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Article

The impact of the February 6th, 2023, Kahramanmaraş epi-centered earthquakes on traditional underground water systems: Gaziantep case

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ABSTRACT

This article aims to compare the findings of an ongoing original doctoral study on the conservation of "traditional underground water systems" in Gaziantep and its vicinity, listed on the World Heritage Tentative List, with the significant damage to the built environment following the February 6th earthquakes and the resulting new situation, in order to define new conservation dynamics accordingly. The study seeks to initiate a discussion on the impact of changing environmental dynamics due to the earthquake on the conservation of these systems, focusing on the fundamental inputs of "resilience" and "vulnerability" in disaster risk management. The study utilized pre-earthquake documentation, such as system status, post-earthquake observations, damage assessments, expert reports, and satellite images, as primary inputs. Considering the earthquakes, the triggered secondary damages, and the scale of the disaster's impact, the comparative study of similar examples has been identified as a limitation. Hence, the article examined the 2003 Iran Bam earthquake's impact on Iranian Qanat Systems, a comparable example listed as a World Heritage Site since 2016. Despite the difficulties related to the accessibility of underground canals and traditional water structures such as kastel and livas, the study obtained significant findings for rapid post-disaster assessment and resilience capacity. The examinations reveal that traditional construction systems in the region are not always human-made, and karstic cave formations beneath historical structures should be evaluated separately, especially after earthquakes. The findings indicate that these water systems being constructed underground increases the resilience and reduces vulnerability of both the source and the users in the face of disasters such as earthquakes. Furthermore, the results support the study's hypothesis on how conservation efforts contribute to water security in the twenty-first century.

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INTRODUCTION

Traditional underground water systems have produced complex technical solutions developed under the influence of different cultures to access and protect water in different geographical regions of the world for centuries. These systems, which have been a critical element in the development of civilizations, have served both the daily drinking water and agricultural production needs of communities in their regions by conveying water

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underground to prevent evaporation. Although some of these systems have not survived to the present day, there are many examples that are still in active use. As envisioned in this study, these systems also have a positive impact on providing water security resilience to local users in their geographical locations.

In the UNESCO World Heritage List, which provides important sanctions for the protection of cultural assets and guarantees the efforts of the State Parties to protect these cultural assets, 10 of the 140 underground structures registered to date are water-related structures (Özdemir, 2020). These systems, which are still in active use, have been inscribed on the UNESCO World Heritage List as being of outstanding universal value.

However, intense population growth, unplanned urbanization, and major disasters in the last century put these systems at risk of extinction. Therefore, the protection and sustainability of these systems are critical for both the continuation of cultural heritage and water security. Understanding the impact of the risks to which these systems are exposed requires specialized studies due to their underground location.

This paper examines the impact of the category 4 earthquake that struck Gaziantep and ten other provinces in its vicinity on 6th February 2023 on traditional underground water systems such as kastels and livas. It aims to determine the conservation dynamics of these systems in the context of resilience and vulnerability parameters after the earthquake. As part of the study, the investigation of the earthquake's impact on the traditional underground water systems in Gaziantep will be supported by an evaluation of the "Persian Qanats" of Iran, which have previously experienced similar disasters and are on the World Heritage List. As a result a new framework for the protection of traditional underground water systems in the face of rapidly evolving disasters will be proposed.

Gaziantep Kastels and Livas: A Traditional Underground System for Water Management

The traditional underground water systems of Gaziantep, "Kastels and Livas," which are the focus of the study, were developed based on a necessity, as in all similar systems.

- Insufficient quantity of water in the Alleben stream in the region,
- That the Gaziantep plateau is unsuitable for lakes,
- Due to the geological structure, a significant proportion of rainfall seeps into the ground, forming groundwater,
- The need to prevent evaporation due to high temperatures,
- The area has geological formations of soft limestone, marly limestone, and chalk that are suitable for the construction of underground water tunnels (UNESCO, 2018).

The 'livas' system in Gaziantep has a different arrangement from the pipe or aqueduct transport systems found in Anatolia. The main feature of the water system is creating a continuous water source and using this water throughout the settlement (Uçar, 2016). A "Kastel," which has various functions, is a public underground water structure with a regional character. Kastels are underground complexes that include lavatories, open spaces, laundry areas, resting places, and mosques (Altın, 2017). The historic water structures of Gaziantep serve as significant evidence of cross-cultural interaction on a global scale, as well as reflecting socio-cultural life and local technical knowledge.

