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Root cause of Critical Infrastructure Failures in the 2023 Southeast Turkey Earthquake: A case study from Hatay

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The 2023 Turkey Earthquake caused widespread collapse and severe damage to Hatay's critical infrastructure, including the airport, water pipelines, telecommunications, railroads, roads, hospitals, and the harbor. These damages resulted in significant destruction and also disrupted search and rescue operations, delayed emergency aid. This devastating event highlighted the inadequacies in pre-disaster planning in Turkey. Shortly after the event, recovery policies were rapidly formulated to address urgent needs which led to reactive measures that focused on returning to baseline conditions. Unfortunately, such approaches perpetuated existing vulnerabilities, as the root causes of these weaknesses were not identified and addressed. Over time, these reactive measures exacerbated social, economic, and environmental challenges, turning future natural disasters into more severe crisis. A proactive approach that incorporates pre-disaster vulnerability assessments and infrastructure evaluations is essential for building long-term resilience. This research fills a critical gap in disaster literature by investigating the root causes of infrastructure failures during the 2023 Southeast Turkey earthquake. Specifically, we explored the shortcomings in disaster management processes and infrastructure planning in Hatay, Turkey that contributed to catastrophic outcomes. The study utilizes a combination of stakeholder interviews, event analysis, and qualitative fault tree analysis to identify these root causes, which remain unclear more than a year after the earthquake. Building on this understanding, we evaluated post-disaster recovery plans to assess their ability to mitigate these identified vulnerabilities. The results offer valuable insights into improving disaster preparedness and recovery strategies.

Keywords: Disaster resilience, earthquake impact, 2023 Southeast Turkey Earthquake, Fault tree analysis, critical infrastructure.

1. Introduction

On February 6th, 2023 southeastern Turkey was hit by two strong earthquakes, with magnitudes of 7.7 and 7.6, centered in Kahramanmaras and Elbistan (AFAD, n.d.-a). These earthquakes caused great destruction in both Turkey and Syria. The impact area of the earthquake in Turkey covered 11 provinces and affected a total of 14 million people which is equal to 16% of the country's total population. In Turkey alone, approximately 50,000 people lost their lives and around 2 million people have been evacuated, hundreds of thousands people suffered the loss of a limb (AFAD, n.d.-b).

Search and rescue efforts began promptly after the earthquakes and continued tirelessly for days. The Turkish government has classified this earthquake as a Level-4 emergency under the Turkey Disaster Response Plan (TAMP), which is the highest level of crisis in the plan. This declaration calls for international aid in addition to the involvement of both first and second group supporting provinces and national resources (Şenol Balaban et al. 2024).

One month after the earthquake, the Presidency of Strategy and Budget announced that the total cost of this disaster to the country was 103.6 billion dollars (Strategy and Budget

Office of the Presidency of the Republic of Türkiye., n.d.). This amount represents a significant financial burden, equivalent to a substantial portion of the national budget, and highlights the extensive economic impact of the disaster.

The 2023 earthquake in Turkey emphasized critical deficiencies in the country's disaster preparedness and response, particularly regarding the management of critical infrastructure. It is important to recognize that the sheer number of casualties and extent of destruction cannot be attributed only to the earthquakes themselves. While powerful earthquakes are a common occurrence in various parts of the world, including countries like Japan and Chile, they do not always result in such catastrophic outcomes. The disparity in the impact of similar magnitude earthquakes can often be traced back to differences in disaster management.

In this paper, we aim to uncover the root causes that contributed to these failures and evaluate post-disaster recovery plans. We argue that in order to be resilient against the future uncertain natural disasters, root causes need to be identified and minimized during the recovery processes to ensure that vulnerabilities are not repeated and existing weaknesses due to inadequate planning are minimized. To do so, this study focuses on the identification of the shortcomings in critical infrastructure planning and management using qualitative fault tree analysis. In addition, we empirically explore how the current recovery plans that are published by the local and central government address these shortcomings.

