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A comparative impact chain analysis of 1999 Kocaeli and 2023 Kahramanmaraş earthquakes

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Abstract

Resilience in the face of crises is crucial for minimizing the impact of disasters and enabling rapid recovery. This study delves into the interlinked consequences of two seismic events that significantly impacted Türkiye in 1999 and 2023. Using an impact chain analysis, the aim is to provide a thorough understanding of the extensive effects on structures, infrastructure, and socio-economic dynamics. The research also examines the evolution of disaster management practices from the 1999 Kocaeli Earthquake to the more recent seismic events in 2023, highlighting advancements in risk management and resilience. Both seismic events revealed vulnerabilities in the construction of buildings, emphasizing seismic shortcomings that led to widespread damage. Earthquakes exert a profound impact on critical infrastructure, affecting transportation, communication, and energy systems, with cascading effects that extend to the broader socio-economic landscape. The effectiveness of the methodology, particularly, the impact chain analysis, is emphasized as it reveals complex causal relationships. Visual representations support effective communication and collaboration among stakeholders, offering a holistic perspective on systemic risks. In conclusion, this study contributes to understand disaster resilience and provides a foundation for subsequent research, policy formulation, and pragmatic strategies for disaster preparedness and response.

Keywords: cascading effect, disaster, earthquake, impact chain, resilience, systemic risk

1. Introduction

Resilience during a crisis involves the crucial qualities of a system to withstand and recover from adverse conditions. In times of crisis, a resilient structure, capable of enduring disasters while maintaining its functions, not only reduces the risk of severe damage but also plays a crucial role in expediting the restoration of normalcy. Moreover, their ability to facilitate timely recovery lessens the environmental burden, aligning with the sustainable use of resources, as the demand for repair and reconstruction resources is reduced. As this study delves into understanding the root causes of disasters and initiatives promoting resilience in crisis, it becomes evident that these interconnected

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efforts pave the way for a more comprehensive and sustainable approach to manage and mitigate the impacts of events. The evaluation of disasters based on their consequences provides a comprehensive perspective on the direct and indirect impacts, fostering a comparison that serves as valuable lessons for the future.

In recent decades, there has been a notable shift towards understanding the root causes of disasters, with initiatives like the FORIN Project (FORIN 2011; Oliver-Smith et al., 2019). This approach goes beyond merely comparing consequences; it delves into uncovering repetitive cause and consequence relationship in various case studies. Additionally, organizations like Eurac (Pittore, 2023) have pioneered methodologies such as impact chain (IC) analysis to explain the causal relationships of climate change at different levels which are also applicable to other disaster events.

In this study, two devastating earthquakes occurred on 1999 and 2023 in Türkiye, respectively, were examined through IC method. The first event took place on August 17th, 1999, at 03:02 (local time) with a magnitude of M_w 7.4 along the North Anatolian Fault (NAF), with an epicenter located in the vicinity of Gölcük, Kocaeli. Henceforth, it will be referred to as the 1999 Kocaeli Earthquake. The second case involves a series of three consecutive earthquakes with magnitudes of 7.7, 7.6, and 6.4 on February 2023 in Türkiye. The initial earthquake originated in Kahramanmaraş-Pazarcık, followed by subsequent earthquakes in Kahramanmaraş-Elbistan and Hatay-Yayladagi (AFAD, 2023). Thereafter, it will be referred to as the 2023 Kahramanmaraş Earthquakes. The geographical settings of two seismic events are presented in Figure 1. As seen in the figure, 1999 Kocaeli Earthquake occured on the Marmara Region while Kahramanmaraş Earthquakes occurred on Southeast Anatolian Region of Türkiye.

