as significant points of interest for research, policymaking, and community preparedness (Reid 2013; Zhou and Botzen 2021). Preparing for disasters is crucial as they can reshape communities, influence behaviors, and elicit responses that may either strengthen resilience or exacerbate vulnerabilities (Akhshik and Beglou 2023; Lai et al. 2017).

Türkiye, situated in a geologically active region, has experienced a range of disasters, with earthquakes being particularly notable due to their devastating impact on life and infrastructure (Sonkaya et al. 2019). The country has a long history of significant seismic activities, affecting millions of residents and necessitating a comprehensive understanding of disaster preparedness and management (Sözen and Genç 2025).

Most recently, the earthquakes of February 6, 2023, with magnitudes of 7.8 and 7.6, further underscored the disaster-related challenges faced by Türkiye (Kahraman 2023). Estimates suggest that up to 60,000 lives were lost, and the country suffered severe infrastructure damage as well as a significant economic recession due to these disasters (Yuryeva et al. 2023). These earthquakes are estimated to have caused damages exceeding $103 billion, representing approximately 9% of the country's Gross Domestic Product (GDP) (Ulupınar et al. 2025).

These kinds of disasters offer an opportunity for collective learning and improvement in disaster readiness (Jusko and Spáč 2024). Analyzing past disaster responses might lead to the development of best practices, improved coordination among response agencies, and enhanced community preparedness efforts. This continuous cycle of learning is a critical process for refining mechanisms aimed at future disaster resilience (Ray-Bennett 2009).

In this context, Humanitarian Supply Chain Management (HSCM) serves as a strategic tool for both pre- and post-disaster efforts. It focuses on the systematic delivery of aid to populations affected by crises (Kobayashi et al. 2019), as well as the collaboration among various entities like governments, Non-Governmental Organizations (NGOs), private sector enterprises, and individuals in disaster management processes (Adem et al. 2018; Cozzolino 2021).

Warehousing and distribution, two of the strategic dimensions of HSCM, are pivotal components for the proper storage of aid in suitable locations and delivering relief supplies to the required areas after a disaster (Temur et al. 2019). Selecting appropriate warehouse locations is a key decision in HSCM. Well-located warehouses enhance the responsiveness and efficiency of disaster relief operations by minimizing transportation times and costs (Rohmawati et al. 2021).

Warehouse location selection is an important step in disaster preparedness processes, ensuring accurate planning and the development of adaptable strategies to address the challenges posed by crises (Wan 2023). Temporary and/or permanent warehouse locations designated for active use during disasters enable victims to access their essential needs safely and quickly (Tezcan et al. 2023).

Therefore, effective distribution channels are also necessary to ensure that crisis-affected populations can fully benefit from the resources provided at properly selected warehouse locations (Baldini et al. 2012). The design of these distribution channels is a vital process

as it ensures the timely delivery of food, water, medical supplies, and other essentials for alleviating human suffering (Paz-Orozco et al. 2023).

From this perspective, this study aims to optimize humanitarian supply chain distribution channels to facilitate the provision of essential aid from the earliest moment after a potential earthquake disaster. To achieve this aim, the study area was first determined. Erzincan Province, which has experienced past earthquakes resulting in significant loss of life and property and is classified as a high-risk seismic zone, was selected as the case study location.

2 Study area

Türkiye, located on the Alpine-Himalayan earthquake belt, one of the world's active seismic zones, is affected by the displacement movements of the Eurasian, Arabian, and African plates due to its geographical location (Chang et al. 2024). The country encompasses several significant and active tectonic structures, including the North Anatolian Fault Zone (NAFZ), the East Anatolian Fault Zone (EAFZ), the Aegean Extensional Zone, and the Bitlis-Zagros Thrust Zone (Bayrak 2022). The Erzincan Plain, located on the NAFZ, is a tectonic plain formed by the movements of this fault (Akar et al. 2024).

Erzincan is located in the northwestern part of the Eastern Anatolia Region between 39° 02' 40.05" north latitude and 38° 16' 40.45" east longitude. The city center, which covers an area of 11,903 km^2, is situated at an elevation of 1185 m above sea level (Karadeniz and Altınbilek 2018). According to data from the Address-Based Population Registration System of the Turkish Statistical Institute (TUIK), the province's total population as of 2024 is 241,239 (TUIK 2025). Additionally, 139,594 individuals reside in the central district of Erzincan in 2024, according to the updated data obtained from Erzincan Municipality.

The study area covers 294 km^2 and includes 69 neighborhoods within the designated region, all connected to the central district of Erzincan Province (Fig. 1). Among the neighborhoods, the least populated is Davarlı with 117 inhabitants, while the most populated is Mimar Sinan with 10,686 inhabitants. In addition, there are 22 healthcare centers (such as hospitals, medical centers, etc.) and 104 schools (such as schools, educational institutions, etc.) within the study area. The main distribution centers of the study area we selected as the Disaster and Emergency Management Presidency (AFAD) main building, the AFAD warehouse area, and the Turkish Red Crescent warehouse center.

Although the Erzincan Plain, where the city of Erzincan is located, generally lies on the North Anatolian Fault (NAF), the Ovacık Fault, an extension of the East Anatolian Fault (EAF), also extend into the Erzincan Plain from the southeast (Altunbilek 1997; Tüysüz 1993). In this context, it can be said that the Erzincan Plain lies at one of the intersections of the NAF and EAF (Tarhan 2007). Both these faults lies, along with surrounding plate movements, make Erzincan highly susceptible for frequent and large earthquakes (Orhan 2019).

As Erzincan Province and its surroundings are located within first-degree earthquake zones, numerous earthquakes have occurred throughout both historical and instrumental periods (Özşahin and Eroğlu 2019). The most significant of these was the Erzincan Earthquake of December 27, 1939 (Mw = 7.9), which ranks among the largest earthquakes ever recorded in Türkiye (Eray Biber 2019).

The Great Erzincan Earthquake of December 27, 1939 (Mw = 7.9) is considered the largest earthquake to occur in Anatolia since the 19th century in terms of magnitude (Koçbulut

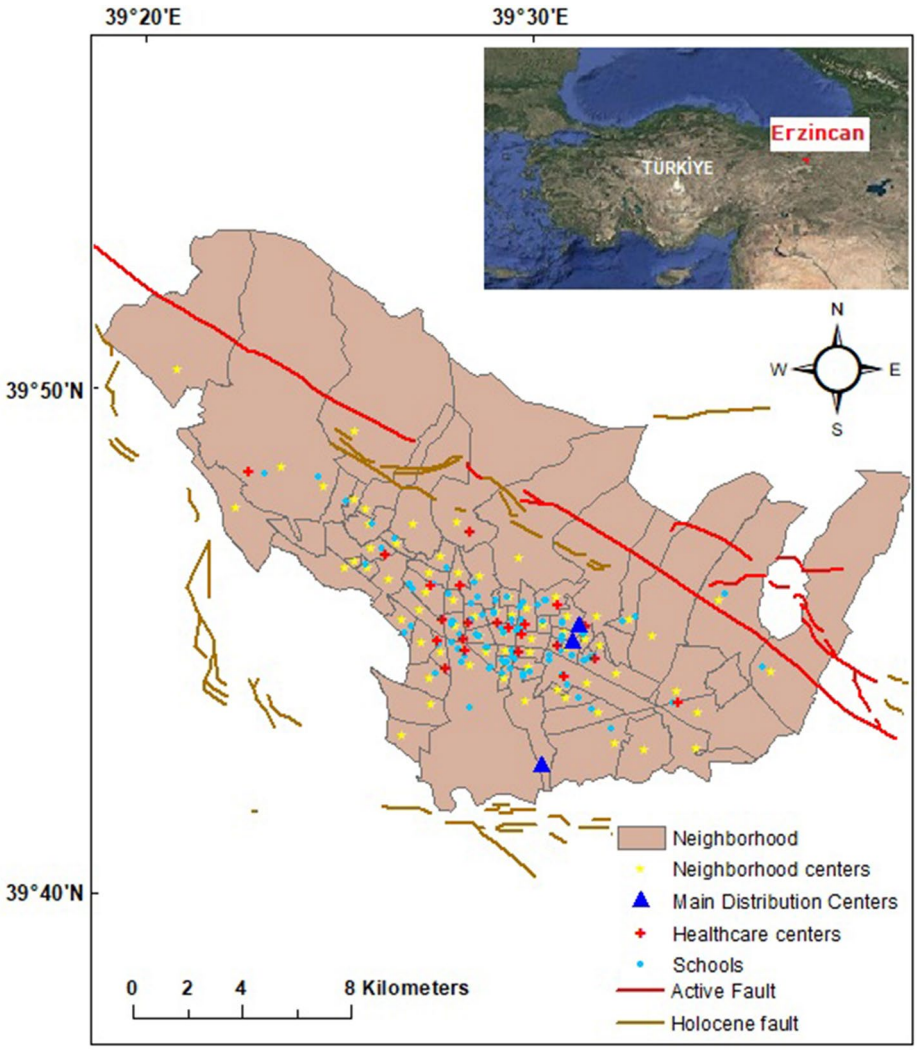


Fig. 1 Study area

2023; Türkkan Tunalı 2023). In terms of loss of life, it ranks as the second deadliest earthquake after the February 6, 2023, Kahramanmaraş Earthquake. The 1939 earthquake was felt throughout the country, particularly in Erzincan and its surrounding area, causing damage in approximately 20% of the country. According to official records, 32,968 people lost their lives, approximately 100,000 were injured, and 116,720 buildings collapsed (Kurtuluş 1993; Özşahin and Eroğlu 2019). Another significant earthquake struck Erzincan on March 13, 1992 (Mw = 6.8), exactly 53 years after the 1939 event. This earthquake resulted in 653 deaths, and 8057 buildings were damaged or destroyed (Şenol 2020).

The occurrence of large earthquakes in Erzincan and its surrounding areas both in historical and instrumental periods indicates that disasters of similar magnitude are likely to happen in the future. This reality underscores the urgent need to implement various pre-

cautionary measures in Erzincan (Akar et al. 2024). An effective HSCM plan should be implemented in the province to minimize the loss of life in the event of a future earthquake and to ensure the timely distribution of medical supplies and food.

To enable accurate planning, the approaches and roles of disaster-related stakeholders must be considered. One of the key actors is AFAD, which coordinates the emergency management and humanitarian logistics operations in the event of an earthquake in Erzincan. Immediately after such an earthquake, AFAD determines the incident level based on evaluations conducted with the information received from the Erzincan Province AFAD Center (AFAD 2022). The level of AFAD's response according to the disaster scale of a possible earthquake in Erzincan Province is presented in Table 1.

According to the classification presented in Table 1, the AFAD Presidency evaluates the earthquake and conducts disaster management processes by ensuring coordination with relevant institutions at both national and local levels. When national capacity proves insufficient, international support becomes necessary. However, current plans do not include temporary or permanent local distribution points where disaster victims in the central region of Erzincan province can reach to obtain aid (Fig. 1).

Based on this inadequacy, this present study investigates how humanitarian aid supply chain distribution channels should be structured and from which locations disaster victims could optimally obtain aid in the event of a potential earthquake in the central district of Erzincan Province. Thus, following specific research questions were determined:

1. *Considering the seismic risk of Erzincan province*, *which buildings and roads could be used for the humanitarian supply chain distribution channels in the event of a possible earthquake?*
2. *In the event of a possible earthquake*, *where should new local distribution points be located based on neighborhood demand in order to ensure the effective distribution of aid from existing main distribution centers?*
3. *In the event of a possible earthquake*, *is it feasible to use healthcare centers and schools as local distribution points instead of establishing new ones*, *for distributing aid from the existing main distribution centers?*
4. *In the event of a possible earthquake*, *is there a need for new main distribution center(s) in terms of distributing all aid?*
5. *What are the second and third alternative local distribution points available for people to access aid?*

To address these research questions, a comprehensive literature review was conducted, and national and international disaster standards were examined. The information obtained from these standards formed the backbone of the study's methodology. Previous studies and their methods and findings were also evaluated. However, no prior studies were identified that

Table 1 AFAD's response level according to the scale of earthquake disaster in Erzincan

Province	Disaster Type	Disaster Scale	Response Status
Erzincan	Earthquake	Level 1	Local resources are sufficient.
		Level 2	Reinforcement from supporting provinces is needed.
		Level 3	National support is needed.
		Level 4	International support is needed.