2. Method

A mixed-methods approach was selected for this case study to provide an understanding of the key factors at play. The study includes qualitative analysis based on semi-structured interviews that is conducted in June 2023, 6-months after the main shock (Aydin et al. 2025) which allowed us to identify the key critical infrastructures based on stakeholder experiences and perspectives. To investigate the root causes of system failures, Fault Tree Analysis (FTA) is employed to identify underlying issues and contributing factors. finally, we evaluated the effectiveness of long-term recovery plans through a comparative analysis of retrospective and prospective risk assessments.

2.1. *Key CI Identification*

Semi-structured interviews conducted by the international research group in June 2023 was used for content analysis. Interviews were conducted with diverse stakeholders, including government officials, members of professional chambers, private sector participants, representatives from legal and institutional bodies, academic professionals and people who live in tent and container settlements, analysed for this study. Our interview protocol consists of 4 main sections, (1) factors leading to catastrophic results, (2) immediate effects of the earthquake (3) post-earthquake conditions (4) opportunities and challenges for recovery. The main questions and interview protocol was published in (Aydin et al. 2025). To identify the root causes, we mainly focused on the interviewees' response on the first and the second part.

In this paper, we applied a thematic analysis to identify, analyse, and report patterns (themes) within data that is specifically focusing on the identification of key infrastructure that led to the major disruption during disaster. The code list and the terms that is used within each code for the identification of the key infrastructure is given in Table 1.

Table 1. Codes and Terms used in analysis of semi-structured interviews

Code	Terms
Education, faculty, campus, classroom	school, teacher, university, student,
Public Buildings	municipal office, government building
Healthcare	hospital, clinic, ambulance, doctor, nurse, medical staff, pharmacy, medicine, treatment

Safety and Security	Police, military, fire department, security, crime, protection, surveillance
Shelter	House, residence
Telecommunication	phone line, internet, signal, connectivity
Transportation	highway, road, railway, port, airport, bus, train, route
Water and Energy Supply	water distribution, sewage, drainage, electricity, power, energy grid, generator, power outage, water outage, gas, gas line

The outcome of this thematic analysis lead to the identification of the key infrastructures.

2.2. *Root cause analysis*

After key critical infrastructures are identified, an analysis was conducted to explore the root causes underlying the management processes of CI's prior to the earthquake. Qualitative FTA was selected as a root cause analysis tool for this research. The first step in the FTA for each critical infrastructure is to define the top event, which represented the system's overall failure during the earthquake. From there, branches were developed to identify the various contributing factors and failure modes that led to this top event until root causes were found.

To derive this information we reviewed the planning, risk assessments, maintenance, and safety measures that were in place before the earthquake in order to identify weaknesses that may have caused the systems to fail during the disaster. Causality reports were reviewed to understand how these planning issues turned into real-world problems. We also looked at government and field reports, which explain how the disaster affected lifelines such as power, water, and healthcare systems. These reports help us understand what went wrong and how the failures unfolded.

2.3. *Evaluation of long-term recovery plans*

In this step, we applied an empirical evaluation of future plans for Hatay. These plans, accessible on the Hatay Planning Office's (Hatay Planlama Merkei, n.d.) websites and the Presidency of Strategy and Budget's earthquake assessment report (Strategy and Budget Office of the Presidency of the Republic of Türkiye., n.d.). The goal of this analysis is to assess the potential impacts of these proposed plans on the resilience and sustainability of Hatay's critical infrastructure systems. The evaluation also focuses on whether these new plans address the root causes identified in previous failures and demonstrate a recognition of past mistakes and shortcomings.

3. Results

3.1. *Key CI Identification*

Figure 1 illustrates the co-occurance matrix for the thematic analysis results.