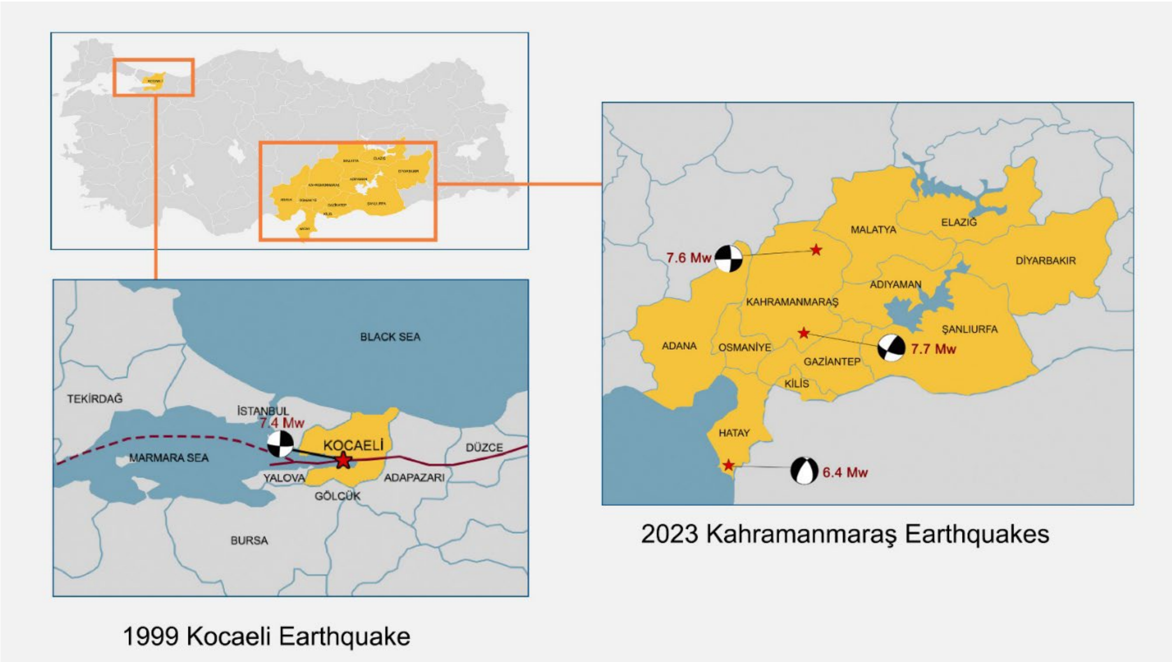

Figure 1 Geographical settings of considered seismic events.

So far, the consequences of earthquakes have been evaluated with some studies focusing on the structural deficiencies exposed during seismic events, while others delve into the social or economic aftermath. However, all this time after 1999 Kocaeli Earthquake, which occurred over 20 years ago, scholarly efforts have predominantly been discipline-specific, neglecting the need for a comprehensive examination, and there has been notably a lack of holistic evaluation integrating all the facets. Therefore, this study aims to bridge this gap by conducting a pioneering evaluation of the interconnected and far-reaching consequences of two devastating earthquakes that occurred in 1999 and 2023. Specifically, a perspective rooted in IC analysis was employed to examine not only the identified interaction types among various components but also to provide a thorough analysis of latent components and their impacts throughout the system. The goal is to offer a detailed understanding of the broader implications of earthquakes, thereby, contributing to a more comprehensive and informed approach to disaster evaluation.

2. A Review of 1999 Kocaeli and 2023 Kahramanmaraş Earthquakes

The Erzincan earthquake in 1939 and the Kocaeli Earthquake in 1999 were the major devastating disasters to ever strike Türkiye until the earthquakes occurred in February 2023. The lack of organization and coordination, as well as losses, in the 1999 Kocaeli Earthquake led the paradigm shifted from disaster management to risk management. The year 2000 can be considered as a new insight in construction and planning implementations. This is due to the fact that the significant losses suffered during the 1999 Kocaeli Earthquake triggered advancements in construction practices and inspection systems. Chronologically, the Turkish Catastrophe Insurance Pool (TCIP) was settled in 2000. The Building Inspection Law (2001), enacted in 2001 and initially applied in 19 pilot provinces, including the cities of Gaziantep and Hatay which experienced earthquakes in February 2023, was later expanded to encompass the entire country in 2011. The deformed bars and ready-mixed concrete have become widespread due to advancements in manufacturing technologies and the availability of technical guidelines. Subsequent to these developments, revisions were made to Türkiye's primary reinforced concrete design and construction code, known as TS500 (2000). The Disaster and Emergency Management Authority (AFAD) was established in 2009 while Türkiye's National Disaster Response Plan and the Urban Transformation Law were both settled in 2012 to enhance the capacity in coping with disasters.

Global observations subsequent to earthquakes, combined with numerous experimental and analytical investigations, lead to updating of seismic codes in the country. These updates involve the incorporation of innovative design principles aimed at accurately evaluating seismic hazards, structural response, and overall resilience. The concept of ductility was introduced at both member and structural levels in 1975, followed by the integration of capacity design principles and critical seismic design details in 1998. In 2007, seismic assessment and retrofitting requirements for existing buildings were added to the code (Ilki & Celep, 2012). More recently, the Türkiye Building Earthquake Code was revised in 2018 (TBEC, 2018). Although seismic codes have been improved for the well-being of structural design and construction since the mid-1900s, amnesty laws and regulations have encouraged the unplanned development due to construction of low quality and vulnerable buildings by non-professionals. The Slum Law no. 775 enacted in 1966, aimed to rehabilitate such areas and took measure in prevention of un-planned development in the future. However, slumisation could not be prevented and another amnesty was enacted in 1976. In 1983, slums built until 1981 were legalized. The 1984 amnesty law reduced the implementation difficulties in the previous laws, provided the right to obtain title deeds, and allowed squatters to build up to 4 storeys on their own land (Sönmez, 1996). Within the new millenium, some amendments were made to the articles of related laws as amnesty. Finally, in 2018, a comprehensive amnesty law was enacted (Figure 2).