Source: (AFAD, 2022)

considered the seismic risk of Erzincan Province while aiming to optimize humanitarian supply chain distribution channels accordingly.

A five-stage, generalizable, novel, and mixed-methods approach was employed to evaluate scenarios within the designated time periods. In the initial stage, the process of selecting appropriate center/warehouse locations and transportation routes was undertaken, taking into account distances to fault lines, the seismic suitability of transportation networks, and the resilience status of buildings, in accordance with relevant standards for humanitarian supply chain management and disaster management. Subsequently, proximity analyses were performed for settlements within the central district of Erzincan Province to identify potential local distribution points employing QGIS, a Geographic Information System software. By assessing the varying distances of potential local distribution points from residential areas, alternative locations where affected individuals could seek assistance after a disaster were identified.

The third stage involved conducting Greenfield Analyses (GFAs) using anyLogistix software to validate the information obtained from the proximity analyses. This analysis facilitated the identification and listing of feasible locations that could serve as local distribution points. Additionally, flow cost calculations were performed to evaluate both the volume of aid required by disaster victims and the distances they would need to travel to access aid. In the fourth stage, mathematical models were developed to assess the performance of the distribution channels outlined in the study's scenarios. Simulation experiments were carried out using anyLogistix, adhering to both national and international disaster standards. Real-time measurements were conducted, and the outcomes of the simulation experiments based on actual routes for the scenarios were reported and compared to determine optimal distribution channels. The final stage involved the identification of secondary and tertiary alternative local distribution points that individuals could utilize in the event of damage to local distribution points and/or access routes following a potential earthquake, employing the shortest path methodology.

3 Literature review

3.1 Humanitarian logistics and supply chain management

Humanitarian Logistics (HL) plays a critical role in responding to crises such as natural disasters, conflicts, pandemics, and other emergencies. It serves as a cornerstone for the efficient execution of disaster relief operations (Salam and Khan 2020). The complexity of these responses necessitates well-structured logistical frameworks that can rapidly mobilize resources, ensure coordination among various humanitarian actors, and address the immediate needs of affected populations (Dwivedi et al. 2018).

Operations such as planning, procurement, storage, transportation, distribution, and coordination of aid, including food, water, medical supplies, and shelter, fall within the scope of humanitarian logistics (Kovács and Spens 2009). HL also encompasses search and rescue operations and provision of emergency communications (Dubey et al. 2019).

Unlike traditional logistics activities, the primary objective of HL activities is to meet the needs of disaster victims as quickly and efficiently as possible, often under chaotic conditions (Chandes and Paché 2010). Because time is considered a critical constraint for activi-

ties carried out after a disaster, and the needs of disaster victims can change dynamically or be uncertain (Moshtari et al. 2021).

HL is characterized by instability in the types, locations, timing, and scale of the needs, the urgency of operations to be executed within short timeframes, and the requirement for timely delivery of aid (Negi and Negi 2021). Therefore, disaster-related operations should be understood and managed within the framework of a supply or relief chain system (Tofighi et al. 2016).

As a prominent concept in this context, HSCM involves the management of activities both before and after a disaster (Negi 2022). It encompasses the supply chain management processes across the four stages of the disaster management life cycle: Mitigation, Preparedness, Response, and Reconstruction (Van Wassenhove 2006).

Mitigation is the first phase and refers to efforts to reduce the probability and impact of disasters before they occur (Das and Sharma 2016). This includes actions such as enforcing building codes, developing land-use plans that avoid hazardous areas, and promoting public awareness campaigns to educate communities about disaster risk (Cicek and Kantarci 2023; Madanian et al. 2020). For instance, strategies such as infrastructure improvements or environmental management practices can significantly reduce vulnerabilities to future disasters (Holguín-Veras et al. 2012; Madanian et al. 2020).

In the Preparedness phase, which also takes place before a disaster, focus on making the necessary arrangements to ensure the successful execution of response and recovery operations (Das and Sharma 2016; Erbeyoğlu and Bilge 2020). The goal is to minimize the negative effects in the area affected by the disaster (Fontainha et al. 2022; Pillitteri et al. 2021). At this stage, a comprehensive response plan is developed, detailing how physical distribution and emergency communications will be handled, how infrastructure assets will be utilized, and the responsibilities of individuals, institutions, and organizations managing the disaster (Kumar and Havey 2013; Kunz et al. 2014).

The Preparedness phase is followed by the Response phase, which includes the operations carried out immediately following a disaster occurs (Altay et al. 2018; Mohamed Shaluf 2008). This stage involves actions such as search and rescue, collection and evaluation of disaster-related data, and ensuring critical communications among stakeholders involved in the response plan (Quarshie and Leuschner 2020; Song et al. 2024).

The recovery phase encompasses the process of returning to normalcy or an improved state following a the disaster (Bueno Gómez and Beato Bergua 2024). This phase not only involves repairing and rebuilding infrastructure, but also includes efforts to restore community functions, provide support for mental health, and enhance resilience against future disasters (Abedin et al. 2014). The recovery phase can be complex and prolonged, requiring effective coordination among various stakeholders, including governmental and non-governmental organizations (Aznar-Crespo et al. 2021; Le Cozannet et al. 2020).

In HSCM, the Mitigation, Preparedness, Response, and Recovery phases follow a sequential and cyclical structure. After the Recovery phase, the cycle returns to the Mitigation stage, which involves implementing actions informed by lessons learned from previous disasters and raising awareness and reducing potential future damages (Pathak and Ahmad 2018).

Understanding these phases provides a framework for efficient humanitarian logistics operations. In order to do that, effective collaboration and coordination among disaster-related actors should be ensured (Heaslip et al. 2019; Zahari et al. 2025), needs should be

determined in accordance with the size and demographic structure of the affected population (Agarwal et al. 2022), logistics infrastructure and capabilities for the products needed in various locations should be assessed (Mejia-Argueta et al. 2018; Xu et al. 2021), and realistic distribution plans (determining optimal distribution center locations, planning distribution routes in accordance with the current transportation infrastructure) should be made in order to provide rapid response and adapt to changing situations after the disaster (Gavidia 2017; Lu et al. 2019).

3.2 Previous studies

The design of distribution channels in HSCM, which is the subject of this research, has been studied by many researchers. In the literature review, it is observed that mathematical modeling and simulation methods are frequently used in these studies. Research conducted on the determination of humanitarian supply chain distribution channels and optimal warehouse locations in the event of a potential natural disaster have been reviewed and are summarized as follows.

In their study, Peker et al. (2016) developed a two-stage model to determine the most suitable location for a distribution center within the scope of disaster logistics for Erzincan Province. In the first stage of the model, criteria that could be used for distribution center site selection were weighted using Analytic Hierarchy Process (AHP) method. In the second stage, the most appropriate location for the distribution center was determined using VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR) method.

Similarly, Boltürk et al. (2016) proposed a novel hesitant fuzzy AHP method for warehouse location selection in the context of humanitarian logistics. They conducted a case study on warehouse site selection for a Turkish humanitarian aid organization. Like this study, Ofluoglu et al. (2017) identified the most suitable warehouse location to be used in disaster logistics in Trabzon. In their study, the weights of the criteria were calculated using the Entropy Method, and the alternative warehouse locations were determined using multi-criteria decision-making techniques, including Simple Average Weight (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and VIKOR.

Temur et al. (2019) designed a logistics network aimed at ensuring that earthquake survivors can access basic humanitarian needs in the shortest possible time. In this study, they used the AHP method to calculate humanitarian aid and need scores for neighborhoods within the study area. They then applied their proposed model to the problem of establishing humanitarian aid distribution centers in the post-earthquake period in the Ümraniye district of Istanbul and restructured the model for different earthquake scenarios.

Ergün et al. (2020) conducted a site selection for an ideal disaster warehouse to be used in the event of a potential disaster in Giresun Province. The weight of criteria was performed using the AHP method, and then the ideal disaster warehouse location was selected using AHS-based MAUT (Multi-Attribute Utility Theory) and SAW methods. Tezcan et al. (2023) identified temporary warehouse locations for Kırıkkale Province to meet the food needs of people after a disaster by using AHP, fuzzy AHP, TOPSIS, Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), VIKOR, and Integer Programming methods.

Correspondingly, Erden et al. (2024) analyzed the site selection criteria for humanitarian logistics distribution centers located in Sakarya Province, Türkiye, by integrating multi-

criteria decision-making methods to determine optimal warehouse locations in disaster logistics. They used the Best-Worst Method (BWM) to identify the criteria and the Additive Ratio Assessment (ARAS) method to evaluate potential distribution center locations based on the established criteria.

Bediroğlu and Yıldırım (2020) conducted a site selection analysis for the establishment of a logistics center within the administrative boundaries of Ordu Province by combining GIS and Multi-Criteria Decision Making (MCDM) methods. Feng et al. (2023) proposed a new approach based on MCDM and GIS to solve the site selection problem for emergency logistics centers (ELCs). Equivalently, Kaya Zelzele and Ergün (2025) identified safe logistics warehouse locations within the scope of disaster logistics in Kilis Province using a GIS-based analytical approach.

On the other hand, Loree and Aros-Vera (2018) developed a mathematical model to address the problem of determining points of distribution (PODs) to be used in Post-Disaster Humanitarian Logistics (PD-HL) and allocating inventory for distribution to nearby areas. Shakibaei et al. (2024) proposed a methodology to improve post-disaster humanitarian logistics using machine learning and multi-criteria decision-making techniques.

Paz-Orozco et al. (2023), in their study combining a deterministic mathematical model with a simulation model, identified the optimal locations for humanitarian distribution centers and points in Popayan, Colombia during the deterministic modeling phase. Using the simulation model, they evaluated scenarios based on real earthquakes in Colombia and Latin America to investigate the logistics system's capacity to respond to different disaster conditions and magnitudes.

Yalcindag et al. (2023) developed a model to determine the locations of warehouses to deliver relief supplies to points of need as quickly as possible in the event of a major earthquake in Istanbul. Using the developed model, warehouse locations were determined with The General Algebraic Modeling System (GAMS), and based on the results, the most suitable scenario was selected and mapped.

Lastly, Desticioğlu Taşdemir (2024) examined the site selection problem for disaster logistics warehouses to be established in the districts outside the central area of Ankara. In the study, cluster covering along with p-median and capacitated p-median models were used to determine the locations of the warehouses. In the study's last stage, accuracy analysis was used to assess the models' efficacy.

In sum, the effective determination of HSC distribution center locations necessitates a meticulous analysis of both qualitative and quantitative factors, employing a diversified methodological approach that includes traditional locational analysis, modern optimization algorithms, and sustainability metrics. Only through such comprehensive evaluations make it possible to achieve the high operational efficiencies and service levels required in disaster management. Therefore, fostering adaptability and leveraging advanced analytical models are paramount in enabling robust distribution channels that adapt the complexities of disaster scenarios.

Generally, some studies appear to neglect seismic vulnerability. Indeed, critical components of HSC distribution channels, including buildings and roads, are susceptible to damage following an earthquake (Pitilakis et al. 2016). Consequently, it is necessary to assess HSC distribution channel scenarios with consideration of seismic vulnerability (Román-de la Sancha and Silva 2020).

Pochan et al. (2020) state that comprehensive seismic risk analyses should be conducted in the region(s) where HSC planning will be carried out. Based on the results of these analyses, it is determined which infrastructure elements may be damaged in the event of a possible earthquake (Zokaee et al. 2016). Therefore, to ensure the effective distribution of post-disaster aid, it is necessary to evaluate the seismic resilience of transportation routes and conduct risk analyses of usable buildings (Adafer et al. 2024; Malekloo et al. 2022).

