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Post-Earthquake Condition of Lifeline Systems Following the Kahramanmaras Earthquakes

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Abstract

The February 6, 2023, Kahramanmaras earthquakes, with magnitudes of Mw 7.7 and Mw 7.6, affected about 14 million people across 11 provinces. One of the most significant issues resulting from these earthquakes is the damage to lifeline systems, which impacts both society and the environment. This study focuses on examining the effects of the earthquakes on lifeline systems, particularly water systems in Gaziantep, Kahramanmaras, Adiyaman, and Hatay. After the earthquakes, the authors conducted multiple visits to GASKI, KASKI, ASKIM, and HATSU. Information about the damages to the water systems was gathered through meetings with personnel, data provided by these organizations, and field observations. Additionally, assessments were made on the immediate and long-term implications of these damages on the affected communities.

Key words: Pipelines, Disaster, Earthquake damage, Lifeline systems, Water transmission

1. Introduction

The devastating earthquakes that struck Turkiye on February 6, 2023, consisted of two primary shocks. The first, the Pazarcik earthquake with a magnitude of Mw 7.7, occurred at 4:17 local time in the Pazarcik district of Kahramanmaras province at a depth of 8.6 kilometers. The second major shock, the Elbistan earthquake with a magnitude of 7.6, occurred at 13:24 local time at a depth of around 7 kilometers. These earthquakes impacted eleven provinces—Gaziantep, Adiyaman, Kahramanmaras, Elazig, Hatay, Malatya, Sanliurfa, Kilis, Osmaniye, Adana, and Diyarbakir—affecting approximately 14 million people.

The earthquakes resulted in over 50,000 fatalities and more than 100,000 injuries. Additionally, over 250,000 buildings were heavily damaged or destroyed [1)]. Besides residential, historical, and industrial buildings, significant damage occurred in lifeline systems, including water, sewage, electricity, and gas systems, which are crucial for delivering essential life-sustaining materials. Ensuring the functionality of these systems post-earthquake is vital for human well-being, economic activities, and search and rescue efforts.

Following the earthquakes, the authors visited the affected zone multiple times to inspect lifeline systems, exchange data with relevant institutions (especially Water Works), and conduct various studies. These ongoing studies aim to examine the performance of lifeline systems, focusing on water systems in Gaziantep, Kahramanmaras, Adiyaman, and Hatay, and to learn lessons to improve the resilience of these systems in earthquake-prone areas.

These earthquakes have caused significant damage, which emphasizes how urgently vulnerable areas need strong disaster preparedness and resilient lifeline systems. Beyond the immediate casualties and structural damage, the prolonged disruption of essential services such as energy, water, electricity, and transportation underscore the necessity for comprehensive structural assessments, community readiness, and strategic planning. Insights gained from this disaster offer invaluable guidance for strengthening system resilience, facilitating rapid recovery, and supporting safety protocols in the future lifeline system development.

To further illustrate the extent of the impact, **Fig. 1** provides a general overview of the water transmission systems, and the various types of damage observed following the earthquakes[2)]. The map points out the damage locations, fault lines, and key system points, including water intake and transmission lines affected by fault ruptures, landslides, and liquefaction areas. Additionally, the figure includes data on east-west offset measurements derived from satellite images, allowing for a clearer understanding of the fault movements. This visualization helps in understanding the impact of seismic events on critical lifeline systems and underscores the importance of reinforcing vulnerable areas to improve disaster preparedness and resilience.

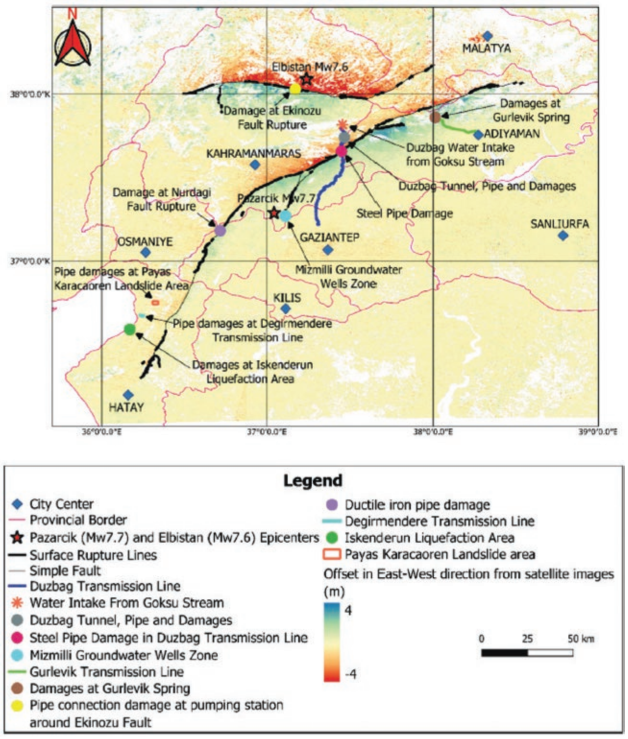

Fig. 1 General Overview of the Damages and Water Transmission Lines[2)].