Studies on the impact of earthquakes on historical water systems in the literature are generally addressed under the broader topic of the effects of disasters on cultural heritage. The preservation of cultural heritage is essentially risk management. Therefore, analyzing the hazards involved in risk management, assessing the potential risks arising from these hazards, and conducting vulnerability analysis, which affects manageability, are fundamental steps in analyzing the risks to cultural heritage (Ünal & Ünal, 2019). Managing the risks that affect these systems is a fundamental necessity for preserving cultural heritage. Currently, the main factors threatening water heritage include population growth and urbanization, as well as disasters such as earthquakes and the floods and droughts brought on by climate change. In disaster situations, the connection with cultural heritage is viewed in two contexts. The first context is the role of traditional systems in enhancing resilience and reducing disaster risks. The second context is the role of actions aimed at mitigating disaster effects and supporting post-disaster recovery (Jigyasu et al., 2013). An understanding of the risks to these systems and their impact on urban resilience is critical to the creation of resilient cities.

There are many studies showing that traditional underground water distribution networks are affected by earthquakes in areas with high seismicity. The study by Pellet et al. (2005) examines the geotechnical performance of Iran's Qanat systems following the 2003 Bam earthquake. This study addresses the subsidence and cracks caused by the earthquake in the Qanat systems. Ambraseys & Melville (2005), in their study evaluating the impact of historical earthquakes on Iran's Qanat systems, highlight the vulnerabilities of these systems in the face of seismic activities. Smerzini et al. (2009), in their study investigating the effects of underground voids on surface earthquake waves, explain how underground water systems are affected during earthquakes. These sources provide critical data to understand the impact of earthquakes on underground water systems and how to protect these systems from seismic events.

Jigyasu (2015) emphasizes the role of traditional water systems in increasing societal resilience during natural disasters and illustrates how historical water tanks and wells in Nepal meet water needs during emergencies. Molden (2019) examines the connection between water heritage and urban development in the Kathmandu Valley of Nepal, highlighting the resilience of traditional water systems. These sources address strategies for preserving traditional water systems and risk management, while also exploring the impact of these systems on societal resilience.

AFAD, in its preliminary assessment report on the Kahramanmaraş earthquakes published in 2023, addresses the impacts of the earthquakes and the subsequent measures taken. Aldemir et al. (2023) present a detailed examination of the Kahramanmaraş earthquakes, assessing their effects on Gaziantep and its surroundings. These sources discuss the impacts of earthquakes on water systems and the measures taken to mitigate these impacts.

The Iranian Persian Qanats World Heritage Site is the most notable example in the literature review. The existence of previous research on post-earthquake effects on traditional groundwater systems (Pellet et al., 2005 and Amini et al., 2004) will be useful for comparison. The inclusion of Gaziantep's traditional underground water systems on the Tentative World Heritage List for their outstanding universal value provides an opportunity for assessment in a common context. The Persian Qanat World Heritage Site Risk Management Plan, published by UNESCO in 2019, details the risk management plan for Iran's Qanat systems. This report encompasses measures that need to be taken against natural and human-induced hazards for underground water heritage in Iran.

The literature review shows that this study will provide new data for conservation strategies by analyzing the effects of large-scale disasters such as earthquakes on these systems under changing conditions. This research is one of the first studies to be carried out on the status of traditional underground water systems in the aftermath of the 6 February earthquake in Gaziantep. It fills a significant gap in the literature on the conservation of these systems.

METHOD OF THE STUDY

This study employs a qualitative research methodology to investigate the post-earthquake conditions and the potential use of traditional underground water systems in the city center of Gaziantep and its vicinity, which were affected by the earthquakes on February 6th, 2023. The research was conducted in two stages, with field visits being the most critical component of the study (Figure 1).

Post-earthquake field research was carried out in the city center of Gaziantep on February 7th, 2023, and in Sam Village, Gaziantep between March 28-30th. Field visits were undertaken to assess both the resilience and vulnerability parameters of the affected areas. These visits involved direct observations and evaluations on-site, which provided a comprehensive understanding of the extent of the damages and the condition of existing infrastructure. The field observations were structured to examine:

- **Physical Condition of Damages:** Detailed inspections of the damages sustained by various structures, focusing on the types and severity of the damages.