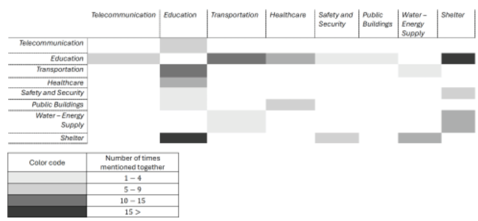

Figure 1. Co-occurrence Matrix

In the interviews, the code 'Education' emerged as one of the frequently mentioned topics, highlighting its importance for recovery, not only for children but for the entire community. Many interviewees emphasized that those who left the city after the earthquake are unlikely to return unless there is a school available for their children to attend. The importance of 'Education' in these discussions is notable, as it frequently appears in conjunction with other infrastructure related codes.

Healthcare services emerged as a major area of concern, not only due to the frequency that it was discussed but also because of the content of the discussions. The inadequacy of healthcare services in immediate recovery was attributed in part to the destruction of half of the public hospitals during the earthquake, where interviews revealed that this destruction was an excepted outcome due to known structural vulnerabilities of public hospital buildings. This suggested that the healthcare system had existing vulnerabilities long before the disaster struck.

Another system that emerged as a significant critical infrastructure in the analysis was transportation services. The damage inflicted on transportation systems by the earthquake created significant obstacles, both for immediate rescue efforts and the broader recovery process. These disruptions hindered the delivery of essential aid and slowed the city's overall path to recovery. Within the code of 'Transportation', two main systems emerged: airport and arterial road. The airport faced significant criticism, especially regarding its site selection during spatial planning. Concerns about its location had been a subject of debate for years prior to the earthquake, with many highlighting that the ground on which it was built was not resistant.

In conclusion, education sector, healthcare services, and airport and main arterial road within transportation systems were selected as key critical infrastructures. These structures appeared not only fundamental to meeting the immediate needs of the population but also essential for ensuring long-term resilience in Hatay.

3.2. *Root cause analysis*

We applied root cause analysis to the identified key critical infrastructures mainly health care system, education and transportation systems. However, it is important to clarify that the education sector, although identified as one of the key critical infrastructures in the previous chapter, was not included in the subsequent analysis. The main reason is the lack of available documents and reports about educational facilities on the pre and post disaster conditions.

Fault tree analysis of health care: Before the earthquake, Hatay had twelve public hospitals. Four districts, namely Payas, Arsuz, Belen, and Defne, lacked public hospitals entirely. The earthquake resulted in either complete collapse or severe damage to more than half of the public hospitals, making them unusable and necessitating their evacuation. At the end, districts had public hospital were Dörtyol, Hassa, Kumlu and Yayladagi. Damages to public hospitals in Iskenderun resulted in causalities due to the collapsed ICU unit.

Furthermore, some hospitals were not operational due to the unavailable services to ICU patients as a result of generator failure. Some functional hospitals that sustained severe damages were evacuated due to the risk of collapse. Of these, only the hospitals in Dörtyol and Hassa had ICU capacity, with 62 beds in Dörtyol and 8 in Hassa however, capacity problems and staff shortages lead to failure of the entire system.

Figure 2 illustrates the fault tree analysis for the healthcare system. This analysis identified two key factors contributing to hospital capacity overload: the pre-existing bed shortage and the loss of hospital buildings due to earthquake damage. These factors were connected using an OR gate, meaning that either the loss of functional hospitals or the sudden increase in demand could have been enough to overwhelm the system. The root cause of the bed shortage was traced to failures in resource allocation and distribution, which were linked with an AND gate, indicating both factors were necessary for the shortage. If only one failure occurred, other regions with sufficient beds could have alleviated the burden, but the combination of both led to the critical shortage.