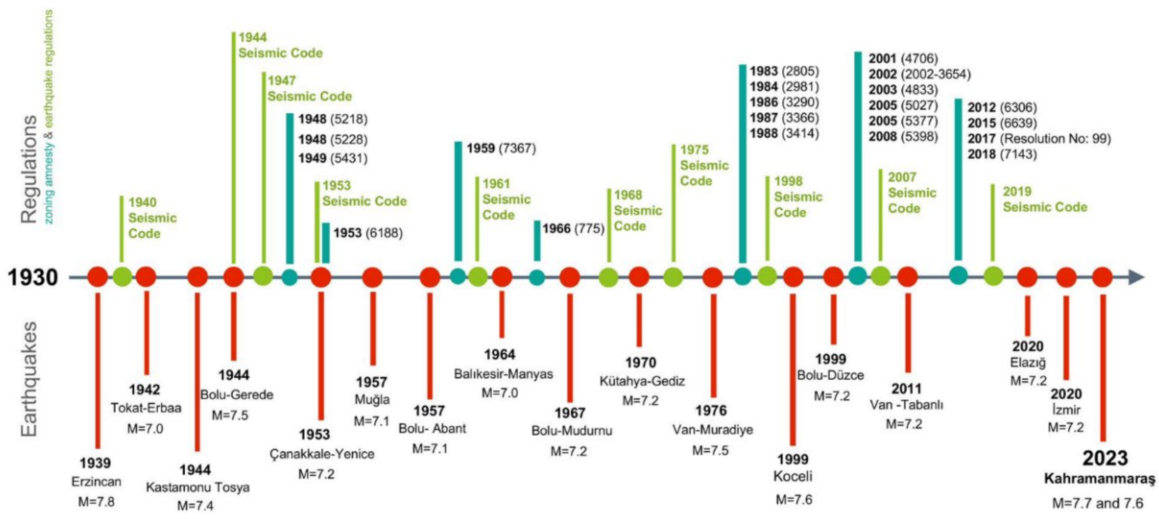

Figure 2 Timeline of earthquakes larger than M_W 7.0 and regulations.

2.1. *Performance of Structures*

At 03:02 a.m. (local time), on August 17, 1999, a M_w 7.4 earthquake occurred on the NAF, which is right-lateral strike-slip fault, in northwestern Türkiye. The hypocenter was located at a depth of 17 km at Kocaeli, 90 km east of Istanbul. Approximately 110 km of the NAF ruptured, with a maximum horizontal offset of 5.5 m and a maximum vertical offset of more than 2.3 m (Sezen et al., 2000). The majority of the destruction resulting from the 1999 Kocaeli Earthquake was centered within a 20 km radius of Gölcük, with significant impact: 18.373 casualties, 48.901 injuries, and approximately 365.000 housing and business units were damaged (TBMM, 2010). The destructive impact resulted in collapses and damage to various structures such as ports, cranes, and pipe systems, exhibiting a spectrum of damage from minor displacements to complete collapses (Altinok, 2001).

On the other hand, seismic activities in February 2023 resulted in a fault rupture spanning over 300 km along the left-lateral East Anatolian Fault. The earthquakes caused a displacement of approximately 3 to 5 meters on the fault. Near the epicenter in Kahramanmaraş-Pazarcık, peak ground acceleration values reached remarkable levels, as high as 2g (AFAD, 2023). These seismic events impacted 11 provinces in Türkiye, namely Kahramanmaraş, Adıyaman, Hatay, Osmaniye, Gaziantep, Kilis, Şanlıurfa, Diyarbakır, Malatya, Adana, and Elazığ, and affected over 14 million people. The devastation caused extensive collapses and damage to various structures, including buildings, bridges, airports, tunnels, hydraulic facilities, lifelines, and network systems. Over 90,000 reinforced concrete structures sustained severe damage, resulting in more than 50,000 casualties (MoEUCC, 2023; SBO, 2023). The region exhibited extensive damage across numerous structures, as illustrated in Figure 3.

Figure 3 A view from the earthquake-hit area, Hatay, Türkiye.

Reconnaissance studies conducted in the affected regions (either in Kocaeli or around Kahramanmaraş) have consistently identified that the inadequate seismic performance of numerous structures primarily stems from their failure to comply with seismic design codes (Sezen et al., 2000; Scawthorn, 2000; Binici et al., 2023; Avcil et al., 2023). Key vulnerabilities include soft-storey buildings, irregular structures, insufficient reinforcement detailing, corrosion of reinforcement, insufficient splice lengths, unconfined lap splices and poor material quality. In numerous structures, strong beams paired with weak columns. In several instances, poorly designed infill walls restricted column height, leading to shear failures, known as short column. Transverse reinforcement was widely spaced with 90-degree hooks, lacking cross ties, thus failing to maintain sufficient ductility. Ground failures, such as liquefaction-induced soil movements and differential settlements, were widespread in certain areas. Similar damage patterns were observed in previous seismic events as well (Celep et al., 2011; Tapan et al., 2013; Gürbüz et al., 2023).

Beyond the extensive damages to buildings, the 2023 Kahramanmaraş Earthquakes had a significant impact on critical infrastructure systems, including bridges, viaducts, tunnels, railways, roadways, airports, and energy infrastructure, such as coal and gas power plants, electrical distribution and transmission networks, liquified petroleum gas terminals, as well as water and wastewater systems (EERI, 2023). It is essential to highlight that these lifelines, comprising vital facilities and structures, play a pivotal role in meeting the fundamental needs of communities as experienced in 1999 Kocaeli Earthquake. Furthermore, breakdowns in communication systems, including base stations (Figure 4a), were notable. These complex challenges posed significant obstacles to recovery and response efforts in the aftermath of the earthquakes.