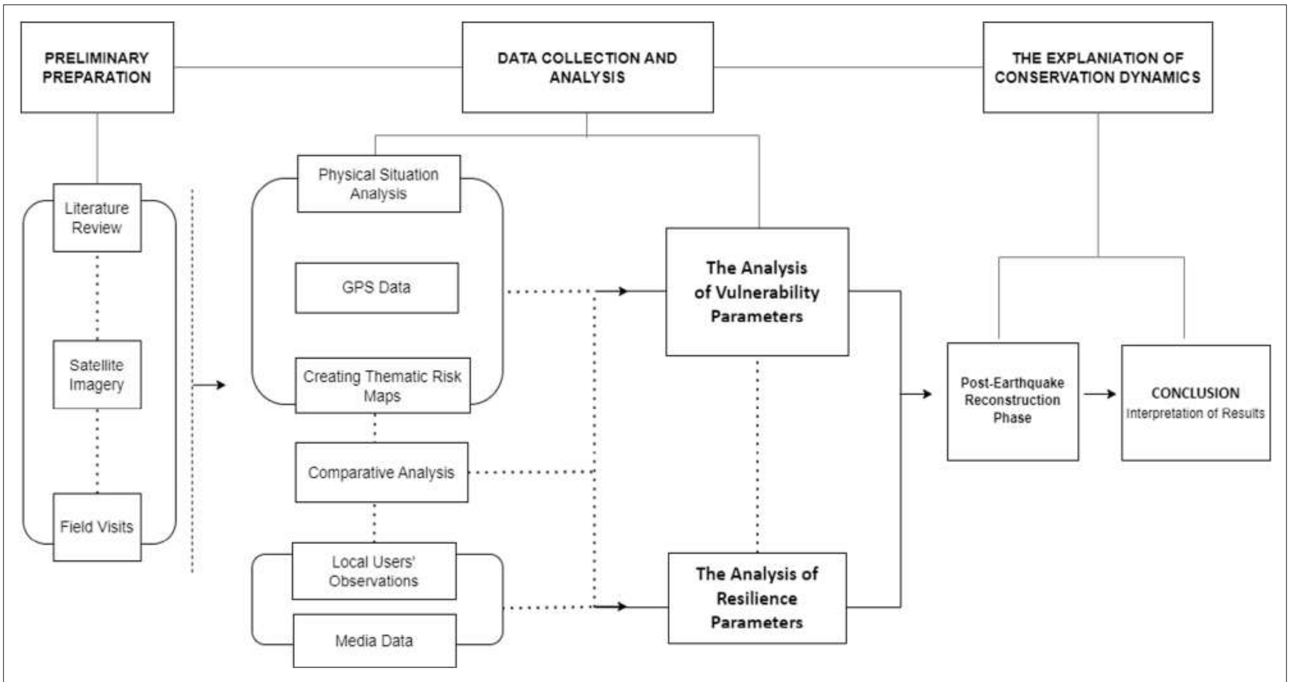


Figure 1. Method flow chart of the research.

This information was analyzed specifically within the 'vulnerability' parameter to understand how different structures fared during the earthquakes.

- **Usability of Traditional Underground Water Systems:** Investigations were carried out to evaluate the potential use of traditional underground water systems in the aftermath of the earthquakes. This included field observation of the physical conditions and operational status of the water systems in question. It also utilized information gathered from reports on the subject, local records, local authorities, residents, and open sources.

Data Analysis

During the post-earthquake field examination, observed damages were photographed and documented, while GPS (Global Positioning System) data were recorded to mark the locations of the structures. The qualitative data collected from field observations were complemented by a thorough literature review. This review aimed to contextualize the field data within broader research on earthquake resilience and traditional water systems. The analysis was divided into two main parameters:

Analysis of Vulnerability Parameters: This involved a detailed examination of the types of structural damages observed during the field visits. The analysis focused on identifying common patterns of vulnerability in the affected structures, considering factors such as construction materials, design, and age of the buildings. Additionally, the comparable structural and technical characteristics of the Iranian qanat systems and the Gaziantep kastels and livas have enabled their comparative examination, as they represent important formations and expressions of cultural richness. Furthermore, the importance of this comparative analysis is underlined by the availability of data on the impact of the 2003 Bam earthquake on the qanat system in Iran. Similarly, assessing the disaster risk to traditional underground water structures in Gaziantep provides crucial information to help manage disaster risk. The last section of the article presented the results of a study conducted in Gaziantep on the conservation of traditional underground water systems during the post-earthquake reconstruction phase. The studies conducted after the earthquake in Iran, which was selected as a case study for measures to be taken during the reconstruction phase after the earthquake, have been examined. Access to the data was facilitated through the "Persian Qanats World Heritage Site Risk Management Plan" prepared in 2019. The nomination file defines the areas designated as "Buffer Zone" as areas designated to protect the qanat and its water supply system from possible natural, environmental, cultural, and landscape hazards. This delineation of boundaries prioritizes protecting the system against the effects of earthquakes (UNESCO, 2019). Therefore, in this study, thematic maps were utilized for assessing ground-based risks, similar to the approach used in the Persian Qanats case. This allowed the assessment of disaster preparedness for existing traditional underground water systems in Gaziantep.

Analysis of Resilience Parameters: The usability of traditional underground water systems was analyzed in terms of their operational status post-earthquake and their potential role in providing water in emergency situations. The field observations and information from open sources were cross-referenced with existing literature to evaluate the resilience of these systems. The literature review included studies on the historical and technical aspects of these water systems, their performance in previous earthquake scenarios, and their adaptability to current needs. This methodology allowed for a comprehensive understanding of both the immediate impacts of the earthquakes and the potential long-term benefits of utilizing traditional underground water systems in enhancing the resilience of the affected communities.

EFFECTS OF THE FEBRUARY 6TH EARTHQUAKE ON TRADITIONAL UNDERGROUND WATER SYSTEMS

The initial earthquakes on February 6th, with magnitudes of 7.7 and 7.6, respectively, were followed by over 1300 smaller aftershocks within the next 72 hours (AFAD, 2023). Given the presence of various traditional underground water systems in the area affected by this devastating disaster, it is necessary to investigate the impact of the earthquake on these traditional underground water systems. Furthermore, as water systems play a critical role in the post-disaster reconstruction phase, examining the potential use cases of these systems is deemed essential. The impact zone of the earthquake includes cities directly affected by the disaster, such as Kahramanmaraş, Gaziantep, Hatay, Osmaniye, Adıyaman, Malatya, Adana, Kilis, Diyarbakır, Elazığ, and Şanlıurfa, which have been declared disaster areas (Resmi Gazete, 2023). An examination of the earthquake history of these regions reveals significant earthquakes in the area from the 19th century to the present, with the least intense of these major earthquakes having a magnitude of 6.8 (Mimarlar Odası, 2023) (Figure 2).

In addition to the loss of life and injuries, the earthquake of 6 February 2023 caused irreversible damage to the built environment. An important feature of these areas is their historical identity, and the historic environment of these cities suffered significant damage from the earthquake. The two magnitude 7 earthquakes caused widespread rural and urban destruction, numerous deaths, environmental damage, and, according to studies, millions of tonnes of construction and demolition waste, including hazardous waste (Doğdu & Alkan, 2023).

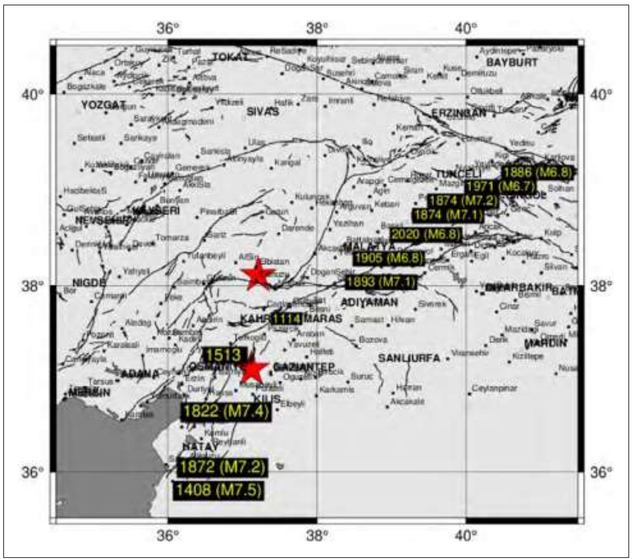


Figure 2. Significant earthquakes in the East Anatolian Fault Zone (Mimarlar Odası, 2023).