In the field of earthquake engineering, potential sites and transportation pathways are selected based on statistical data, including the building importance coefficient and fault avoidance zones, as well as damage scenarios that may be induced by earthquakes (Güllü and Karameşe 2021; Nurlu 2017). Thus, this kind of integrated design allows for the deterministic evaluation of earthquake scenarios (Agarwal et al. 2022).

In summary, previous research on humanitarian supply chain distribution network design predominantly concentrates on multi-criteria decision-making methodologies for warehouse site selection, mathematical optimization models aimed at minimizing costs or maximizing coverage under static demand assumptions, or GIS-based analyses that offer spatial insights but lack robustness in dynamic system contexts performance. The consideration of planning HSC distribution channels through the utilization of empirical data and scenarios, while accounting for seismic resilience and/or vulnerability, is an uncommon practice.

Therefore, this study employed a five-step, generalizable, novel, and mixed-methodology approach that can be applied in future research. Firstly, the process of determining appropriate center/warehouse locations and transportation routes was conducted based on distance from fault lines, seismic suitability of transportation networks, and the resilience status of buildings in line with related standards to HSCM and disaster management. Secondly, proximity analyses were performed to identify local distribution points where individuals can access aid, based on the identified candidate buildings and routes.

Thirdly, Greenfield analyses were executed to select which demand points were served from the most suitable local distribution point options. In the fourth stage, simulations were carried out utilizing scenarios involving the chosen distribution channel alternatives to determine the optimal scenario. The final stage involved the identification of secondary and tertiary alternative local distribution points that individuals could utilize in the event of damage to local distribution points and/or access routes following a potential earthquake, employing the shortest path methodology.

This combination facilitated the evaluation of structural and roadway damage in the event of a potential earthquake, the assessment of spatial accessibility within neighborhood contexts, the optimization of facility placements considering access distances, the execution of simulations accounting for time-dependent demand and operational limitations, and the identification of alternative aid distribution points. Prior to engaging in all methodological steps, an assessment of relevant national and international standards pertaining to HSCM and disaster management, which must be considered, was conducted under the following section.

3.3 Relevant standards

In order to carry out efficient HSCM operations, effective collaboration and coordination among disaster-related stakeholders should be ensured (Heaslip et al. 2019; Zahari et al. 2025), needs should be determined in accordance with the size and demographic structure of

the affected population (Agarwal et al. 2022), logistics infrastructure and capabilities for the products needed in various locations should be assessed (Mejia-Argueta et al. 2018; Xu et al. 2021), and realistic distribution plans (determining optimal distribution center locations, planning distribution routes in accordance with the current transportation infrastructure) should be made in order to enable rapid response and adaptability to changing post-disaster conditions (Gavidia 2017; Lu et al. 2019).

AFAD's disaster response plan is implemented in line with international standards for disaster management. In this context, several standards must be taken into consideration concerning humanitarian assistance and emergency responses following a potential earthquake. The international standards are presented in Table 2.

When evaluating the responses in Table 2, the first step is to ensure the necessary coordination to effectively carry out activities in the post-disaster period. Emergency communication channels (Emergency Coordination Centers, Radios, Satellite Phones) should be utilized, and disruptions to the communication infrastructure must be prevented. Next, the earthquake-affected areas must be identified. This requires damage mapping, along with an assessment of priorities and urgent needs.

Table 2 Disaster response types and timeframes in international standards

Emergency Level	Response Type	Response Content	Suggested Timeframe	Source
High	Communication and Coordination	Effective Emergency Coordination Centers, Effective Communication via Radios and Satellite Phones	0–24 h	(ISO 2018; UNDAC 2024)
High	Data Collection and Evaluation	Damage Mapping, Determination of Urgencies, Rapid Needs Assessment	0–48 h	(Sphere 2018; UNDAC 2024)
High	Search and Rescue	Conducting Search and Rescue Operations	24–48 h	(INSARAG 2020a, 2020b, 2020c, 2020d, 2020e; UNDAC 2024)
High	Logistics Operations	Storage, Coordination, Fleet Management, Access Mapping, Route Planning	24–48 h	(INSARAG 2020e; ISO 2017; Sphere 2018)
High	Medical Assistance	Trauma Care Kits, Emergency Surgical Vehicles, Mobile Clinics, Pharmaceutical Support, Medical Care Services	24–72 h	(UNDAC 2024; WHO 2021)
High	Water Supply	Clean Water, Purification Tablets, Storage Containers	Within 72 h	(Sphere 2018; UNHCR 2017; WFP 2002)
Medium	Food Assistance	Baby Foods, Ready-to-Eat Meals, Dry Foods	72–120 h	(INSARAG 2020a; Sphere 2018; WFP 2002)
Medium	Shelter	Emergency Tents, Tarpaulins, Sleeping Mats	72–120 h	(Sphere 2018; UNDAC 2024)
Medium	Distribution of Other Needs	Hygiene Kits, Cooking Sets, Blankets, Clothing	72–120 h	(Desbareau et al. 2009; Sphere 2018)
Medium	Psychosocial Support	Mobile Mental Health Teams, Child-Friendly Spaces, Psychological Support Units	72–168 h	(UNDAC 2024; WHO 2021)
Low	Transition to Recovery	Education and Livelihood Improvements, Semi-Permanent Shelters	Within 2 weeks	(Sphere 2018; WHO 2021)
Low	Transition to Re-Planning	New Improvements, Reconstruction Plans, Repairs of Local Systems	Within 4 weeks	(UNDAC 2024; WHO 2021)

Concurrently with these responses, search and rescue operations, medical aid delivery, and logistics activities must be planned. The efficient execution of all subsequent aid processes, water supply, food distribution, shelter provision, basic needs delivery, and psychosocial support depend on the accuracy, timeliness, and feasibility of the logistics operation plans.

The continuous and effective execution of HSCM activities before transitioning to the post-earthquake recovery and replanning phase is of strategic importance. Therefore, primary attention should be directed toward critical factors that determine the effectiveness of HSCM operations.

Along with these national and international standards and guidelines, we reviewed previous research on the seismicity in the central district of Erzincan Province. The assessment of seismic suitability for this area was provided in Sect. 4.3.

4 Methodology

This study, which aimed to determine the shape of humanitarian aid supply chain distribution channels following a potential earthquake in the central district of Erzincan, followed the methodology outlined in Fig. 2.

As shown in Fig. 2, the study's approach consisted of several stages. First, previous studies on the subject, HSCM literature, and national and international standards were examined. Based on this information, a multi-stage methodological approach was used to determine the HSC distribution channels to be used in the event of a possible earthquake in the central district of Erzincan Province.

The seismic suitability of the study area was evaluated to identify the roads and buildings to be used in these distribution channels. Based on information from previous studies, distance from fault lines, the seismic suitability of transportation networks, and the resilience status of buildings were identified. Most suitable transportation elements (roads and buildings) that were at low risk of damage during or after an earthquake were determined based on these evaluations.

Proximity analyses were conducted to determine local distribution points where individuals could access assistance, based on the candidate buildings and routes. Then, Greenfield analyses were performed to determine which demand points could be served by the most suitable local distribution point options. Subsequently, simulations were conducted utilizing

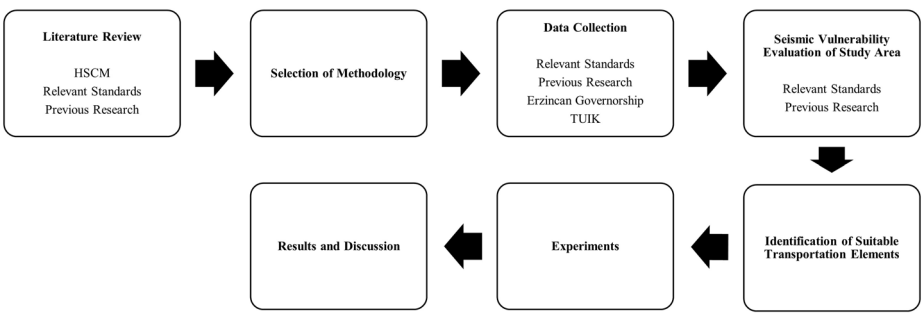


Fig. 2 Research methodology diagram

scenarios that incorporated the selected distribution channel alternatives to determine the most appropriate scenario. Finally, in the event of damage to local distribution points and/or access routes following a potential earthquake, secondary and tertiary alternative local distribution points accessible to individuals were determined employing the shortest path method. These experiments were followed by an evaluation and discussion of the findings.

In line with this planning, the time periods and aid emphasized in relevant national and international standards were identified and were incorporated into the simulation-based optimization of mathematical models. Additionally, a specific timeframe was defined for a potential earthquake scenario, and the other time periods were adjusted accordingly. The specified timeframes and aid types were presented in Table 3.

As shown in Table 3, assuming a one-minute earthquake occurred at 11:59 PM on July 8, 2025, all preparations had to be completed before the earthquake, and the necessary resources had to be stored in locations close to the population (Jusko and Spáč 2024). Therefore, we defined a period before the earthquake, called the Sourcing Time Period, as the timeframe for acquiring these resources. Certainly, due to the absence of definitive information regarding the timing of the earthquake or the feasibility of completing the necessary preparations within that period, we selected this timeframe as a representative. We noted that we considered this period only for the necessary calculations. Also, we emphasized that real-world sourcing plans must be implemented immediately, without waiting for an earthquake.

However, international standards provide clear guidance on post-earthquake procedures. The first 72 h (Emergency Aid Time) after an earthquake are considered critical for meeting the emergency nutrition and water needs of disaster victims (UNHCR 2017). Emergency Food Aid (EFA) kits, which should be provided per person, are offered to disaster victims during this period (Oral et al. 2017).

The period between 3 and 7 days after an earthquake is considered the First Aid Time Period. Family Food Kits (FFK), Family Hygiene Kits (FHK), and Non-Food Items (NFI) kits are provided to disaster victims per household during this period. NFIs contain items such as shelter, bedding, clothing, heating and lighting equipment, FFKs contain family food aid, and FHKs contain hygiene materials (Peyrassol et al. 2009; UNHCR 2017; WFP 2002). Furthermore, due to the disruption of daily life, it is recommended that FFKs' distribution to families should continue during Recovery Time Period (WFP 2002).

In this research, which aimed to determine how the HSC distribution channels should be structured following a potential earthquake affecting the central district of Erzincan Province, we evaluated four scenarios to ensure accurate calculations for the considered periods. These scenarios were shown in Fig. 3.

The four scenarios presented in Fig. 3 summarized potential strategies for post-earthquake aid distribution. We used these scenarios to answer research questions. Scenario 1 involved delivering resources from existing MDCs to LDPs such as schools and health-

Table 3 Aid types and time periods of the study

Aid Type	Period	Start Time	End Time	Duration
All Aid	Sourcing Time Period	6.11.2025–00:00:00	6.18.2025–00:00:00	1 week
-	Earthquake	7.8.2025–23:59:00	7.9.2025–00:00:00	1 min
EFA	Emergency Aid Time Period	7.9.2025–00:00:00	7.12.2025–00:00:00	3 days
FFK, FHK, NFI	First Aid Time Period	7.12.2025–00:00:00	7.16.2025–00:00:00	4 days
FFK	Recovery Time Period	7.16.2025–00:00:00	9.7.2025–00:00:00	53 days

care centers. Since this scenario utilized existing infrastructure, no additional investment in buildings or facilities was required. However, the inclusion of new MDCs or the establishment of additional LDPs would incur construction and operational costs.

In contrast, Scenario 2 was based on using new LDPs rather than existing schools and healthcare centers. Consequently, this scenario included investment costs for setting up these new facilities. Similarly, Scenario 3 considered adding a new MDC location while continuing to use existing schools and healthcare centers as LDPs. Therefore, this scenario included costs associated with establishing a new MDC but not with new LDPs.