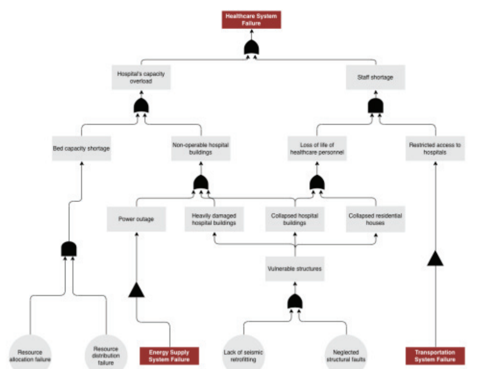

Figure 2. Fault Tree Analysis of healthcare services

Fault tree analysis of transportation system:

Based on interviews and reviewing of reports, it was evident that the earthquake caused extensive damage to Hatay Airport, making it unusable during the initial emergency response efforts. Hatay Airport was closed to traffic due to fractures and cracks at 45 different points along the 3-kilometer runway after the earthquake (Palabiyik 2023). According to the preliminary assessment report by (TMMOB 2023b), the road infrastructure in Hatay was non-functional for the first two days following the earthquake. As a result, aid trucks were unable to reach the city during this critical period. Moreover, heavy construction equipment, such as caterpillars, required for rubble removal for access to people under and rescue teams could not access the city due to the severe damage on the roads (TMMOB 2023a).

Site selection of Hatay airport was a major contributing factors. The main problem here is that it was built on the type of soul that is prone to liquefaction. Furthermore, the airport is located at the intersection of three faults, Dead Sea Fault, Karasu Fault, and Cyprus- Antakya Fault (Özşahin 2024) which intensify the vulnerabilities. Therefore both spatial and structural vulnerability were identified as critical factors contributing the runway damage and connected through AND gate.

Figure 3 illustrates the fault tree analysis for the transportation system. The first major factor contributing to the failure of the transportation system is the non-operational status of Hatay Airport. This resulted from failures in the water and energy infrastructure, significant damage to the runway, and damage to the airport's connection road to the city. These three factors are connected to the airport's non-operational state via an OR gate, as any one of them could have compromised the airport's functionality. While the water and energy failures are outside the scope of this study, it is important to note that these were linked via an OR gate, as each independently contributed to the airport's overall infrastructure failure.

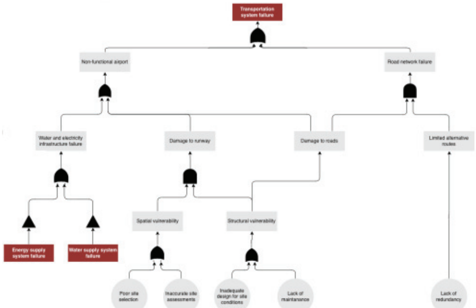

Figure 3. Fault Tree Analysis of transportation infrastructure

3.3. *Evaluation of long-term recovery plans*

Shortly after the earthquake and completion of the immediate recovery actions, central and local governments have published master plans for Hatay. These plans include information on site selection, infrastructure expansions as well.

According to the published plans for health care services, it is expected to build more hospitals and distribute them more evenly through the city and districts in Hatay. On the other hand, there is no indication on if this expansion will also increase the bed capacity of the hospitals. Without a significant expansion, the long-term plans remains insufficient to meet the needs of the population.

As mentioned, staff shortage was one of the causes of the healthcare system failure which was associated with two main factors "loss of healthcare personnel" and "transportation system failure". It is unclear how the new plans will directly address this risk in the future. Our analysis showed that accessibility via transport network could alleviate some of these issues including staff shortage. Furthermore, site selection of the hospitals need to be done carefully considering the accessibility which can directly impact the risk of staff shortage. We found no evidence that comprehensive assessments (such as investigations on proximity to risky areas) have been conducted to evaluate the suitability of the proposed locations for the new road networks or hospitals in the updated plans.

The new road network plans provide alternative routes that enhance connectivity and reduce dependency on single pathways. With the introduction of new transportation routes, including the Payas-Hassa connection and the extension of highways to Reyhanli, the overall redundancy of the transportation network has been improved. However, road extensions still exclude some districts that previously had limited accessibility, such as Kumlu and Altinözü.