The field study conducted to investigate how the underground water heritage in urban areas was affected by the disaster revealed that the extent of destruction was lower in the city center of Gaziantep. For example, in the city center of Hatay Antakya, the estimated archaeological aqueduct and kastel structure were damaged by collapsing rubble piles. Gaziantep's underground water structures, known as kastels, were damaged by the secondary effects of the earthquake. The kastel in the village of Sam, outside the center of Gaziantep, was affected by debris from surrounding structures after the earthquake. This can be attributed to the fact that previous planning decisions for the preservation of the historical environment in the city center were more organized compared to those in village settlements. Examples of historic water structures were not immediately destroyed by the earthquake; only partial damage occurred to kastel structures where their presence above ground could be observed due to the secondary effects of the earthquake. This section describes the effects of the earthquake on kastels, based on field observations and existing assessment forms.

In Gaziantep, there are six known kastels and their associated livas in the city centre. The names of the kastels are Pişirici, Kozluca, İmam-ı Gazali, Şeyh Fethullah, İhsan Bey, and Ahmet Çelebi (Figure 3).

The construction of the kastels is based on the geographical features of Gaziantep. The deep underground water level and the inadequacy of the existing rivers at low altitudes forced the craftsmen of Gaziantep to find a solution. This solution was to carve the limestone found underground. This allowed water to flow from the source to the city center and create a specific slope. The kastel structures were designed to allow public access to the water via steps (Çam, 1984). According to Altuğ (2013), the kastels not only provided access to water but also served as natural cooling areas for the local community in the days before modern cooling technology. These structures provided a comfortable environment that satisfied the worship needs