Finally, Scenario 4 incorporated both the addition of a new MDC and the use of new LDPs. It represented the most comprehensive investment scenario among the four. Decision-makers could evaluate the outcomes derived from these scenarios and use them to optimize HSC operations in response to a potential earthquake.

4.1 Selection of methodology

Based on information obtained from the literature review, a mixed-methods approach was employed to evaluate the study's scenarios. The first step involved accessing data relevant to the research problem and determining suitable center/storage locations and transportation routes, based on distance from fault lines, the seismic suitability of transportation networks, and the structural integrity of buildings, in accordance with HSCM and disaster management standards.

In the second step, proximity analyses were conducted based on the residential locations of people living in the central district of Erzincan Province to identify potential alternative LDP locations. In HSCM, the application of buffering techniques in proximity analysis enables organizations to evaluate how effectively potential distribution centers can serve affected populations within defined distances, thereby facilitating efficient operations during emergencies (Abd Majid et al. 2019; Das et al. 2023).

We utilized the QGIS software, a multi-platform-supported, free, and open-source GIS application, to perform proximity analyses. Buffering, a commonly applied technique in proximity analysis, involves creating a zone at a specified distance around polygon, line, or

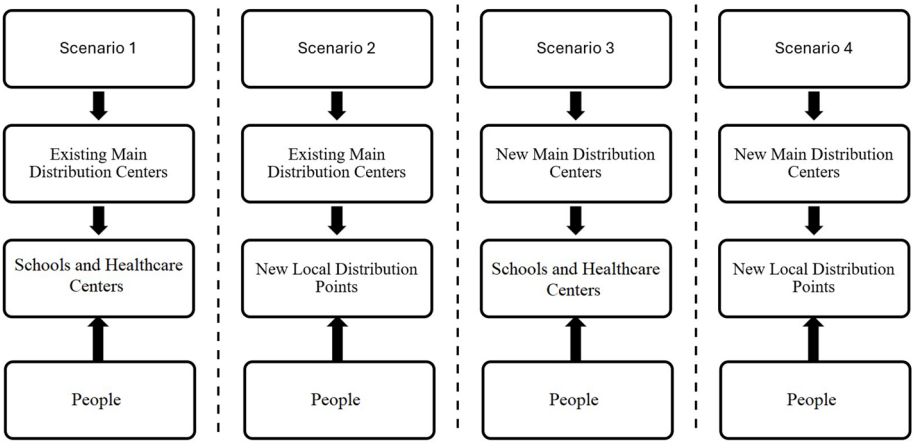


Fig. 3 Scenarios of the study

point features (Ahmed et al. 2018). To ensure that disaster victims could access aid easily after the earthquake, LDPs were required to be located within a reasonable walking distance from their residences. This distance was limited to 5 km, allowing affected individuals to reach aid points without excessive difficulty (Nagamine et al. 2016; WFP 2002; Yang et al. 2020). Accordingly, buffer zones of 1, 2, 3, 4, and 5 km were generated to identify potential LDP locations.

In the third step, we employed the free Personal Learning Edition (version 3.3.2) of anyLogistix software, which has been increasingly popular for conducting GFAs. This method was one of the methods frequently used in the initial stages of supply chain network design (Adhitya et al. 2022). GFA helped determine the optimal number and location of facilities within supply chain distribution channels to ensure the most cost-effective delivery of resources to demand points (Ivanov 2024). Thus, the results from the proximity analyses were compared with the GFAs' outputs to identify the most optimal LDP locations.

In the fourth step, we simulated the distribution channels using anyLogistix software, considering the identified LDPs. Simulation was necessary for such problems due to the involvement of time parameters (Ivanov et al. 2010). These simulation methods were useful for understanding operational dynamics and providing critical data at decision-making points in various processes (Balkar and İnce 2025). Therefore, a mathematical model of the research problem was developed. This channel optimization model, along with the generated simulation models, was implemented in anyLogistix software. Subsequently, optimization experiments were conducted.

Finally, we used QGIS to identify routes disaster victims could take to reach primary, secondary, and tertiary LDPs, selecting paths with minimal post-earthquake damage risk. The Shortest Path Method (SPM) tool was used to pinpoint alternative LDPs (secondary and tertiary), allowing individuals to access them in the event of damage to local distribution points or access routes after a potential earthquake.

Before performing all specified analyses, trial runs were conducted in the relevant programs using sample data for validation. After the preliminary tests were completed, log files were recorded, original data were checked, and each analysis was carried out in detail and carefully.

4.2 Dataset of case-study

To obtain the relevant data for the study, an initial field visit was conducted in the central district of Erzincan Province. During this visit, the Erzincan Municipality provided valuable support in identifying key information. In addition, a previously compiled database (Akar et al. 2024) was utilized to assess the geographical characteristics of the region. The data used in this study, along with their sources, were presented in Table 4.

The data in Table 4 were stored in a database and used in the later stages of the study. As of the end of 2024, there were 69 neighborhoods in the central district of Erzincan Province. A total of 139,594 people resided in the study area, as shown in Appendix Table 5. Based on the average household size, the average number of families per neighborhood was calculated. In total, 52,174 families resided in the region.

MDCs, healthcare centers, and schools considered in the analyses were coded as in Appendix Table 5 to enhance the efficiency of calculations. All geographic data were imported into QGIS software for proximity analyses. These analyses were conducted by

considering the locations and population densities of the settlements. Additional data were imported into anyLogistix for GFAs and simulations experiments. Detailed results were provided in the corresponding analysis sections.

4.3 An assessment of the suitability of distribution centers and transportation routes to seismic activities

This research aims to identify the humanitarian supply chain distribution channels within the central district of Erzincan province, an area characterized by high seismic activity. In line with this goal, we examined the seismic suitability of transportation routes, main, and local distribution buildings.

Building damage and casualties following an earthquake are most severe in close proximity to the relevant active fault (Xu et al. 2011). Maintaining a certain distance from active faults is the most effective method to reduce or prevent the destruction caused by such disasters. Studies on earthquakes indicate that the vast majority of deaths and building collapses occur within a narrow zone along the faults, and the adverse effects of the disaster gradually decrease as the distance from the fault line increases (He et al. 2022).

To reduce the margin of error in the identification and mapping of faults and to mitigate the impact of the expected surface fault hazard on engineering structures (roads, bridges, viaducts, intersections, tunnels, etc.), a buffer zone is established on both sides of the surface fault hazard area (Nurlu 2017). In strike-slip faults where earthquakes occur, lateral movements or displacements are observed, whereas normal faults exhibit vertical displacements. In their study, Gürboğa et al. (2016) suggested that the buffer zones to be established for strike-slip faults should be at least 40 m (20+20) and at most 100 m (30+20), while for normal faults, the buffer zones could be 55 m (40+15).

Another parameter that increases seismic design forces based on the functional importance of structures in earthquake engineering is the building importance factor. The primary purpose of this parameter is to ensure that certain buildings remain operational even after earthquakes (Güllü and Karameşe 2021). Studies have shown that increasing the building importance factor values defined in regulations contributes to the improvement of the seismic performance of structures (Güllü and Karameşe 2021; Sukumar et al. 2017; Vielma et al. 2025).

According to the earthquake building regulations prepared by the Republic of Türkiye's Ministry of Environment and Urbanism (RTMEU), healthcare centers and schools are in the group with the highest building importance coefficient ($I = 1.5$) (RTMEU 2018). Furthermore, according to another study (Başgöze and Güncü 2023) conducted in the central

Table 4 Dataset of the research

Data Type	Data Content	Source
Geographical Data	Vector Data of Erzincan Province Central District Map (Geographic Locations of Neighborhoods, Buildings, Healthcare Centers, Schools, MDCs, etc.)	(Akar et al. 2024; Emre et al. 2012)
Demographic Data	Population and Geographic Locations of Neighborhoods, Demographic Characteristics of Population, Data of Households, etc.	(Erzincan Municipality 2025; TUIK 2025)
Logistical Data	Types and Dimensions of Aid, Capacities of Transportation Vehicles, Characteristics of Facilities, Duration of Distribution and Other Operations, etc.	(AFAD 2022; Oral et al. 2017; WFP 2002)

district of Erzincan Province, buildings in this group are considered to be at low risk of damage in a possible earthquake. Therefore, schools and healthcare centers with high building importance coefficients were considered as candidates for local distribution points in this study.

Moreover, transportation systems need to function effectively so that people affected by the earthquake can reach local distribution points and obtain their needs. To prevent obstacles caused by road damage after an earthquake, it is necessary to determine the risk of road closures (Nurlu 2017). The probability of road closures is 98% for roads with a width of 2 to 6 m, 11% for roads with a width of 7 to 15 m, and 0.3% for roads with a width of 16 m or more, according to a previous study (JICA and IMM 2002). In line with these statistics, we selected roads within the HSC distribution channels in the central district of Erzincan province that are at least 10 m wide.

The development of seismic resilience maps is of great importance in the planning of transportation networks to be used after seismic events. However, conducting such studies for transportation networks is costly and time-consuming (Byun and D'Ayala 2022). Therefore, in this study, the seismic suitability of the selected routes was evaluated instead of seismic resilience mapping. In this evaluation, the potential closure risks of the roads along the selected routes following possible seismic activity were considered. Since the main and local distribution centers have at least one frontage on roads with widths of 10 m or more, the risk of road closures is considered to be low (JICA and IMM 2002). Subsequently, the usability of the selected candidate buildings after seismic activity was examined. For this purpose, the evaluation indicated that the selected candidate buildings have the highest building importance factor specified in the earthquake regulation (RTMEU, 2018) (I = 1.5) and, due to their one- to three-story configuration, have a low risk of damage (Başgöze and Güncü 2023). This demonstrates that the buildings selected as MDCs and LDPs are expected to remain usable after seismic activity. Finally, the proximity of the buildings and roads used in this study to the NAF, which has a high potential for earthquake generation in the region, was examined to assess their post-seismic usability.

Consequently, the 1:250,000-scale Active Fault Map of Turkey, Erzincan NJ 37 − 3 sheet, prepared by Emre et al. (2012) under the General Directorate of Mineral Research and Exploration (GDMER), was digitized, and the resulting NAF data were incorporated into the database. The analysis conducted using the building, road, and fault line layers in the database showed that the selected candidate buildings and roads are located approximately 3,500 m away from the NAF (Fig. 4). Accordingly, it was observed that the selected candidate buildings and roads are situated in appropriate locations, as they lie outside the risk zones associated with fault lines, as also indicated in the study by Gürboğa et al. (2016). Overall, these findings confirm that the selected distribution centers and transportation routes will remain usable after seismic activity.

Additionally, contingent upon the characteristics of the study region, supplementary factors influencing post-earthquake damage may also be included in the evaluation process. Particularly, local conditions, such as site amplification and soil properties, can significantly alter the intensity of ground motion and the structural response (Stewart et al. 2003). Moreover, the seismic vulnerability of bridges (which are critical components of transportation networks), is a crucial determinant of overall system performance (Nielson and DesRoches 2007). Furthermore, secondary hazards such as liquefaction and ground failure serve to increase the vulnerability of infrastructures (Bird and Bommer 2004; Youd and Idriss 2001).