After earthquakes, a critical challenge that frequently emerges is the occurrence of fires (Figure 4b). Seismic activity has the potential to disrupt gas and electrical systems, leading to leakages and short circuits, consequently sparking fires in vulnerable areas. Moreover, the collapse of buildings and infrastructure can impede firefighting efforts, intensifying the difficulty of extinguishing the fires. In the aftermath of earthquakes, the seismic performance of buildings may deteriorate due to both the structural damage from the initial earthquake and subsequent fires, amplifying the risks and challenges faced in these situations (Demir et al., 2020a; 2020b; 2022).

Figure 4a Damaged base station due to collapse of the building (photo from Kahramanmaraş).

Figure 4b Fire following earthquake (photo from Nurdağı, Gaziantep).

2.2. *Economic Outline of the 1999 Kocaeli and 2023 Kahramanmaraş Earthquakes*

The economic effects of earthquakes can be estimated through various approaches. The World Bank (1999) identifies three key aspects: direct costs (physical damage to assets), indirect costs (output losses, lost earnings, and emergency relief expenses), and secondary effects (short to medium-term consequences on overall economic performance, fiscal accounts, balance of payments, poverty rates, and government policies). Kundak (2010) offers a different perspective, categorizing economic losses as stock costs from immediate losses (e.g., building collapse), stock and flow costs from business activity losses or from infrastructure damage.

The affected region by the 1999 Kocaeli Earthquake hosts Türkiye's heavy industry, including petrochemicals, car manufacturing, paper, chemicals and cement (Durukal & Erdik, 2008). The General Directorate of Disaster Affairs of Türkiye calculated overall economic damage amounted to roughly 10 billion USD, equivalent to approximately 4% of the Gross Domestic Product (GDP) in 1999. On the other hand, Durukal and Erdik (2008) estimated the total cost around 16 billion USD, which accounts for 7% of the GDP in 1999. In the damage report published by the Turkish Earthquake Foundation, direct losses were estimated to be over 5 billion USD (Özmen, 2000). Therefore, the expected indirect losses were either equal or greater than the direct losses due to 1999 Kocaeli Earthquake.

The economic context of the 2023 Kahramanmaraş Earthquakes is notable. The affected region, comprising 11 provinces, accounted for 9.8% of GDP in 2021, contributing approximately 79 billion USD to the national income. However, the per capita national income in these provinces falls below the national average, with an average per capita GDP of 5.924 USD in 2021. Despite this, the region played a significant role in national economic growth, contributing 0.98 points to the 11.4% growth recorded in 2021. In terms of exports, the region held an 8.6% share in 2022, with Gaziantep standing out with a 4.4% share. The 11 provinces collectively represented 6.7% of the 2022 imports, with Gaziantep and Hatay leading with shares of 2.3% and 2.1%, respectively.

Various organizations and public offices have presented divergent economic impact assessments following the 2023 Kahramanmaraş Earthquakes. TURKONFED (2023) suggests an economic cost of 84 billion USD, equivalent to 10.3% of the 2021 GDP. Strategy and Budget Office of Presidency of Türkiye (2023) emphasizes housing damage as the primary economic burden, accounting for 54.9% (1,073.9 billion TRY; 56.9 billion USD), followed by public infrastructure and service buildings at 12.9 billion USD. Private sector damage, excluding housing, was estimated at 11.8 billion USD, covering various industries and sectors. Taking into account insurance sector losses, tradespersons' revenue losses, and macroeconomic impacts, the total financial burden was estimated at 2 trillion TRY (103.6 billion USD), equal to 9% of the 2023 GDP forecast. According to BETAM (2023), the total financial burden ranges from 77.4 to 104.8 billion USD, representing 8.6% to 11.6% of the GDP forecast for 2023.

In the year preceding the earthquake, the 11 provinces collectively exported 11.1 billion USD between February and July 2022. However, after the earthquakes in 2023, total exports during the same months declined to 8.9 billion USD, marking a 20% decrease. Gaziantep, the leading exporter in the region, witnessed a decline of nearly 0.5 billion USD but displayed signs of recovery. In contrast, Hatay and Kahramanmaraş did not show similar signs of improvement. According to the TEPAV Employment Watch May 2023 Bulletin (TEPAV, 2023), the employment declined in the 11 provinces amounted to 374.5 thousand jobs, equivalent to around 1% of total employment, in the first five months of 2023. This decline varied across provinces, reaching 30% in Malatya, Kahramanmaraş, and Hatay due to life losses and migration. Elazığ, Kilis, Gaziantep, and Şanlıurfa experienced a 10% decline, while other affected provinces like Kilis, Adana, Diyarbakır, and Osmaniye saw a 5% decrease in employment (Figure 5).