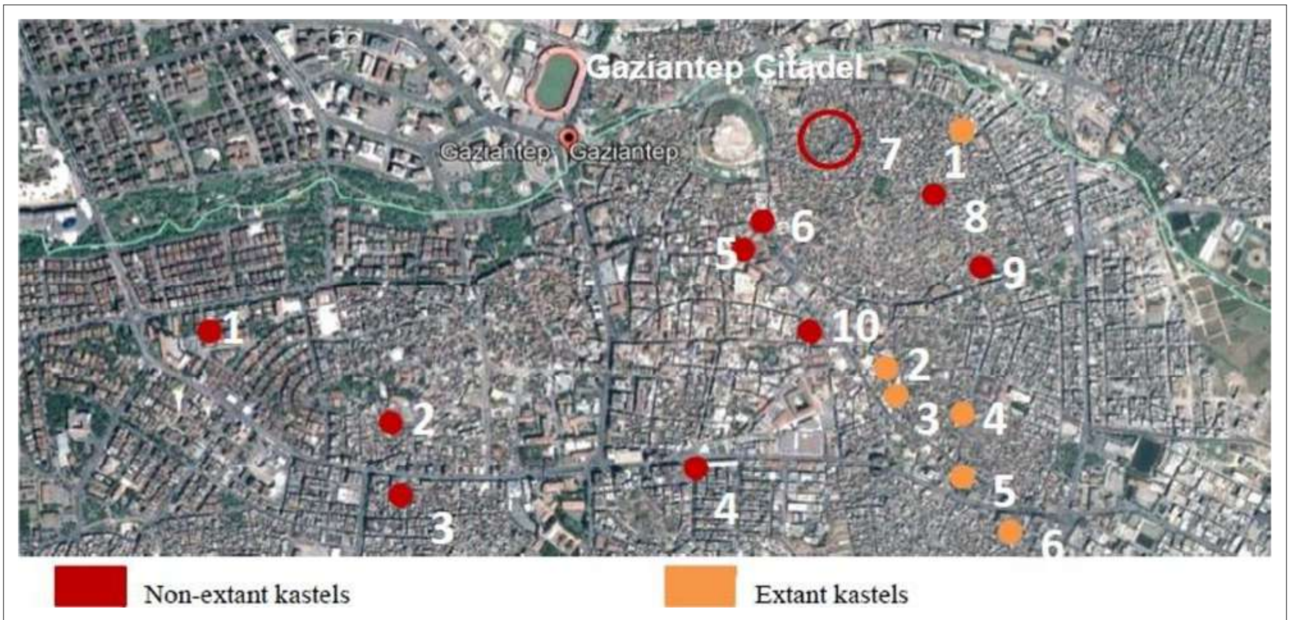


Figure 3. The non-extant and extant Kastels located in Gaziantep, Non-extant kastels: 1. Kastel of Eşraf, 2. Kastel of Şahveli, 3. Kastel of Ayşe Bacı, 4. Kastel of Şeyhcan, 5. Kastel of Kabainek, 6. Kastel of Sultan Gavri, 7. Kastel of Mehak, 8. Kastel of Kanalıcı, 9.10. Unknown; Extant kastels: 1. Kastel of İmam Gazali, 2. Kastel of Kozluca, 3. Kastel of Pişirici,4. Kastel of Şeyh Fethullah, 5. Kastel of İhsan Bey, 6. Kastel of Ahmet Çelebi (Uçar et al, 2018).

of the people in the region. The plan schemes also reveal the forms of the structures and how they are integrated into the bedrock (Figure 4). The water mains, known locally as 'livas,' are historic systems designed to bring water from the Pancarlı and Esenbek sources outside the city centre to the regional population by gravity.

The latest findings regarding the livas and kastels in the city have not yet been disseminated to NGOs such as the OBRUK Cave Team and the ÇEKÜL Foundation/Gaziantep, as well as governmental agencies like the Ministry of Culture, the Cultural Heritage Protection Board, and the Gaziantep Cultural Heritage Protection Board. According to the assessment forms received from Gaziantep Conservation Board and Monuments Directorate after the 6 February earthquake, the Ahmet Çelebi Mosque and its kastel and the İhsanbey Mosque and its kastel were moderately damaged. The Mosque of Şeyh Fethullah and its kastel sustained minor damage, while the İmam Gazali and Kozluca kastels were reported undamaged. Since the last visits on 23.11.2023, the Kozluca and İhsanbey kastels in the region are open to the public again. However, the Pişirici, Şeyh Fethullah, and Ahmet Çelebi kastels are not accessible. The İmam Gazali kastel remains partially open for visits, similar to its previous condition (Figure 5)[1].

Except for the kastels indicated as "no damage" in the Ministry reports, the condition of other kastels has been summarized during the fieldwork conducted. Furthermore, information regarding the post-earthquake condition of a kastel located outside the city has also been provided as a result of the fieldwork conducted in the area. This example is one of the instances that suffered physical damage following the earthquake. In spite of the identification studies conducted in the area being sufficient for a quick assessment, detailed studies by different disciplines are required to fully determine the damage.

The Kastel of Pişirici (Number 3)
This kastel building is the oldest of them. It was built in 1283. At the entrance to the structure, which is about 30 steps below ground level, there is a pool and a vault