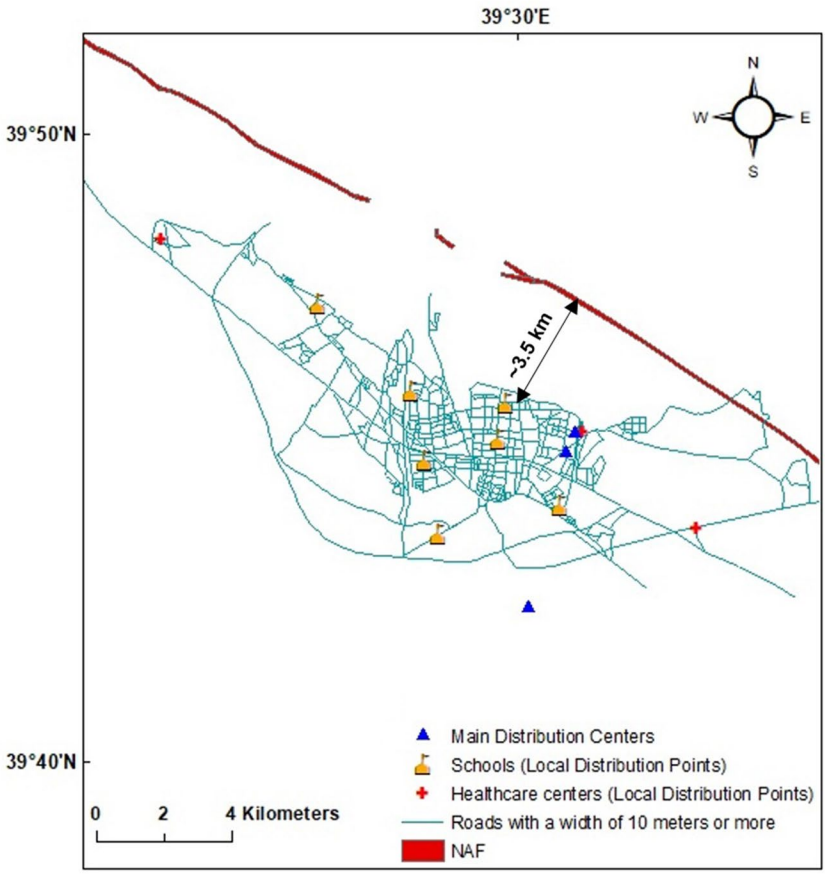


Fig. 4 Mapping considering seismotectonic context of the study area

Therefore, it is essential to incorporate the interactions between transportation networks and the built environment into risk assessments (Argyroudis et al. 2015; Pitilakis et al. 2014). Depending on the specific requirements of the study area, incorporating these factors into a comprehensive risk assessment is of great importance. The aforementioned elements, identified as limitations within the scope of this study, will be considered as key criteria in future risk assessment studies.

4.4 Experiments

To ensure that disaster victims could easily access aid after an earthquake, it was necessary to designate LDPs that are both easily accessible and close to residential areas. For this purpose, considering the locations of residential areas, ten buildings were selected as representative among schools and healthcare facilities within the neighborhoods in accordance with the seismic suitability evaluation of the study area. The suitability of these buildings as potential LDPs was examined using the generated buffer zones.

In addition to proximity analyses, we used GFAs in this study. We considered the geographical midpoints of the neighborhoods in the case study area. Thus, by considering the Euclidean distances between locations, we identified local distribution points that disaster victims could reach with minimal transportation costs (Ivanov 2024). Such "Gravity Models" help minimize both internal and external transportation costs within the system (Chopra and Meindl 2016).

In the GFAs of this study, ordered coordinate pairs $(x_i\,;y_i)$ represent the geographic locations of disaster victims in need of assistance in $i-th$ neighborhood. These locations are considered as the midpoints of neighborhoods in the central district of Erzincan Province, based on their population density. The decision variables $\left(P_x\,;P_y\right)$ represent the locations of the LDPs calculated based on the data input into the specified parameters.

For these analyses, transportation costs are assumed to be linearly proportional to the distances between LDPs - neighborhoods of disaster victims and their demands for assistance. First, the distances $d\left((P_x\,;P_y);(x_i\,;y_i)\right)$ between the locations of the neighborhoods of disaster victims and the LDPs are calculated. By multiplying the demands of disaster victims $(D(x_i\,;y_i))$ in each neighborhood by these distances, we create the objective function in (1).

$$\min Z(P_x\,;P_y) = \sum {}^{N}_{i-1} d\left((P_x\,;P_y);(x_i\,;y_i)\right) * D\left(x_i\,;y_i\right) \tag{1}$$

The objective function (1) involves minimizing the total distance multiplied by the demand, where N denotes the number of neighborhoods (demand points) considered in the study area. Since the assumption is that the distances of potential LDPs to the locations of the disaster victims' neighborhoods and transportation costs are linearly proportional, the lower the Z value, the better the result.

Provided that the candidate LDPs' locations do not coincide with any demand point, the continuous objective function in (1) is differentiable with respect to P_x and P_y. Therefore, the first-order conditions are obtained by taking the partial derivatives of Z with respect to the coordinates of the LDPs. The partial derivatives with respect to P_x and P_y are shown in Eq. (2) and Eq. (3).

$$\frac{\partial Z}{\partial P_x} = \sum {}^{N}_{i=1} D\left(x_i\,;y_i\right) \frac{P_y - x_i}{\sqrt{\left(P_x - x_i\right)^2 + \left(P_y - y_i\right)^2}} \tag{2}$$

$$\frac{\partial Z}{\partial P_y} = \sum {}^{N}_{i=1} D\left(x_i\,;y_i\right) \frac{P_y - y_i}{\sqrt{\left(P_x - x_i\right)^2 + \left(P_y - y_i\right)^2}} \tag{3}$$

The values of the expressions in Eqs. (2) and (3) are set equal to 0 in order to obtain the first-order optimality conditions. Rearranging these conditions yields the fixed-point relations given in Eq. (4) and Eq. (5). These equations are used to iteratively calculate the coordinates P_x and P_y of the LDP (Jaffal et al. 2025; Ivanov 2024).

$$P_x = \frac{\sum_{i=1}^{N} \frac{D(x_i ; y_i) * x_i}{\sqrt{(P_x - x_i)^2 + (P_y - y_i)^2}}}{\sum_{i=1}^{N} \frac{D(x_i ; y_i)}{\sqrt{(P_x - x_i)^2 + (P_y - y_i)^2}}} \tag{4}$$

$$P_y = \frac{\sum_{i=1}^{N} \frac{D(x_i ; y_i) * y_i}{\sqrt{(P_x - x_i)^2 + (P_y - y_i)^2}}}{\sum_{i=1}^{N} \frac{D(x_i ; y_i)}{\sqrt{(P_x - x_i)^2 + (P_y - y_i)^2}}} \tag{5}$$

Because P_x and P_y appear on both sides of Eqs. (4) and (5), these expressions do not provide a closed-form explicit solution. Instead, they define the classical fixed-point update relations of the Weiszfeld procedure. The iterative process continues until the location coordinates converge and the optimum or near-optimum value of the objective function is obtained (Beck and Sabach 2015; Pilotta and Torres 2011).

Furthermore, the distances between the LDPs and the demand points and/or the desired number of LDPs are entered as parameters into the anyLogistix software environment for subsequent GFA experiments and scenario-based logistics evaluations (Ivanov 2024).

Because detailed information on the operational capacity of the MDCs used for distribution was not available, we calculated the optimization of HSC distribution channels based solely on transportation costs. Initially, we assumed that there were no aid resources in LDPs, and MDCs had unlimited inventory. We simulated the delivery of aid from MDCs to LDPs for a two-month period, consistent with the study's time periods. The indices, parameters, and variables of the mathematical model used for simulation and SPM experiments of the scenarios were presented in Table 6.

Using the elements listed in Table 6, we constructed the objective function in Eq. (6), which aims to minimize transportation costs in HSC distribution channels at the case study location.

$$min\, T = \sum_{j=1}^{L} \sum_{i=1}^{M} C * d_{ij} * Q_{ij} \tag{6}$$

We then added a constraint, as shown in Eq. (7), that ensures the demand at each LDP is fully satisfied.

$$Q_{ijt} \geq D_{ijt}\,, \forall\, j \in L \tag{7}$$

Considering models (6) and (7), we input the necessary formulations and experimental settings into four scenarios created in anyLogistix. For each scenario, we evaluated various Key Performance Indicators (KPIs) and determined the most suitable scenario.

Following these experiments, we used SPM analysis to identify the effective access distances from all neighborhoods to the candidate LDPs. All calculations were performed in QGIS utilizing its network analysis tools, in line with Eq. (8).

Table 6 Elements of the simulation and SPM experiments

Indices, Parameters and Variables	
Indices	**Content**
r	Period Index, $r \in [1; P]$)
t	Running Time Index (Two Months)
i	MDC Number, $i \in [1; M]$)
j	LDP Number, $j \in [1; L]$)
k	Neighborhood Number, $k \in [1; N]$)
a	Alternative LDP Number, $a \in [1; A]$)
Parameters	**Content**
M	Number of MDCs
L	Number of LDPs
N	Number of Neighborhoods
A	Number of Alternative LDPs (Primary, Secondary, and Tertiary)
P	Time Periods
D	Demand in a r-th period, in m^3
C	Transportation Costs per m^3, in ₺
Variables	**Content**
d	Distance, in km(calculated based on real routes)
o	$\{1(\text{If } j-\text{th LDP is assigned as } a-\text{th option for } k-\text{th neighborhood}) \vee 0 \text{ (otherwise)}\}$
Q	Shipment Quantities in between MDCs to LDPs, in m^3
T	Total Transportation Cost, in ₺
I	Unlimited Inventory in a r-th period, in m^3 ($I_{it} = \infty$)
SD	Shortest Distance, in km(calculated based on real routes)

$$min\, SD = \sum_{a=1}^{A} \sum_{j=1}^{L} \sum_{k=1}^{N} d_{jk} * o_{jka} \tag{8}$$

As demonstrated in Eq. (8), the aim is to minimize the total distance individuals can travel along low-earthquake-risk routes to determine LDP alternatives that meet the aid requests of each neighborhood. Furthermore, we incorporate constraint (Eq. (9)) to ensure the assignment of precisely one LDP per rank for each neighborhood, as well as constraint (Eq. (10)) to prevent the repetition of LDPs across different ranks for the same neighborhood.

$$\sum {}_{j=1}^{L} o_{jka} = 1,\ \forall\, k\ \in\ N,\ \forall\, a\ \in\ A \tag{9}$$

$$\sum {}_{a=1}^{A} o_{jka} \leq\ 1,\ \forall\, k\ \in\ N,\ \forall\, j\ \in\ L \tag{10}$$

Accordingly, based on the optimum scenario determined by simulation analyses, the shortest-distance routes between points were determined via QGIS for the selection of primary, secondary, and tertiary LDPs.

5 Results and discussion

As outlined in the methodology section, this research adopted a mixed-methods approach. Potential New Local Distribution Points (NLDPs) were identified using proximity analyses and GFAs. The results obtained were reported and evaluated. Finally, the simulations and SPM analyses were conducted according to the research scenarios in line with the seismic suitability of the study area.

5.1 Findings of proximity analyses and GFAs

To determine which places could be used as LDPs, proximity analyses of potential locations (healthcare centers, hospitals, schools, etc.) were conducted for both the lower limit of a 1 km and the upper limit of a 5 km service radius. The most suitable locations were identified by combining the different functional uses of these facilities through proximity analyses. The results indicated that, for a 1 km service radius, 30 neighborhood centers were included within the service area out of a total of 69 neighborhoods, while 39 neighborhoods remained outside. For a 2 km service radius, 11 neighborhoods were outside the service area; for a 3 km radius, this number decreased to 4, and for a 4 km radius, only 2 neighborhoods were excluded. When the service radius was extended to 5 km, all 69 designated neighborhoods fell within the service area. Accordingly, potential NLDPs were identified based on the proximity analysis results, as shown in Fig. 5.