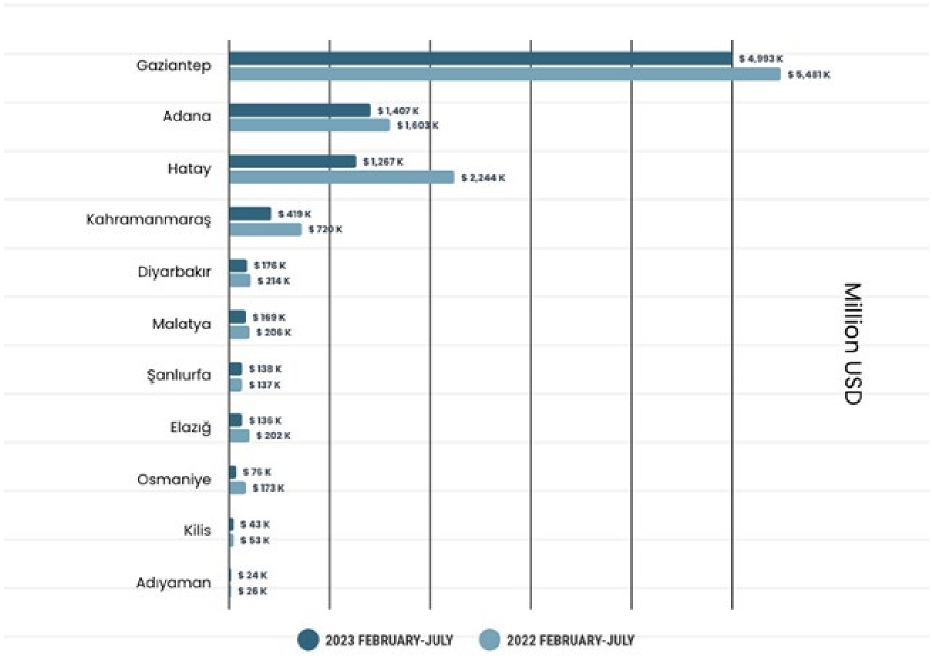

Figure 5 Provincial exports before and after the 2023 Kahramanmaraş Earthquakes (Turkstat, 2023).

3. Methodology: Impact Chain and Forensic Analysis

The components of risk and their interactions present complex systems which are able to cause chaotic situations once facing severe hazards. Consequently, delineation of these components within their specific features, particularly for risk assessment, provides a wider perspective to better understand the causal relationship among them which can either amplify or mitigate the adverse impacts of hazards. Hereby, the forensic investigation of disasters project (FORIN 2011; Oliver-Smith et al. 2019) launched an innovative perspective on risk assessment. For instance, organizations such as Forensic Architecture aim to identify the social, economic, political, environmental, and cultural factors that influence the root causes of events by using spatial techniques and technologies (Weizman et al., 2010). Similarly, the Forensic Investigations of Disasters (FORIN 2011; Oliver-Smith et al., 2019) project embraces a comprehensive causal typology that recognizes the intricate interplay of human agency and natural processes in disaster risk.

Impact Chain is a collaborative framework developed by Eurac Research in partnership with various stakeholders, originally designed for climate risk assessments in the European Alps and later applied to Germany's national climate risk and vulnerability study (Pittore et al., 2023). This framework presents intricate cause-and-effect relationships behind specific climate risks within a defined context. It categorizes factors and processes into hazard, vulnerability, or exposure components, emphasizing participatory development that integrates local data, knowledge, and past experiences. They are graphical models that depict the causal relationships between climate hazards, exposure, vulnerability, and risk outcomes in a specific context (e.g., region, sector, system) (PARATUS Project, 2023). The visual representations of complex climate interactions enable effective communication and collaboration among stakeholders, ensuring a holistic understanding of climate change impacts and risks (Zebisch et al., 2022). They evolve from current climate risk scenarios to embrace future projections, considering shifts in climate, exposure (e.g., urbanization), and vulnerabilities (e.g., an aging population).

Although initially employed to delineate complex systems on the focus of climate change, the IC method extends its applicability to synthesize the causal relationships based on different hazards and their potential impacts. Likewise to its utilization in climate change studies, the IC method applied to hazard and risk evaluation yields outcomes from a collaborative and participatory process, engaging both experts and stakeholders. This collaborative effort forms the foundation for a robust risk assessment, aligning with the fundamental components of risks, namely hazard, exposure, and vulnerability. These assessments illustrate how different hazards can trigger cascading impacts across diverse exposed subsystems (United Nations Office for Disaster Risk Reduction, 2019). Moreover, the IC method provides a comprehensive perspective on how risks spread through systems, contributing to an enhanced comprehension of systemic risks. Impact chains also help to discuss potential risk reduction measures in the early stages of the risk assessment process by highlighting vulnerabilities, identifying adaptation gaps and explaining risk mechanisms. Thus, the IC method emerges as a valuable tool not only in climate change studies but also in broader hazard and risk evaluation scenarios.

4. Discussion

In this section, based on the background presented previously, the 1999 Kocaeli and Kahramanmaraş Earthquakes are reviewed through the perspective of IC approach. To deploy the IC analysis on these events, a comprehensive dataset encompassing losses, detailed information about damaged structures (buildings, infrastructure, etc.), scientific findings, and operational reports were thoroughly collected. To conduct IC analysis effectively, a software platform is required to facilitate efficient visualization, along with a database capable of managing structured data updates. Among several available options, the KUMU and MIRO software tools have been employed for IC analysis due to their user-friendly interfaces, offering advantages in data representation (Kumu 2011; Miro, 2011). They facilitate ease of comprehension while accurately capturing the complexity inherent in the system. The IC analysis of 1999 Kocaeli and 2023 Kahramanmaraş Earthquakes are presented in Figures 6 and 7, respectively.