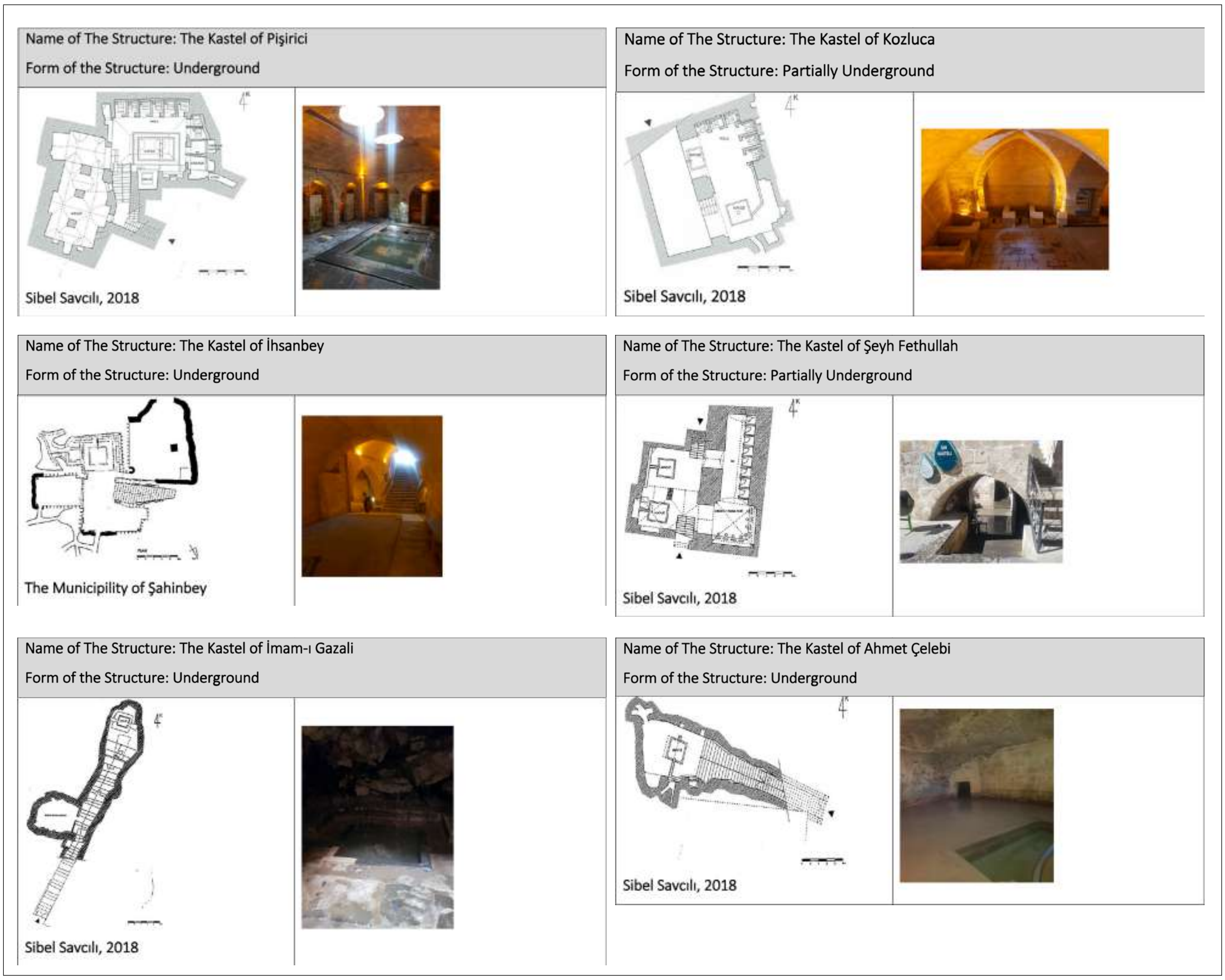


Figure 4. The Kastels in Gaziantep (Savcılı, 2018; Uçar et al., 2018).