The GFAs were also performed to verify the locations of these NLDPs. To conduct the GFAs, the aid demand quantities of neighborhood residents, the frequency of their aid requests, their geographic locations, the types of aid required, and the study time periods were determined in accordance with international standards and imported into the anyLogistix software. The optimal locations of the NLDPs were determined using this program

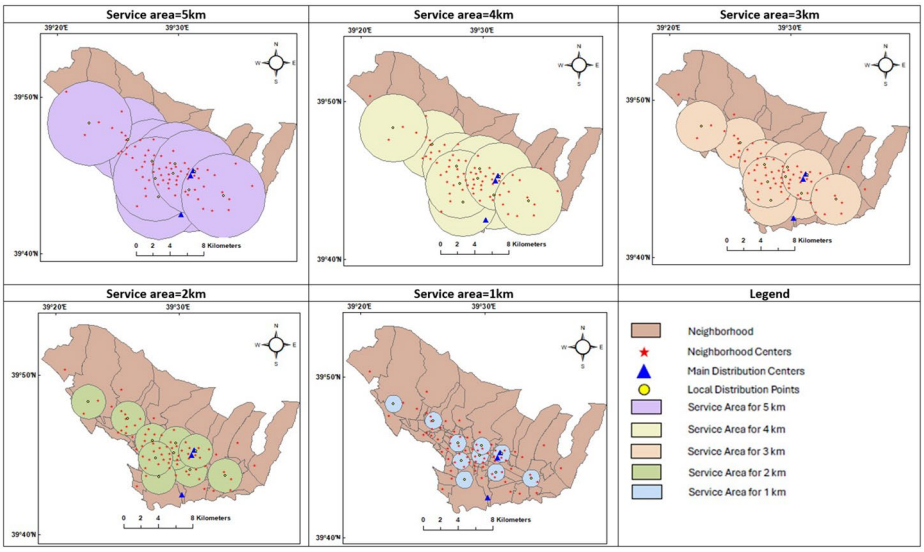


Fig. 5 Results of proximity analyses

for various service distances to neighborhoods (1, 2, 3, 4, and 5 km). Information on these locations and the calculated Flow Cost Estimations (FCEs) were presented in Table 7.

By comparing the results of the GFAs and proximity analyses, it was observed that service distances of 4 and 5 km covered all neighborhoods. Although this coverage was comprehensive, such large service areas could hinder easy access to LDPs for people after a disaster. Furthermore, $FCE^{4<d\leq 5}$ and $FCE^{3<d\leq 4}$ were higher than the statistics for other service distances. However, an examination of the results for the 1 and 2 km service distance scenarios indicated that a greater number of NLDPs were generated. Moreover, these NLDPs exhibited significant variations in workload and FCE. Therefore, NLDPs with a service radius of up to 3 km were considered in the subsequent sections of the analysis.

5.2 Findings of simulations

Results from the proximity analyses and GFAs were reported to evaluate the study's scenarios. Data related to the identified NLDPs, along with existing schools and healthcare centers, were imported into the anyLogistix software. Furthermore, proximity analyses were used to determine which NLDPs or LDPs received service from which MDCs.

To evaluate the mathematical models developed for the simulation experiments, data such as the LDPs' aid request amounts, geographic locations, aid types, and detailed information about the MDCs were imported into the software. Additionally, assumptions such as unlimited inventory for MDCs and standard data for aid delivery (vehicle capacity = 20 m^3, partial delivery, different volumes of aid types, shipment characteristics, etc.) were implemented in the software.

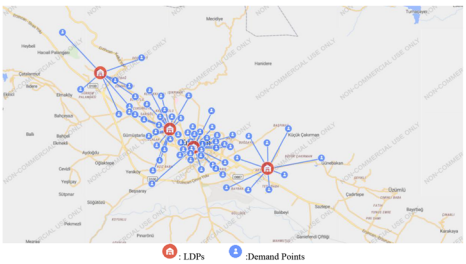
The scenarios considered in the simulation experiments were reviewed. Subsequently, these HSC distribution channels were simulated over a two-month period using real-world routes. The MDCs, LDPs, and neighborhood IDs included in the scenarios were listed in Table 8.

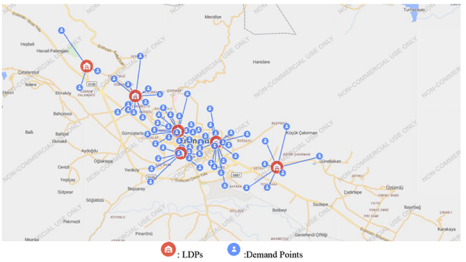
As shown in Table 8, each scenario incorporates different HSC distribution channels. For scenarios 3 and 4, a new MDC (including Main Sports Facility) was added to the distribution network. Furthermore, for validation purposes before conducting the simulation experiments, the output data of log files were analyzed, and preliminary tests were performed. Then, simulation experiments were carried out for each scenario. The calculated KPIs were reported and presented in Table 9.

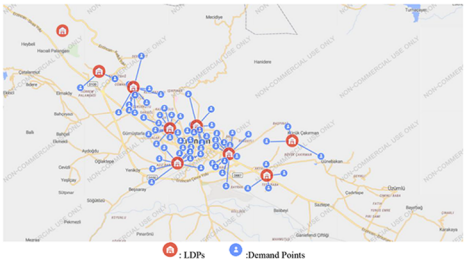
As indicated in Table 9, the total transportation cost (T= 306,653.091 ₺) and average transportation cost per item (10,959.000 ₺) were the lowest in Scenario 3. HSC distribution channels in this scenario fully meet the aid demands $(Total\ Aid\ Demand = 27981.944\ m^3)$ of the disaster victims. Also, traveled distance $(5239.052\ kms)$, lead time $(0.142\ day)$, and mean lead time $(0.004\ day)$ in this scenario were the lowest compared to the other scenarios. Although the number of shipped vehicles and vehicle capacity utilization ratio were better in Scenario 2 and Scenario 4, these statistics show that transportation operations could be carried out at lower costs.

Scenario 3 appeared more suitable for HSC distribution network operations to be conducted through LDPs (including schools and healthcare centers) accessible to disaster victims. Even though the analysis covers only real-world transportation-based calculations, it revealed that geographical factors can significantly alter HSC distribution network performance.

Table 7 Results of GFAs

Distance to Settlements (*km*)	Results of GFAs				
	Map View	$NLDP_i^{4<d\leq5}$	Latitude of NLDPs (°)	Longitude of NLDPs (°)	FCE (*pcs*km*)
$4 < d \leq 5$		$NLDP_1^{4<d\leq5}$	39.74641531	39.48911224	**765,749.0249**
		$NLDP_2^{4<d\leq5}$	39.7296148	39.5662511	180,469.8269
		$NLDP_3^{4<d\leq5}$	39.76139581	39.46417134	310,668.7808
		$NLDP_4^{4<d\leq5}$	39.8064792	39.39147988	**67,818.70717**
				Total	**1,324,706.34**

Distance to Settlements (*km*)	Results of GFAs				
	Map View	$NLDP_i^{3<d\leq4}$	Latitude of NLDPs (°)	Longitude of NLDPs (°)	FCE (*pcs*km*)
$3 < d \leq 4$		$NLDP_1^{3<d\leq4}$	39.7292325	39.57773369	45,597.82767
		$NLDP_2^{3<d\leq4}$	39.78647738	39.42917637	43,620.84033
		$NLDP_3^{3<d\leq4}$	39.81036796	39.37841315	**12,870.28017**
		$NLDP_4^{3<d\leq4}$	39.75827241	39.47406115	**509,243.3826**
		$NLDP_5^{3<d\leq4}$	39.74047537	39.47708098	114,634.2119
		$NLDP_6^{3<d\leq4}$	39.74905171	39.51405869	321,195.9208
				TOTAL	**1,047,162.46**

Distance to Settlements (*km*)	Results of GFAs				
	Map View	$NLDP_i^{2<d\leq3}$	Latitude of NLDPs (°)	Longitude of NLDPs (°)	FCE (*pcs*km*)
$2 < d \leq 3$		$NLDP_1^{2<d\leq3}$	39.76225865	39.49243609	210,311.0649
		$NLDP_2^{2<d\leq3}$	39.73263309	39.47260701	192,554.431
		$NLDP_3^{2<d\leq3}$	39.7398222	39.52604046	258,154.369
		$NLDP_4^{2<d\leq3}$	39.79341216	39.4260235	**0**
		$NLDP_5^{2<d\leq3}$	39.83890152	39.35189819	38,269.87047
		$NLDP_6^{2<d\leq3}$	39.80619775	39.39041766	5,848.975675
		$NLDP_7^{2<d\leq3}$	39.7603672	39.46465196	**275,735.5377**
		$NLDP_8^{2<d\leq3}$	39.72288156	39.56602974	22,590.9857
		$NLDP_9^{2<d\leq3}$	39.75041377	39.59228154	10,607.99075
				Total	**1,014,073.23**

Distance to Settlements (*km*)	Results of GFAs				
	Map View	$NLDP_i^{1<d\leq2}$	Latitude of NLDPs (°)	Longitude of NLDPs (°)	FCE (*pcs*km*)
$1 < d \leq 2$		$NLDP_1^{1<d\leq2}$	39.80593514	39.41967141	7,603.747648
		$NLDP_2^{1<d\leq2}$	39.83890152	39.35189819	**0**
		$NLDP_3^{1<d\leq2}$	39.72037128	39.56534749	22,944.43769
		$NLDP_4^{1<d\leq2}$	39.73294985	39.45230114	9,764.306988
		$NLDP_5^{1<d\leq2}$	39.74073241	39.48120769	126,981.2503
		$NLDP_6^{1<d\leq2}$	39.73100835	39.52366825	53,811.78957
		$NLDP_7^{1<d\leq2}$	39.75167109	39.52537197	125,576.5714
		$NLDP_8^{1<d\leq2}$	39.73789978	39.62260056	**0**
		$NLDP_9^{1<d\leq2}$	39.75941528	39.58378186	2,937.694913
		$NLDP_{10}^{1<d\leq2}$	39.78392339	39.42943213	23,286.44981
		$NLDP_{11}^{1<d\leq2}$	39.80423377	39.3870589	4,118.158641
		$NLDP_{12}^{1<d\leq2}$	39.75663771	39.49230642	**153,592.0048**
		$NLDP_{13}^{1<d\leq2}$	39.77425515	39.48632172	31,617.86039
		$NLDP_{14}^{1<d\leq2}$	39.75723113	39.46457576	135,648.0349
		$NLDP_{15}^{1<d\leq2}$	39.77425709	39.46232678	25,194.90275
				Total	**723,077.21**

Table 7 (continued)

Distance to Settlements (*km*)	Map View		Results of GFAs		
			$NLDP_i^{0<d\leq1}$	Latitude of NLDPs (°)	Longitude of NLDPs (°)	FCE (*pcs*km*)
$0 < d \leq 1$			$NLDP_1^{0<d\leq1}$	39.83890152	39.35189819	0
			$NLDP_2^{0<d\leq1}$	39.71789978	39.62260056	0
			$NLDP_3^{0<d\leq1}$	39.71220016	39.54610062	0
			$NLDP_4^{0<d\leq1}$	39.72282637	39.44588259	1,741.462606
			$NLDP_5^{0<d\leq1}$	39.74445575	39.45465554	6,181.018612
			$NLDP_6^{0<d\leq1}$	39.79882479	39.41149511	3,071.202965
			$NLDP_7^{0<d\leq1}$	39.81829834	39.43470001	0
			$NLDP_8^{0<d\leq1}$	39.73390887	39.5038336	26,699.28744
			$NLDP_9^{0<d\leq1}$	39.76325685	39.48145806	47,301.31619
			$NLDP_{10}^{0<d\leq1}$	39.76328865	39.44387022	35,369.03499
			$NLDP_{11}^{0<d\leq1}$	39.75567852	39.46929306	**79,118.32676**
			$NLDP_{12}^{0<d\leq1}$	39.7222976	39.52022685	4,636.729732
			$NLDP_{13}^{0<d\leq1}$	39.73689284	39.53174732	18,828.46012
			$NLDP_{14}^{0<d\leq1}$	39.7879982	39.48410034	0
			$NLDP_{15}^{0<d\leq1}$	39.77590179	39.50799942	0
			$NLDP_{16}^{0<d\leq1}$	39.74990082	39.56579971	0
			$NLDP_{17}^{0<d\leq1}$	39.76169968	39.58810043	0
			$NLDP_{18}^{0<d\leq1}$	39.74803269	39.52386794	2,475.603497
			$NLDP_{19}^{0<d\leq1}$	39.75574512	39.54128222	12,669.13833
			$NLDP_{20}^{0<d\leq1}$	39.71260071	39.56809998	0
			$NLDP_{21}^{0<d\leq1}$	39.72789992	39.57485057	7,930.875085
			$NLDP_{22}^{0<d\leq1}$	39.7724816	39.4643705	17,593.39522
			$NLDP_{23}^{0<d\leq1}$	39.78640689	39.44724822	6,018.882833
			$NLDP_{24}^{0<d\leq1}$	39.79299927	39.37129974	0
			$NLDP_{25}^{0<d\leq1}$	39.8064003	39.39009857	0
			$NLDP_{26}^{0<d\leq1}$	39.77591015	39.4219919	2,720.051674
			$NLDP_{27}^{0<d\leq1}$	39.78730011	39.42829895	0
			$NLDP_{28}^{0<d\leq1}$	39.74025199	39.47745498	33,417.96827
			$NLDP_{29}^{0<d\leq1}$	39.74846543	39.48775222	22,478.51966
			$NLDP_{30}^{0<d\leq1}$	39.75181515	39.50899806	74,829.12868
			$NLDP_{31}^{0<d\leq1}$	39.75998861	39.49931313	38,878.96216
				Total		**441,959.3648**

5.3 Findings of SPM analyses

Given the seismic suitability of the central district of Erzincan Province, SPM analyses were conducted on roads with a low risk of closure or damage during an earthquake disaster. The results of these analyses were presented in Table 10.