For the airport recovery, structural reinforcements, such as runway renovations and upgraded flood barriers, are intended to enhance the airports resilience are planned. These interventions alone may not be sufficient in the event of a high-impact disaster. These measures address immediate concerns but do not eliminate the fundamental risks associated with the airports geographic and geological setting.

4. Discussion

Our analysis showed that even before the 6th of February earthquake, vulnerabilities in the health care system existed. One significant factor leading to disaster was the insufficient bed capacities in Hatay. Compounded factors such as the loss of hospital buildings and the unavailable critical services (i.e., power and transportation) due to earthquake damage rendered healthcare system dysfunctional and severely limited its capacity to provide essential medical care and emergency response.

Furthermore, we identified that the resource allocation and distribution (such as site selection of the critical functions as healthcare system) resulted in high susceptibility to critical failures. Clearly, spatial planning of critical services needs careful consideration of high magnitude events to prevent hazards turn into disasters with catastrophic consequences. Currently, factors such as staff shortage, accessibility to critical services after disasters, detrimental effects of cascading failures are not considered when planning healthcare systems and allocation of the facilities. Pre-disaster planning should take into account these factors, and enhance disaster management plans accordingly.

When the recovery plans were investigated in terms of how they address the pre-existing problems, it was noted that the distribution of resources was more even across the districts in Hatay. The planned increase in bed capacities together with the even distribution of resources is expected to help healthcare systems in future disruptions. On the other hand, there are still open points to be addressed, such as lack of seismic retrofitting of health care facilities which remains unresolved in the recovery plans. Furthermore, staff shortage risk is closely tied to the transportation systems resilience. Yet, recovery plans currently do not handle dependencies between systems explicitly. We argue that dependency between transportation and healthcare system and co-planning would help strengthening the disaster management process in Turkey.

The failure of the transportation system in Hatay during the earthquake revealed the importance of redundant capacity to recover after the disasters. inadequate design for site conditions, lack of maintenance and redundancy and poor site selection of airport in Hatay led to significant delays in emergency response. While road network redundancy was addressed in the new plans by increasing the alternative routes, the airport location remained the same.

The current recovery plan for the airport aims to apply structural reinforcements such as runway renovations, and flood barriers. The decision to maintain the current airport location despite its vulnerabilities is in fact a common issue in infrastructure planning globally. Once the significant investments are committed in a particular site, decision makers opt in to reinforcing the existing structures rather than considering a more suitable alternative location. In Hatay's case, while above-mentioned structural reinforcements may mitigate some risks, the root cause of the problem which is the poor site selection remains unresolved.

For long term resilience, recovery plans must address all root causes in the future plans. Siloed sectoral planning and management leads to cascading failures and result in more detrimental consequences when critical infrastructures are exposed to high impact disasters. Furthermore recovery strategies should go beyond reactive recovery measures such as reinforcing existing structures which only perpetuate the vulnerabilities. Instead, the disaster management plans should focus on integrated, adaptive recovery approaches to enhance the preparedness for high impact disasters and enable transformative shifts in infrastructure planning.

4. Conclusion

While Hatay's recovery plans have factors on critical infrastructure improvements, such as healthcare capacity and transportation network redundancy, they often address immediate needs without fully mitigating root causes, which contrasts with the Sendai Framework's emphasis on eliminating risks at their source.

Turkey's disaster management strategies could benefit from integrating these global frameworks, and aligning recovery policies with long-term resilience metrics within these frameworks. Alignment with global best practices, particularly in governance, risk assessments, and cross-sector resilience building, would strengthen Turkey's ability to adapt recovery strategies to its unique geographic and seismic challenges.

Finally, it has been emphasized that the going back to the status-quo after disasters results in perpetuating the existing vulnerabilities (Birkmann et al. 2010). Recovery and reconstruction planning should focus on transformative changes and avoid short-sighted decisions (Krishnan, Aydin, and Comes 2024). To be able to endorse transformation towards long-term resilience, we argue that recovery plans must comprehensively address all significant root causes.

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