2. Research Background

Disasters have the potential to cause damage to a variety of lifeline systems, including lifeline networks. The failure of these systems to work properly has a significant impact on the emergency response that occurs after an earthquake.

There are many studies on the effect of earthquakes on lifeline systems. In a study conducted by Erdik (2000), the author examined the extent of the damage caused to the lifeline system after the Kocaeli earthquake in 1999 and estimated the cost of the damage to be around 1 billion dollars[3)]. Hwang *et al.* (2004) studied natural gas pipeline damages after 1999 Chi Chi earthquake in Taiwan with a magnitude of Mw 7.6[4)]. Scawthorn *et al.* (2006a) investigated water, wastewater and electric power performances after Mw=6.6 Niigata Ken Chuetsu earthquake in 2004[5)]. Scawthorn *et al.* (2006b) presented lifeline performances in Indonesia including energy sources, water sources, transportation and communication after the Great Sumatra earthquake and tsunami in December 2004[6)]. Maruyama *et al.* (2011) examined the distribution of damage to buried pipelines caused by Niigata Chuetsu-Oki earthquake, which had a magnitude of 6.6, in Japan in 2007[7)]. Tang *et al.* (2011) summarized the performance of lifelines including seaports, communication, electric power, transportation, airports, water and wastewater after 2010 Biobio earthquake in Chile with a magnitude of Mw 8.8[8)]. Davis *et al.* (2012) demonstrated the effects of Mw=6.7 Northridge earthquake in 1994 on the water system of Los Angeles in terms of water delivery, fire protection, quantity, quality and functionality[9)]. O'Rourke *et al.* (2014) conducted a study on how water, wastewater, and gas distribution systems in Christchurch, New Zealand responded to the Canterbury earthquake series in 2010 and 2011[10)]. Wham *et al.* (2017) investigated to the damages in the water supply systems after Kumamoto Earthquakes occurred in Japan in 2016 and presented a summary of the observations and data collected by US and Japanese researchers and other individuals[11)]. Toprak *et al.* (2018 and 2019) studied pipeline damages from Mw=6.2 Christchurch earthquake in 2011 and developed new correlations of cast iron, polyvinyl and asbestos cement pipeline damages by using three different liquefaction parameters to estimate liquefaction vulnerability[12, 13)]. Lemnitzer *et al.* (2021) provides a comprehensive overview of the damage caused to vital lifelines after the 2017 Central-Mexico earthquake with a magnitude of Mw 7.1[14)]. Toprak *et al.*, (2024a, 2024b, 2024c, 2024d, 2024e) conducted studies on the condition of water supply systems and pipelines after the Kahramanmaras earthquakes[2, 15, 16, 17, 18)].

3. Overview of Lifeline Performances after the Kahramanmaras Earthquakes

Lifeline systems are crucial for maintaining the economic and social stability of provinces, especially after earthquakes. Damage to wastewater and water supply systems hampers recovery efforts and disrupts vital public services. The February 6, 2023, earthquakes caused significant damage to drinking water pipelines in eleven affected provinces. Geohazards (e.g., surface fault ruptures, landslides, liquefaction, etc.) and strong shaking were the primary causes of pipe damage. **Table 1** provides detailed information on the water administration district service areas and lifeline systems in regions affected by the earthquakes[18]. The data highlights the scope and diversity of water management systems in districts managed by Gaziantep Water and Sewerage Administration (GASKI), Kahramanmaras Water and Sewerage Administration (KASKI), Hatay Water and Sewerage Administration (HATSU), and Adiyaman Water and Sewerage Administration Directorate (ASKIM), including population served, pipeline lengths, and daily water supply capacities, underscoring the challenges in restoring these systems following the earthquakes.

Table 1 Detailed Information About the Water Administration District Service Area and Systems[18].