At the network level, the total distance to the first LDPs was 188,483.66 m, compared with 261,518.47 m and 348,597.06 m for the second and third LDPs, respectively. This corresponded to average distances of approximately 2,731.64 m for the primary LDP, 3,790.12 m for the secondary LDP, and 5,052.13 m for the tertiary LDP per neighborhood. Regarding accessibility thresholds, 44 out of 69 neighborhoods (≈63.8%) had their primary LDP located within 3,000 m. For the secondary LDP, 33 out of 69 neighborhoods (≈47.8%) were within this distance. Lastly, for the tertiary LDP, the proportion decreased to approximately 23.2%.

Consequently, while the primary LDP remained within a reasonable walking distance for a significant portion of the population, the secondary and particularly the tertiary options were markedly farther. In the event of an earthquake, the LDP options exhibited slight variations compared to the outcomes of other analyses, attributable to the risk of damage to the routes individuals might select. Nevertheless, these LDP options were considered significant alternatives for individuals.

6 Conclusion

The effectiveness of humanitarian supply chain distribution networks is vital in disasters such as earthquakes. Rapid action in accordance with response plans is necessary to effectively conduct post-disaster search and rescue, medical support, communication, and coordination operations. In such a crisis, people should move to assembly areas without panic and obtain the resources they need at LDPs, which are the endpoints of HSC distribution channels.

Table 8 HSC distribution channels based on selected places for scenarios

Scenario	MDCs	LDPs	Neighborhood IDs
Scenario 1	Main_AFAD_Center	School_DTOKI	42, 43, 44
	Main_AFAD_Center	School_MO	45, 46, 47, 48, 49
	Main_AFAD_Center	School_EL	50, 51, 52, 53, 54
	Main_AFAD_Warehouse	School_GCT	1, 2, 3, 4, 5, 6, 7
	Main_AFAD_Warehouse	Healthcare_Akyazı	8, 9, 10, 11, 12, 13, 14, 15, 16
	Main_AFAD_Warehouse	School_15TSAIH	62, 63, 64, 65, 66, 67, 68, 69
	Main_Kızılay	Healthcare_Gecit	55, 56, 57, 58, 59, 60, 61
	Main_Kızılay	School_SPSZ	17, 18, 19, 20, 21
	Main_Kızılay	School_CFI	22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39
	Main_Kızılay	Healthcare_EBYU	40, 41
Scenario	**MDCs**	**LDPs**	**Neighborhood IDs**
Scenario 2	Main_AFAD_Center	$NLDP_1^{2<d\leq 3}$	31, 45, 46, 47, 49, 50, 51, 52, 53, 56, 57, 61
	Main_AFAD_Center	$NLDP_6^{2<d\leq 3}$	34, 39, 41
	Main_AFAD_Center	$NLDP_9^{2<d\leq 3}$	10, 11, 12
	Main_AFAD_Warehouse	$NLDP_2^{2<d\leq 3}$	1, 2, 3, 4, 6, 7, 20, 21, 54, 64, 67
	Main_AFAD_Warehouse	$NLDP_3^{2<d\leq 3}$	13, 14, 15, 55, 58, 59, 60, 62, 63, 65, 66, 69
	Main_AFAD_Warehouse	$NLDP_8^{2<d\leq 3}$	8, 9, 16, 68
	Main_Kızılay	$NLDP_4^{2<d\leq 3}$	22, 23, 24, 25, 26, 27, 29, 30, 33, 37
	Main_Kızılay	$NLDP_5^{2<d\leq 3}$	40
	Main_Kızılay	$NLDP_7^{2<d\leq 3}$	5, 17, 18, 19, 28, 32, 35, 36, 38, 42, 43, 44, 48
Scenario	**MDCs**	**LDPs**	**Neighborhood IDs**
Scenario 3	Main_AFAD_Center	School_MO	45, 46, 47, 48, 49
	Main_AFAD_Center	School_EL	50, 51, 52, 53, 54
	Main_AFAD_Warehouse	School_GCT	1, 2, 3, 4, 5, 6, 7
	Main_AFAD_Warehouse	Healthcare_Akyazı	8, 9, 10, 11, 12, 13, 14, 15, 16
	Main_Kızılay	School_15TSAIH	62, 63, 64, 65, 66, 67, 68, 69
	Main_Kızılay	Healthcare_Gecit	55, 56, 57, 58, 59, 60, 61
	Main_Sports_Facility	School_SPSZ	17, 18, 19, 20, 21
	Main_Sports_Facility	School_CFI	22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39
	Main_Sports_Facility	Healthcare_EBYU	40, 41
	Main_Sports_Facility	School_DTOKI	42, 43, 44
Scenario	**MDCs**	**LDPs**	**Neighborhood IDs**

Table 8 (continued)

Scenario	MDCs	LDPs	Neighborhood IDs
Scenario 4	Main_AFAD_Center	$NLDP_9^{2<d\leq 3}$	10, 11, 12
	Main_AFAD_Center	$NLDP_3^{2<d\leq 3}$	13, 14, 15, 55, 58, 59, 60, 62, 63, 65, 66, 69
	Main_AFAD_Warehouse	$NLDP_2^{2<d\leq 3}$	1, 2, 3, 4, 6, 7, 20, 21, 54, 64, 67
	Main_AFAD_Warehouse	$NLDP_8^{2<d\leq 3}$	8, 9, 16, 68
	Main_Kızılay	$NLDP_7^{2<d\leq 3}$	5, 17, 18, 19, 28, 32, 35, 36, 38, 42, 43, 44, 48
	Main_Sports_Facility	$NLDP_1^{2<d\leq 3}$	31, 45, 46, 47, 49, 50, 51, 52, 53, 56, 57, 61
	Main_Sports_Facility	$NLDP_4^{2<d\leq 3}$	22, 23, 24, 25, 26, 27, 29, 30, 33, 37
	Main_Sports_Facility	$NLDP_5^{2<d\leq 3}$	40
	Main_Sports_Facility	$NLDP_6^{2<d\leq 3}$	34, 39, 41

Table 9 Performance comparison between scenarios

KPIs	Scenarios			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Transportation Cost *(₺)*	461,871.036	474,842.781	**306,653.091**	416,228.844
Average Transportation Cost per Item *(₺)*	15,156.000	16,971.000	**10,959.000**	14,874.000
Service Level *(%)*	100.000	100.000	100.000	100.000
Amount of Aid Received by Disaster Victims *(m^3)*	27,981.944	27,981.944	27,981.944	27,981.944
Lead Time *(day)*	0.215	0.290	**0.142**	0.235
Mean Lead Time *(day)*	0.005	0.008	**0.004**	0.007
Vehicle Capacity Utilization *(ratio)*	0.976	**0.978**	0.976	**0.978**
Shipped Vehicles *(number)*	1,433.000	**1,431.000**	1,433.000	**1,431.000**
Traveled Distance *(km)*	7,898.853	8,259.040	**5,239.052**	7,206.133

For these networks to function effectively, the necessary basic preparations (such as identifying meeting places and aid distribution points, continuous resource inventory monitoring, sustainable replenishment of resources in critical locations, and strengthening infrastructure to ensure seamless communication and coordination among all HSC actors) must be completed before an earthquake. Therefore, HSC distribution channels that operate smoothly and can respond quickly to needs are essential.

Following a potential earthquake in the central district of Erzincan Province, this study investigated how HSC distribution channels could function. In this context, real-world data were utilized to assess the current situation in the specified region and to develop recommendations for future planning. First, the research findings suggested that the geographic locations of MDCs and LDPs are critically important for effective HSC distribution. This information is crucial to ensure that disaster victims can easily access the resources they need after an earthquake.

Second, the findings indicated that the most suitable locations for disaster victims to obtain assistance after a potential earthquake were School_MO, School_EL, School_GCT, Healthcare_Akyazı, School_15TSAIH, Healthcare_Gecit, School_SPSZ, School_CFI, Healthcare_EBYU, and School_DTOKI. Third, it was observed that transportation opera-