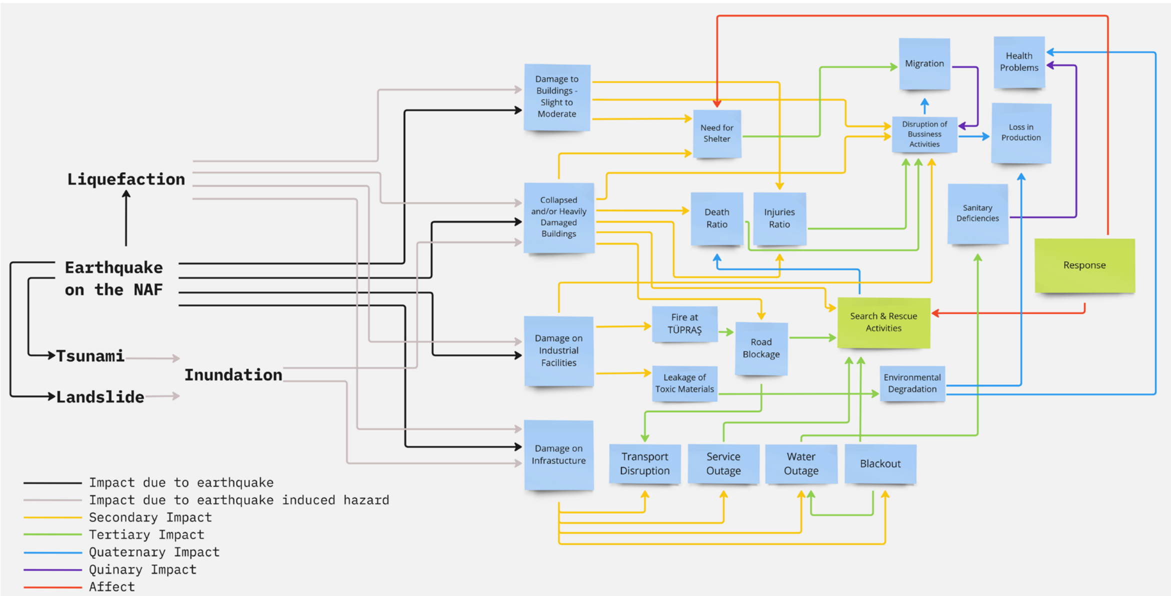

Figure 6 Visualization of impact chain for 1999 Kocaeli Earthquake.

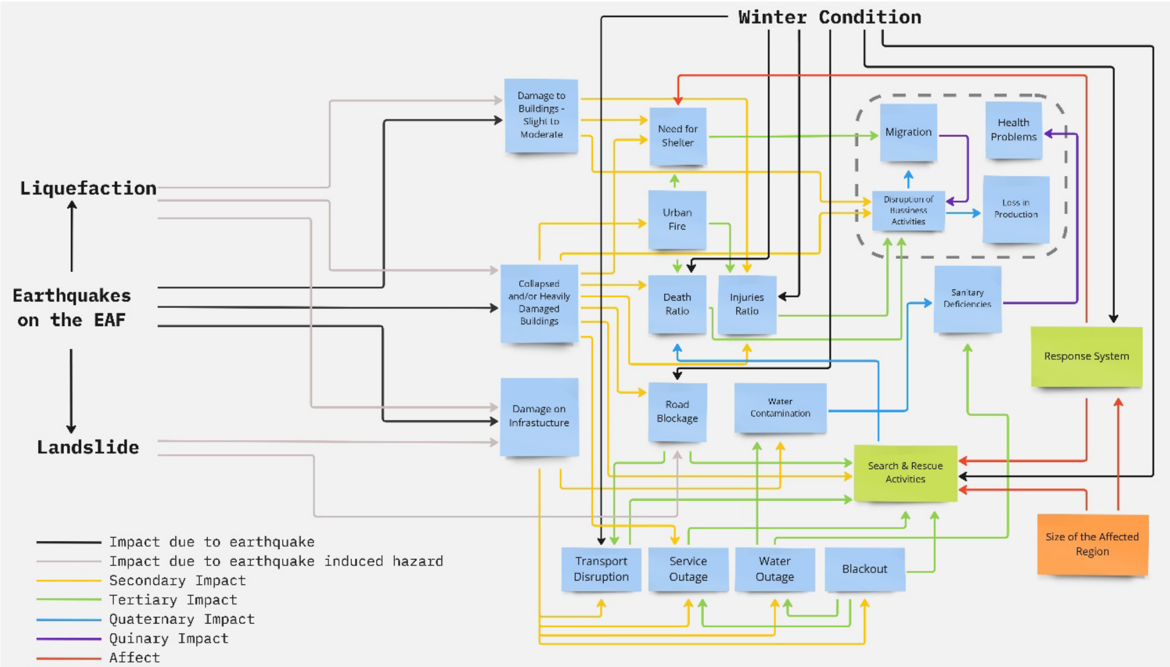

Figure 7 Visualization of impact chain for 2023 Kahramanmaraş Earthquakes.