	GASKI	KASKI	HATSU	ASKIM
Population Served	2,163,572	1,177,360	1,628,894	316,140
Service Area (km^2)	7,222	14,519	5,524	1,814
Number of cities/towns served	9	11	15	1
Number of Subscribers	763,000	468,357	630,000	82,000
Number of Employees	2240	952	2030	167
Water Quantity Supplied (m^3/year)	189,965,106 (T)	180,000,000 (T)	70,640,000 (T)	22,075,200 (CC)
Avg. Daily Water Supply (m^3)	520,450	500,000 (T)	193,534	60,840
Drinking Water Pipeline Length (km)	2,629	3,200	2,400	550
Transmission Pipeline Length (km)	280	97	230	191
Capacity of Drinking Water Treatment Plants (m^3/day)	462,640	90,000	130,000	None

T = total district; CC = city center

The total damage to the lifeline systems, including electricity, natural gas, petroleum, and fuel systems, was estimated at 13.8 billion TL, with the most significant impact in Hatay, Malatya, Kahramanmaras, and Gaziantep. Transformer stations and other electrical systems sustained significant damage, as illustrated in **Fig. 2**. In the transportation sector, the earthquakes caused landslides, bridge and tunnel damages, and highway cracks. Approximately 1,500 containers were damaged due to the fire at Iskenderun Port, and the runway at Hatay Airport was also affected. The impact on communication systems, including base stations and network systems, amounted to around 3.5 billion TL within the earthquake-affected area[1].

Fig. 2 Adana City Transformer Center TR184 Damage[17].

4. Water System Performance in Gaziantep after Kahramanmaras Earthquakes

Gaziantep includes nine districts—Sahinbey, Sehitkamil, Nizip, Nurdagi, Islahiye, Oguzeli, Yavuzeli, Karkamis, and Araban—with a population of over 2.16 million people. Sahinbey and Sehitkamil form the city center, receiving approximately 555,000 m^3 of water daily from Duzbag, Kartalkaya, Mizmilli sources, and in-city wells (**Table 2**). The water is treated at Hacibaba Drinking Water Treatment Plant. After the earthquake, water supply resumed in 2 days, but the lines sustained damage.

Table 2 Water Transmission Lines supplying Gaziantep city center[19].

Water Transmission Line	Length	Pipe Type	Pipe Diameter
Duzbag Line	82 km	Steel	Ø2600 mm
Kartalkaya Pre-stressed Concrete (PSC) Line	54 km	PSC	Ø1400 mm
Kartalkaya Steel Line	54 km	Steel	Ø1800 mm
Mizmilli Wells Line	41.5 km	Steel	Ø1200 mm

In the first week, the Duzbag line experienced power outages and structural damage in the tunnel and at the fault line intersection (**Fig. 3**), leading to a month-long delay in its reuse.

Kartalkaya PSC line experienced failures and severe damage to pumping facilities, leading to its discontinuation (**Fig. 4**). The steel transmission line, however, resumed supply 1-2 days post-earthquake. The Mizmilli line remained mostly intact but had pump station damage and water turbidity due to tectonic movements. Water supply resumed in 2 days, but the water was only usable for purposes other than drinking. Turbidity issues persisted despite efforts to wait it out. In the non-central districts, well water was primarily used. Nurdagi faced energy problems, resolving water supply by the 4th day with generators. Nurdagi and Islahiye had pipe damage near fault lines, while the other districts had no major issues.

5. Water System Performance in Kahramanmaras after Kahramanmaras Earthquakes

Kahramanmaras consists of Afrin, Andirin, Caglayancerit, Dulkadiroglu, Ekinozu, Elbistan, Goksun, Nurhak, Onikisubat, Pazarcik, and Turkoglu districts. The city center, developed in Dulkadiroglu and Onikisubat, accounts for 55.32% of the 430,854 water subscribers.

Post-earthquake, water loss increased from 55% to 75%, with a 400% rise in daily malfunctions. Within a month, 90% of the city was supplied with water[20].