Table 10 Alternative LDPs based on SPM analyses

Neighborhood ID	1st LDP	SD (m)	2nd LDP	SD (m)	3rd LDP	SD (m)
1	School_GCT	2,364.79	School_DTOKI	5,311.31	School_SPSZ	3,043.68
2	School_GCT	7,156.53	School_SPSZ	8,516.23	School_DTOKI	10,618.30
3	School_GCT	4,559.25	School_EL	1,580.00	School_SPSZ	1,948.25
4	School_GCT	5,975.06	School_SPSZ	967.55	School_EL	3,003.74
5	School_GCT	6,298.76	School_SPSZ	1,983.70	School_DTOKI	4,251.33
6	School_GCT	1,866.61	School_SPSZ	2,111.37	School_EL	2,047.03
7	School_GCT	1,827.42	School_SPSZ	2,775.64	School_15TSAIH	5,879.44
8	Healthcare_Akyazı	1,661.23	School_15TSAIH	6,383.07	Healthcare_Gecit	6,874.22
9	Healthcare_Akyazı	490.68	School_15TSAIH	5,226.76	Healthcare_Gecit	5,086.12
10	Healthcare_Akyazı	5,481.29	School_15TSAIH	7,549.91	Healthcare_Gecit	5,949.53
11	Healthcare_Akyazı	4,136.55	Healthcare_Gecit	2,860.55	School_15TSAIH	4,460.94
12	Healthcare_Akyazı	4,669.02	Healthcare_Gecit	8,270.57	School_15TSAIH	9,637.29
13	Healthcare_Akyazı	3,995.93	School_MO	1,932.35	Healthcare_Gecit	2,634.00
14	Healthcare_Akyazı	3,084.93	Healthcare_Gecit	3,237.19	School_15TSAIH	2,849.42
15	Healthcare_Akyazı	5,244.20	Healthcare_Gecit	1,958.57	School_15TSAIH	4,027.79
16	Healthcare_Akyazı	3,035.32	School_15TSAIH	6,646.41	Healthcare_Gecit	7,176.18
17	School_SPSZ	1,225.80	School_EL	1,935.44	School_MO	2,733.45
18	School_SPSZ	1,310.51	School_DTOKI	1,412.31	School_EL	2,722.52
19	School_SPSZ	2,682.97	School_DTOKI	2,613.75	School_EL	4,232.61
20	School_SPSZ	1,126.44	School_EL	1,932.48	School_GCT	3,414.86
21	School_SPSZ	1,608.90	School_DTOKI	3,848.70	School_GCT	3,185.57
22	School_CFI	2,108.40	Healthcare_Ebyu	7,645.00	School_DTOKI	4,638.01
23	School_CFI	254.85	Healthcare_Ebyu	6,132.00	School_DTOKI	4,641.17
24	School_CFI	1,183.79	Healthcare_Ebyu	7,132.00	School_DTOKI	4,254.93
25	School_CFI	5,787.36	Healthcare_Ebyu	6,787.00	School_DTOKI	10,109.20
26	School_CFI	2,527.83	Healthcare_Ebyu	7,805.00	School_DTOKI	5,503.88
27	School_CFI	1,459.58	Healthcare_Ebyu	5,437.00	School_DTOKI	5,707.17
28	School_CFI	3,551.65	School_DTOKI	2,499.79	Healthcare_Ebyu	9,500.00
29	School_CFI	1,341.82	School_DTOKI	3,295.78	Healthcare_Ebyu	7,514.00
30	School_CFI	1,889.39	School_DTOKI	4,933.72	Healthcare_Ebyu	7,404.00
31	School_CFI	3,655.02	Healthcare_Ebyu	9,728.00	School_DTOKI	3,169.73
32	School_CFI	3,159.58	School_DTOKI	1,700.84	School_MO	4,416.36
33	School_CFI	1,798.41	School_DTOKI	3,697.37	Healthcare_Ebyu	7,871.00
34	School_CFI	2,457.14	Healthcare_Ebyu	4,176.00	School_DTOKI	6,778.98
35	School_CFI	3,138.55	School_DTOKI	1,985.66	School_MO	4,701.18
36	School_CFI	2,528.74	School_DTOKI	3,829.37	School_SPSZ	4,422.91
37	School_CFI	828.25	Healthcare_Ebyu	5,865.00	School_DTOKI	5,048.45
38	School_CFI	4,844.15	School_SPSZ	2,665.01	School_DTOKI	4,932.64
39	School_CFI	4,993.91	Healthcare_Ebyu	2,176.00	School_DTOKI	12,279.00
40	Healthcare_Ebyu	5,706.55	School_CFI	10,236.00	School_DTOKI	16,419.00
41	Healthcare_Ebyu	2,620.66	School_CFI	5,960.00	School_DTOKI	13,259.00
42	School_DTOKI	1,016.42	School_MO	3,483.23	School_SPSZ	3,230.25
43	School_DTOKI	481.85	School_MO	3,101.42	School_SPSZ	2,298.59
44	School_DTOKI	1,729.39	School_SPSZ	1,776.82	School_EL	2,180.17
45	School_MO	759.42	School_EL	1,160.03	Healthcare_Gecit	3,507.61

Table 10 (continued)

Neighborhood ID	1st LDP	SD (m)	2nd LDP	SD (m)	3rd LDP	SD (m)
46	School_MO	1,118.69	School_EL	1,647.82	Healthcare_Gecit	3,837.86
47	School_MO	2,319.21	School_DTOKI	4,981.24	School_EL	2,931.72
48	School_MO	2,926.16	School_DTOKI	1,425.94	School_EL	3,147.22
49	School_MO	930.30	School_EL	778.83	School_SPSZ	3,026.41
50	School_EL	1,449.64	School_MO	1,375.39	School_DTOKI	2,320.98
51	School_EL	829.26	School_MO	1,794.53	Healthcare_Gecit	2,683.81
52	School_EL	1,143.66	School_15TSAIH	1,827.20	Healthcare_Gecit	3,831.66
53	School_EL	1,286.52	Healthcare_Gecit	2,682.82	School_15TSAIH	2,273.56
54	School_EL	1,060.92	School_MO	2,379.71	School_SPSZ	2,027.66
55	Healthcare_Gecit	2,987.80	School_EL	2,830.45	School_15TSAIH	2,757.88
56	Healthcare_Gecit	2,021.12	School_MO	2,030.22	School_EL	2,396.90
57	Healthcare_Gecit	1,514.09	School_MO	1,523.19	School_EL	2,841.43
58	Healthcare_Gecit	3,774.97	School_15TSAIH	2,525.59	Healthcare_Akyazı	5,039.24
59	Healthcare_Gecit	3,135.11	School_15TSAIH	3,069.49	Healthcare_Akyazı	5,256.39
60	Healthcare_Gecit	4,261.25	School_15TSAIH	2,354.06	Healthcare_Akyazı	4,469.70
61	Healthcare_Gecit	2,501.35	School_15TSAIH	3,149.57	Healthcare_Akyazı	6,327.38
62	School_15TSAIH	1,001.48	School_GCT	4,269.67	Healthcare_Akyazı	4,762.67
63	School_15TSAIH	6,968.45	School_GCT	10,537.52	Healthcare_Akyazı	3,369.71
64	School_15TSAIH	2,006.50	School_GCT	3,034.87	Healthcare_Akyazı	6,476.06
65	School_15TSAIH	656.11	School_GCT	4,225.36	Healthcare_Akyazı	5,051.44
66	School_15TSAIH	1,858.14	Healthcare_Gecit	1,270.88	Healthcare_Akyazı	5,046.91
67	School_15TSAIH	1,778.70	Healthcare_Gecit	3,024.18	School_GCT	3,077.64
68	School_15TSAIH	6,885.65	Healthcare_Akyazı	3,286.91	School_GCT	10,454.72
69	School_15TSAIH	4,443.39	Healthcare_Akyazı	3,231.15	School_GCT	5,624.61
Total Distance		**188,483.36**		**261,518.47**		**348,597.06**

tions from existing MDCs to these LDPs incurred high costs. Accordingly, the results demonstrated that these costs could be reduced by adding a new MDC (including the Main_Sports_Facility) to the HSC distribution network. Finally, based on the results of the SPM analyses conducted with consideration of the seismic resistance of the study area, primary, secondary, and tertiary LDPs (including healthcare centers and schools) that individuals may prefer for various reasons were identified.

These public buildings can be used to serve disaster victims and can be prepared for post-disaster relief distribution activities without incurring significant establishment, operational, or additional costs. Although some economic liabilities may be overlooked by decision-makers during an earthquake, it would be more prudent to avoid unnecessary expenditures and instead allocate resources to more critical needs such as infrastructure, improved communication and coordination systems, and investments in technologies that accelerate response operations.

Furthermore, in the event of an earthquake, communication systems may fail. Prior to such situations, it is necessary to prepare an HSC master plan for the province and inform the public about how operations will be conducted in accordance with this plan. In this way, people can be informed in advance about critical information such as temporary assembly areas, primary LDPs, and alternative access points. At the same time, personnel from governmental institutions, non-governmental organizations, and other disaster management stakeholders will possess essential information for post-earthquake operations, thereby reducing the negative impacts of potential communication disruptions.

The study has several limitations that open avenues for future research. The earthquake damage scenarios used are stylized and rely on assumptions regarding facility operability, road blockages, and population displacement rather than on detailed engineering-based vulnerability models. In addition, demand patterns are derived from static population data, and behavioral aspects such as spontaneous evacuation or changes in mobility patterns are not explicitly represented. Future research could address these limitations by integrating detailed seismic hazard analyses, network-based accessibility models, and behavioral response frameworks.

Despite these limitations, this study represents an important preliminary effort for disaster planning, as it incorporates real population densities, current household numbers, actual geographic locations, real transportation routes, and operational methods aligned with international standards. Thus, decision-makers and policy implementers can derive valuable insights from the study's findings.

Although the empirical analysis focused on the central district of Erzincan, the proposed methodology and several substantive findings are transferable to other earthquake-prone regions. The five-stage approach can be replicated in contexts where spatial data on population, public buildings, seismic suitability, and road networks are available. Moreover, the insight that existing schools and healthcare centers can function as LDPs is relevant for many cities in Türkiye and elsewhere. Nevertheless, the specific configuration of MDCs and LDPs will depend on local hazard characteristics, urban morphology, and institutional arrangements. Therefore, the Erzincan case can be viewed as a template adaptable to other high-risk areas.

Future research can further advance this field by developing comprehensive HSC master plans, evaluating humanitarian aid distribution effectiveness, and designing real-time disaster information systems. Additional theoretical and analytical studies are also needed to generalize different approaches across national and international standards and to generate practical solutions for improving HSC distribution channels.

Appendix

Table 5 IDs/Codes of Healthcare Centers, Schools, MDCs and Neighborhoods

Neighborhoods								
ID	Neighborhood	Population	ID	Neighborhood	Population	ID	Neighborhood	Population
1	Aziz Baba	485	24	Çukurkuyu	405	47	Kurutilek	444
2	Cemal Gürsel	232	25	Dereyurt	176	48	Menderes	3593
3	Hocabey	1671	26	Ertuğrul Gazi	136	49	Yenimahalle	2678
4	Mimar Sinan	10686	27	Esentepe	354	50	Arslanlı	5421
5	Özgürlük	736	28	Hamidiye	3399	51	Atatürk	4588
6	Taksim	1801	29	Hancı	295	52	İnönü	5867
7	Üçkonak	278	30	Hoca Ahmet Yesevi	164	53	Karaağaç	339
8	Aktoprak	592	31	Işıkpınar	604	54	Kızılay	1148
9	Akyazı	935	32	Kavakyolu	2389	55	Akşemsettin	2221
10	Başpınar	338	33	Keklikkayasi	618	56	Barbaros	2084
11	Buğdaylı	188	34	Osman Gazi	439	57	Başbağlar	2445
12	Büyükçakırman	320	35	Paşa	577	58	Demetevler	862
13	İzzetpaşa	2559	36	Sarıgöl	716	59	Gazi	614
14	Mengüceli	3517	37	Şehit Serhat Yurtbaşı	447	60	Yenidoğan	628
15	Munzur	3475	38	Ulalar	1999	61	Yunus Emre	6155
16	Terzibaba	468	39	Yalnızbağ	1372	62	Barış	843
17	Bahçelievler	3807	40	Davarlı	117	63	Bayrak	465
18	Ergenekon	7549	41	Hürrempalangası	117	64	Çarşı	2652
19	Gölcük	1443	42	Demirkent	3843	65	Ersevenler	961
20	Halitpaşa	3406	43	Osmanlı	5165	66	Fatih	3487
21	Mustafa Kemal Paşa	595	44	Yavuz Selim	7922	67	Gülabibey	1352
22	Bozyazı	270	45	Cumhuriyet	7373	68	Sancak	721
23	Bulutlu	1582	46	Kazım Karabekir	3096	69	Şehit Cengiz Topel	1370

Codes of Healthcare Centers, Schools and MDCs

Code	Name	Code	Name
School_DTOKI	Demirkent TOKİ Primary and Secondary School	School_SPSZ	Martyr Police Officer Salih Zengin Secondary School
School_MO	Mehmetçik Secondary School	School_CFI	Çukurkuyu Fatih Primary School
School_EL	Erzincan High School	Healthcare_EBYU	EBYU Family Healthcare Center
School_GCT	Gül Celal Toraman Vocational and Technical Anatolian High School	Main_AFAD_Center	Erzincan Provincial Directorate of AFAD
Healthcare_Akyazı	Akyazı Healthcare Center	Main_AFAD_Warehouse	Erzincan Provincial Directorate's Warehouse of AFAD

Table 5 IDs/Codes of Healthcare Centers, Schools, MDCs and Neighborhoods

Neighborhoods							
ID	Neighborhood	Population	ID	Neighborhood	Population	ID	Neighborhood	Population
School_15TSAIH	15 July Martyrs Anatolian Imam Hatip High School				Main_Kızılay		Erzincan Red Crescent Branch Presidency	
Healthcare_Gecit	Geçit Family Healthcare Center				Main_Sports_Facility		Erzincan Indoor Sports Hall	

Source: Erzincan Municipality 2025

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Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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