The diagrams produced to illustrate the IC process of both earthquakes outline the sequence of each impact on the response system. Black arrows depict the immediate and direct effects of earthquakes, while gray arrows define the impacts resulting from earthquake-induced hazards. Orange arrows represent secondary impacts stemming from physical failures in the urban system. Likewise, green, blue and purple arrows show consecutive impacts. Red arrows are associated with the response process, signifying an "affect" on specific situations and notions. Thereby, green boxes refer to interventions to ease the adverse consequences of these calamities.

It's important to highlight that the temporal characteristics of both earthquakes were comparable, with the 1999 Kocaeli Earthquake occurring at 03:02 (local time) and the first earthquake taking place at 04:17 (local time) for 2023 Kahramanmaraş Earthquakes. When assessing the magnitude of these earthquakes, both are classified as devastating, falling into the category of seismic activity with a M_w exceeding 7.0. However, the challenging situation during the 2023 Kahramanmaraş Earthquakes was further exacerbated by adverse winter conditions.

When comparing the earthquake-induced hazards in both cases, it is observed that liquefaction caused settlement in the field land zone and water saturated area. On the other hand, inundation occurred after the 1999 Kocaeli Earthquake due to a local landslide through the Izmit Bay and tsunami triggered by the earthquake (Altinok, 2001). Whereas aftermath of 2023 Kahramanmaraş Earthquakes, landslides were observed mostly at mountainous areas where the roads were either physically damaged or blocked by rockfall.

As aforementioned, due to the persistency of the repetitive inadequate implementation practices in structural systems of buildings, both earthquakes led to total collapse on significant number of buildings, causing an increase in casualties. Furthermore, the increased ratio of uninhabitable residential buildings was led to a notable demand for immediate temporary and then permanent shelters.

In both instances, significant disruptions to infrastructural facilities were evident albeit with some nuances. The damage on transportation system can be examined based on physical and functional failures. Physical failures result from the deformation of transportation modes and blockages due to various reasons. Functional failures pertain to the overburdening of transportation infrastructure due to high demand, also known as traffic. Since the viaducts and tunnels of the main highway (known as TEM) were not completed in 1999, the direct highway connection between Istanbul and Ankara was only provided by the Bolu Mountain pass (known as

D100). During the 1999 Kocaeli Earthquake, two expressways traveling from Istanbul to Ankara remained undamaged; however, some connections, such as bridges, collapsed, impeding traffic flow in the transit circulation. For instance, at the Sakarya crossing of the TEM highway, a part of the road was out of use due to ground subsidence and bridge collapses. Within the inner city, collapsed buildings obstructed the passage of emergency vehicles and private cars. Additionally, a large fire at the TÜPRAŞ Oil Refinery hindered traffic flow in the surrounding area. Furthermore, heavy and accelerated traffic from/to the affected area caused congestions, as observed during the 2023 Kahramanmaraş Earthquakes as well. The performance of the transportation system aftermath of the 2023 Kahramanmaraş Earthquakes can be considered deficient due to large cracks and subsidence on transit roads, blockages from collapsed buildings, and large rocks resulting from local landslides. Moreover, heavy snow made accessibility more difficult in several areas. In certain zones, rails were bent in an 'S' shape, a phenomenon also observed as a consequence of the 1999 Kocaeli Earthquake. Regarding the performance of transportation modes, damages to maritime transport following the 1999 Kocaeli Earthquake and air transport after 2023 Kahramanmaraş Earthquakes were highlighted. In the case of the 1999 Kocaeli Earthquake, the epicenter was located at Gölcük in the İzmit Bay, where several ports and docks were situated for logistics and passenger transportation. However, either due to liquefaction in the area or a lack of anchorage at the docks, sea transportation infrastructure sustained notable damages, making them unusable for evacuation and the delivery of necessary goods. Likewise, 2023 Kahramanmaraş Earthquakes caused lateral crack on runway at the Hatay Airport. Given that Hatay was the most severely impacted region among the provinces affected by the 2023 Kahramanmaraş Earthquakes, the destruction of the airport hindered immediate response efforts.

The failures and malfunctions of other infrastructural facilities, including water, sewerage, electricity, natural gas, and communication systems, had cascading impacts primarily on search and rescue activities and the living conditions of earthquake survivors. The breakage of pipe systems in both earthquakes resulted in interference with water and sewerage systems, leading to sanitary problems for earthquake survivors and response and recovery teams. A notable difference in the IC of infrastructural deficiencies when comparing the 1999 and 2023 earthquakes is evident in the realm of communication. In 1999, mobile phone coverage and usage in Türkiye were limited. According to TÜBITAK-BILGEM (2001), the number of mobile phone users was around 8 million, constituting approximately 12% of the country's population. In contrast, landline analogue phones were still prevalent for communication. Therefore, despite widespread destruction during the 1999 Kocaeli Earthquake, analogue lines worked properly and remained unaffected by the blackout. From the 1999 through 2023, while landline analogue phone subscriptions decreased from 33% to 13% according to the population, mobile subscriptions increased from 12% to 105% (BTK, 2023). Consequently, communication system has become more dependent on the functioning of mobile infrastructure system. During 2023 Kahramanmaraş Earthquakes, base stations which had been installed on the tops of buildings suffered damage due to the collapse of these structures (Figure 4a). Furthermore, prolonged power outages led to the depletion of mobile phone batteries and the incapacitation of standing base stations, hindering communication. Recognizing the widespread use of mobile communication, it's clear that it has made sharing information easier, even in challenging situations, such as identifying the location of victims under debris, when it's functioning properly. However, it's important to note that along with its benefits, it also facilitates the dissemination of misinformation and the spread of provocative news.