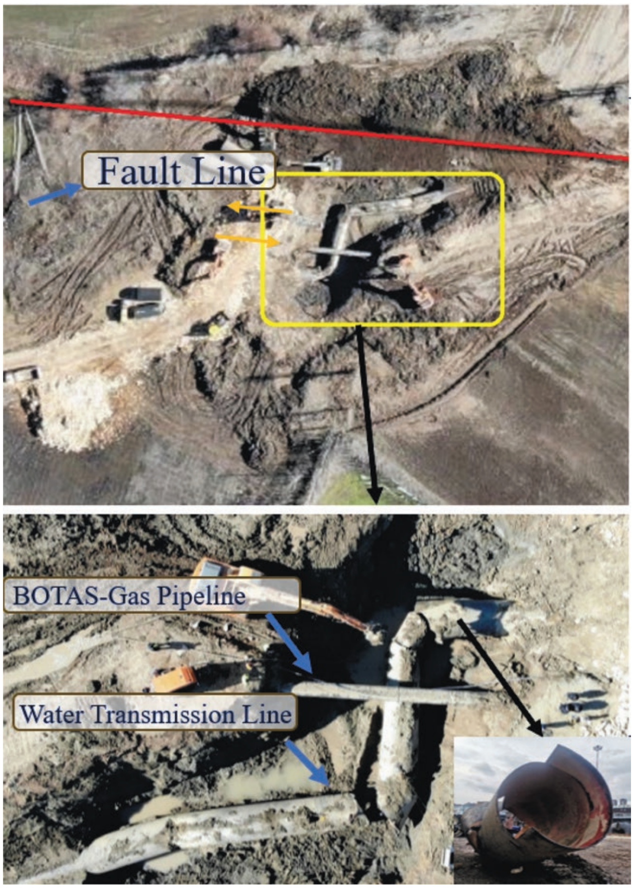

Fig. 3 Intersection of BOTAS Petrol and Gaziantep Main Water Transmission Pipeline with Fault Rupture[2].

Fig. 4 Kartalkaya Pipeline Damage Repair Operations.

The drinking water for Kahramanmaras's center comes from Karasu (1,500 L/sec), Ayvali Dam (1,000 L/sec), Pinarbasi (500 L/sec), and southern wells (645 L/sec). The water system includes four groups of transmission lines. Karasu water is conveyed through 46.4 km of steel pipes. Ayvali Dam water is sent to Ayvali Drinking Water Treatment Plant via a 10 km, 1400-mm steel line. This plant, with a capacity of 90,000 m^3/day, serves Onikisubat and Dulkadiroglu. Water flow in the city center is 50% gravity and 50% pumping, supported by five pumping stations.

Most earthquake damage occurred in Dulkadiroglu. The lifeline system renewal will begin in Kanlidere, the city's oldest neighborhood. KASKI plans to use ductile iron pipes for diameters over 300 mm and polyethylene pipes (PE) for smaller diameters. Before the earthquake, network pipes in Afsin and Goksun were replaced with PE pipes, resulting in fewer issues. Inspections in Turkoglu Sekeroba revealed that a 160 mm PE pipe stretched almost a meter along the fault line but continued to supply water. KASKI also began blinding water supply lines to buildings destroyed by the earthquake (**Fig. 5**).

a) Blinding Operations at Destroyed Buildings

b) Operation of Repair of PVC Pipe

Fig. 5 Repair Works Done by KASKI Teams (Courtesy of KASKI).

6. Lifeline System Performance in Adiyaman after Kahramanmaras Earthquakes

Adiyaman was severely impacted by the February 6th Kahramanmaras Earthquakes. Significant damage occurred in the city center and Golbasi district. Adiyaman's population decreased by about 5%, with the city center and Golbasi experiencing 10% and 5% declines, respectively, due to the earthquake. In Adiyaman province, critical lifeline systems like water supply, sewerage, natural gas, and telecommunications faced major issues. Water supply in the city began at specific locations on the 4th day and reached nearly all areas within a month. Golbasi's entire lifeline systems, especially the gas and water networks, became unusable and required substantial renewal due to the fault line and poor soil conditions.

Adiyaman's water supply sources, including Gurlevik, Havseri, Tut-Medetsiz, and Koru-Palanlı, were heavily impacted. The Gurlevik steel water pipeline suffered significant landslide damage, recording 25 serious issues along the line (**Fig. 6**). The city center faced numerous distribution system damages, necessitating around 100 daily repairs.

Overall, the damages in Adiyaman resulted from earthquake-induced landslides and lifeline deficiencies, including the lack of implementation of earthquake-resistant systems, with primary causes being faulting effects, liquefaction, lateral spreading, and aging systems.

Fig. 6 Pipe Damages at Gurlevik Spring, Adiyaman[2].

7. Water System Performance in Hatay after Kahramanmaras Earthquakes

Hatay was one of the most severely affected provinces by the Maras earthquake, with over 22,000 deaths and 774,500 displaced, including 350,000 Syrian refugees. Significant demographic shifts occurred, with 75% of the population moving to rural areas, causing surges in some areas and resulting in the lifeline system shortages. Arsuz and Samandag saw substantial population growth, complicating rescue and reconstruction efforts. To address water shortages, dozens of wells were drilled, and damaged pipes were repaired.

The earthquake caused the municipal building to collapse, severing phone and internet services. Steel pipes on the fault line were damaged, while ductile iron pipes performed best, though demolition activities caused most of the network damage. Old asbestos pipes in Kirikhan posed challenges, while ductile and polyethylene (PE) performed well overall. Breaks occurred in steel pipes over the Karasehir Dam, and 38 water tanks were damaged, leading to a five-day water shortage.