When natural hazards strike large settlements, it is nearly inevitable that they trigger technological accidents, commonly referred to as NaTech (natural hazards triggering technological accidents). Such incidents occurred in both earthquakes. During the 1999 Kocaeli Earthquake, which took place near Türkiye's most industrialized region, several industrial facilities sustained damage, leading to environmental degradation due to the leakage of toxic materials. It should be noted that the most immediate consequences of earthquakes can be described but it is always challenging to comprehend the latent impacts. For instance, details concerning environmental degradation following the 1999 Kocaeli Earthquake and its subsequent effects on public health only became apparent three to five years after the seismic event (Dündar & Altundağ, 2002; Dündar & Pala, 2003; Cruz et al., 2004; Steinberg & Cruz, 2004). As a long-term consequence, it has been observed that the health of individuals exposed to toxic substances was adversely affected (Girgin, 2011). Furthermore, the most notable accident was the fire at the Tüpraş Oil Refinery. Similarly, in the 2023 Kahramanmaraş Earthquakes, urban fires were observed in some parts of inner cities. Additionally, a fire broke out at the Iskenderun Port in the dock zone, highlighting the multifaceted challenges associated with technological accidents triggered by seismic events.

Prior to the 2023 Kahramanmaraş Earthquakes, the 1939 Erzincan Earthquake held the highest fatality toll, with the 1999 Kocaeli Earthquake ranking the second. The substantial increase in casualties during the 2023 Kahramanmaraş Earthquakes can be attributed not only to the magnitude of the earthquakes but also to the vulnerability of the building stock. Additionally, harsh winter conditions and shortcomings in search and rescue operations contributed to the increase in life losses. Unlike the 1999 Kocaeli Earthquake, which occurred in August, allowing disaster victims to meet their sheltering needs in open areas and tents, the 2023 Kahramanmaraş Earthquakes in February presented challenges. The tents dispatched to the region provided limited protection, and the construction of temporary shelters took a considerable amount of time. Nevertheless, in both earthquakes, temporary migrations occurred as the demand for shelter could not be fully met. Furthermore, since many sectors were damaged, disrupting trade, disaster victims migrated due to difficulties in meeting their daily needs. As a consequence of migration, even businesses that survived the earthquake without damage suffered, they struggled to find both employees and customers.

When comparing the response systems of both earthquakes, it is worthy to note that, during the 1999 Kocaeli Earthquake period, disaster and risk management practices were not well established, briefly, a formalized response “system” was absent. Furthermore, there was no comprehensive management system in place to be implemented after such a significant disaster. Therefore, voluntary efforts played a crucial role in search and rescue activities following the 1999 Kocaeli Earthquake. However, from 1999 to 2023, several new adjustments have been made in the disaster response system, including the Disaster Response Plan of Türkiye established by AFAD (2013). During the 2023 Kahramanmaraş Earthquakes, the primary reasons for deficiencies in the implementation of the response plan were the size of the earthquake-hit region (11 provinces) and severe winter conditions. Moreover, inadequate personnel and equipment, along with a lack of organization, posed additional challenges in field operations. In addition to bottlenecks in search and rescue activities, there were logistic problems in providing shelter for the disaster victims after the earthquake.

5. Conclusion

Resilience in a crisis involves anticipating, mitigating, and preparing for probable risks, ensuring systems (hereby urban systems) maintain their integrity and functionality. Therefore, evaluating disasters based on consequences offers valuable lessons for the future by providing a comprehensive perspective on direct and indirect impacts. Hence, this study highlights the importance of causal relationship of cascading effects of disasters through a holistic approach. The comparative analysis of the 1999 Kocaeli and 2023 Kahramanmaraş Earthquakes reveals the evolution in Türkiye's risk mitigation strategies.

Notably, the 1999 Kocaeli Earthquake prompted significant changes in construction practices, legislation, and the establishment of disaster response mechanisms, expected to improve resilience. On the other hand, both earthquakes revealed seismic deficiencies of the buildings leading to extensive damage. The impact on critical infrastructure, including transportation, communication, and energy systems, highlights the cascading effects of earthquakes on communities. Lessons from the breakdowns in communication systems post-2023 Kahramanmaraş Earthquakes emphasize the growing dependence on mobile infrastructure and the need for resilient communication strategies. The overview of economic losses, export declines, and employment shifts provides valuable insights for future risk mitigation and recovery planning. The employed IC methodology reveals the complex causal relationships between hazards, exposure, vulnerability, and risk outcomes. The visual representations aid in communication and collaboration among stakeholders, offering a comprehensive perspective on systemic risks.

In conclusion, this study contributes to the broader understanding of disaster resilience by offering insights into the interconnected consequences of earthquakes. The findings provide a foundation for future research, policy development, and practical strategies to enhance disaster preparedness and response, ultimately fostering a more resilient society in the face of events.

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Resume

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