Before the earthquake, HATSU had 630,000 subscribers, but nearly 300,000 were lost. Support from fourteen water and sewerage administrations from other provinces focused on transmission lines for about two months. Coordination was managed by the OHAL Governorship. About 190 container cities were established, and permanent residences began to be constructed by various agencies.

A €370 million investment package has been approved for Hatay's lifeline system, with a project pool worth €3 billion. €1.8 billion from the European Investment Bank, JICA, and the World Bank is allocated for lifeline systems, including €373 million for HATSU.

8. Conclusion and Recommendations

The February 6, 2023, Kahramanmaras earthquakes significantly impacted millions of people across eleven provinces, causing widespread destruction to essential lifeline systems. This study focuses on the earthquake-induced damages to lifeline systems, particularly emphasizing the impact on water systems in Gaziantep, Kahramanmaras, Adiyaman, and Hatay. These regions experienced severe disruptions, highlighting the critical importance of robust lifeline in earthquake zones for the rapid recovery of the population in healthy conditions.

Lifeline systems, such as water, sewerage, and electricity, are vital for maintaining societal stability, especially after an earthquake. Minimizing the extent of damage to these lifeline systems and ensuring prompt repairs are crucial steps in the aftermath of such a disaster. Analyzing the structural damages caused by previous earthquakes and establishing a cause-effect link is an efficient approach to mitigating future damages. By understanding these relationships, essential safeguards can be implemented in advance, reducing the recurrence of such damages in future earthquakes.

The earthquakes in Kahramanmaras demonstrated the necessity for both domestic and foreign investments in the affected zones, which significantly accelerated the recovery process. However, if these investments had been made proactively, the lifeline systems could have withstood the earthquake's impact with less damage. Strengthening communication between institutions within each province of Turkiye is essential for increasing the speed of recovery after an earthquake and effectively addressing problems before they occur. Improved coordination ensures that measures are taken promptly and efficiently, minimizing the disaster's impact on essential services.

A notable issue identified was the age of the pipelines. Many of the pipes damaged by the earthquake were old and deteriorated. In high-risk earthquake areas, preemptively replacing old pipes would enhance the speed and effectiveness of recovery efforts post-disaster. Municipalities in earthquake-prone provinces must prioritize lifeline system investments, and the government should allocate sufficient funds for these initiatives. In addition, identifying alternative water sources is crucial for addressing potential water supply problems that may arise due to pipe damages, turbidity, or pump station failures.

The structural integrity of buildings in earthquake zones also significantly affects water supply systems. Heavily damaged or demolished buildings can cause pipe damage during demolition, leading to water cuts and wastage. Even if water is supplied to these areas, damage to subscriber connections within the buildings can result in significant water loss. Ensuring the strength of buildings and minimizing the number of heavily damaged structures can mitigate these issues.

Furthermore, population changes following an earthquake should be considered in future provincial population estimates. In areas where new container cities are built to accommodate displaced populations, new water lines will be necessary, increasing the overall water demand in the region. Effective planning and lifeline system development can help meet these needs efficiently.

In summary, the February 6, 2023, earthquakes underscored the importance of resilient lifeline systems in earthquake-prone areas. Strengthening inter-institutional communication within each province of Turkiye is crucial for a swift recovery after such disasters. By investing in robust lifeline system, replacing old systems, and ensuring effective coordination, the adverse effects of earthquakes on lifeline systems can be significantly reduced, ensuring the well-being of affected populations and the continued functionality of essential services.

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カフラマンマラシュ地震後のライフラインインフラの状況

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要　旨

2023 年 2 月 6 日に発生した Mw7.7 と Mw7.6 のカフラマンマラシュ地震は，11 州の約 1,400 万人に影響を与えた．この地震による最も深刻な問題の 1 つは，社会と環境の両方に影響を及ぼしているライフラインシステムの被害である．本研究は，ガジアンテップ，カフラマンマラシュ，アディヤマン，ハタイにおけるライフライン，特に水道設備への地震の影響を調査することに焦点を当てる．地震後，著者らは GASKI，KASKI，ASKIM，HATSU に対して複数回の訪問調査を実施した．水道システムの被害に関する情報は，職員への面接，これらの組織から提供されたデータ，現地調査を通じて収集した．さらに，これらの被害が被災したコミュニティに与える直接的および長期的な影響についても評価を行った．

キーワード：水道管，災害，地震被害，ライフラインインフラ，送配水