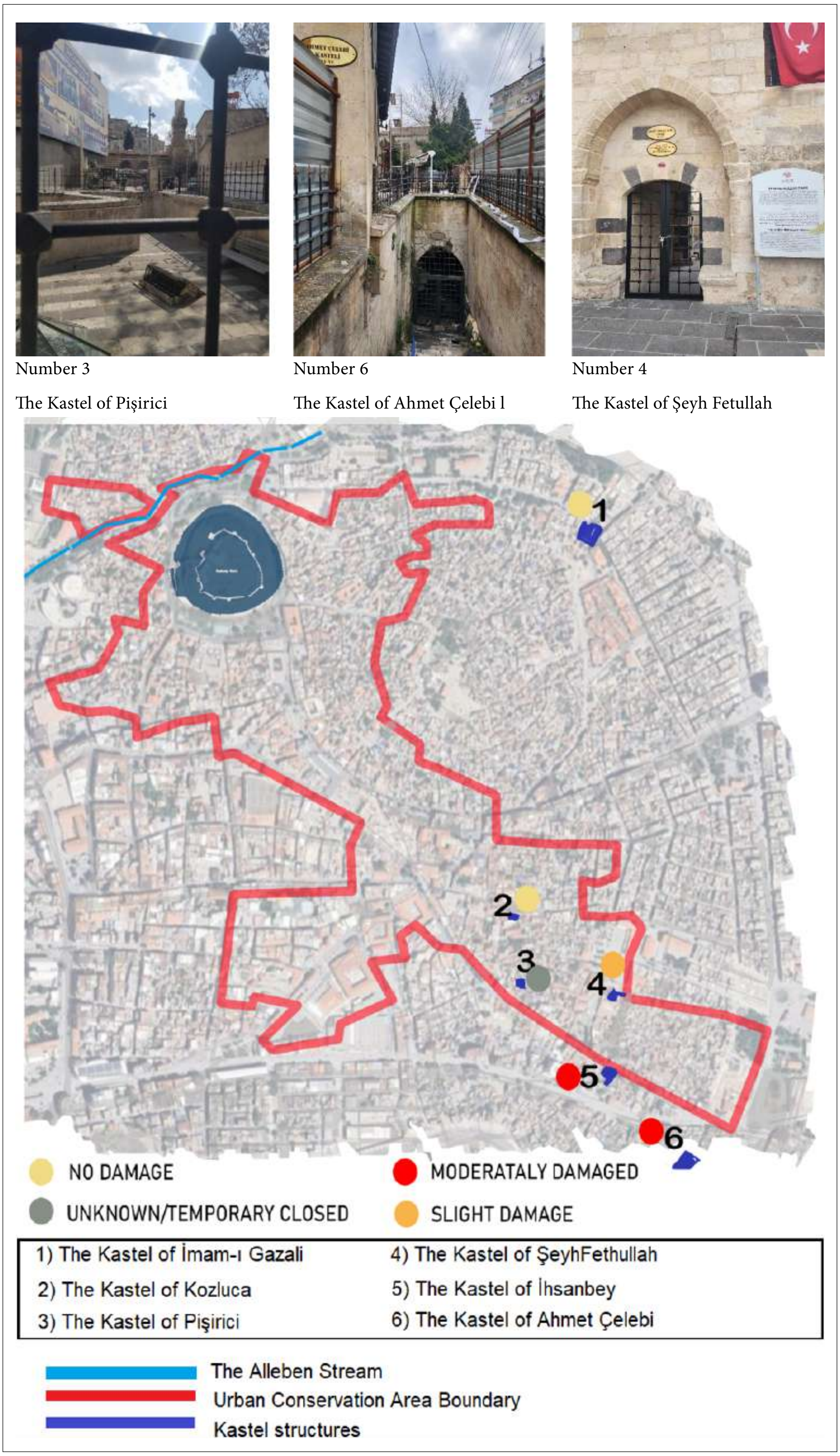


Figure 5. According to reports, the post-earthquake situation of the Kastels in Gaziantep City Center.

covering the pool. The building also has toilets and laundry facilities (Çam, 1984). During the fieldwork, no entrance was provided into the Kastel of Pişirici because access to the site was closed post-earthquake. Only the surrounding area of the structure could be examined. However, discussions with the ÇEKÜL Foundation and the OBRUK Cave Team revealed that the Kastel of Pişirici was accessed and inspected through a special authorized study, and no damage was observed.

The Kastel of Şeyh Fethullah and The Kastel of Ahmet Çelebi (Number 4 and Number 6)

The Kastel of Şeyh Fethullah was built in the 16th century and was made of hewn stone. It is used as part of the ablution center in the courtyard of the Şeyh Fethullah Mosque. On the southwest wall, there is a livas connection (Çam, 2006). It has been temporarily closed due to a fragment detachment from the minaret of the mosque in the courtyard where the kastel is located. While the structural cracks and the falling stones of the minaret did not cause any damage to the kastel structure, effects such as collapse and fragment loss in the tall buildings surrounding the kastels can increase their vulnerability in the event of an earthquake. Similarly, the Kastel of Ahmet Çelebi is also temporarily closed, with ongoing restoration work focusing on strengthening the minaret. During the site visit, no visible physical damage was observed at the entrance of the kastel.

The Kastel of Büyük Pınar in the Sam Village

While the primary or secondary effects of the earthquake did not cause destruction to the kastel structures in the city center, a kastel structure located outside the city center suffered secondary damage due to the impact of surrounding buildings. The kastel, locally known as "Büyük Pınar" (37.151771, 37.304160), is located in the village square of Sam. There was a seven-story apartment building approximately 1 meter south of this open kastel structure before the earthquake. During the intentional demolition of the apartment building due to the damage it sustained after the earthquake, part of the building collapsed towards the historic water structure (Figure 6). The kastel's structural integrity was compromised when debris from the collapsing apartment building struck its walls. The impact caused significant cracking along the lower portion of the wall and displaced several stones from the structure's base, leading to instability. This incident can be cited as an example of damage and destruction due to the secondary effect of the earthquake.

Historic Underground Water Cistern of The Gaziantep Castle

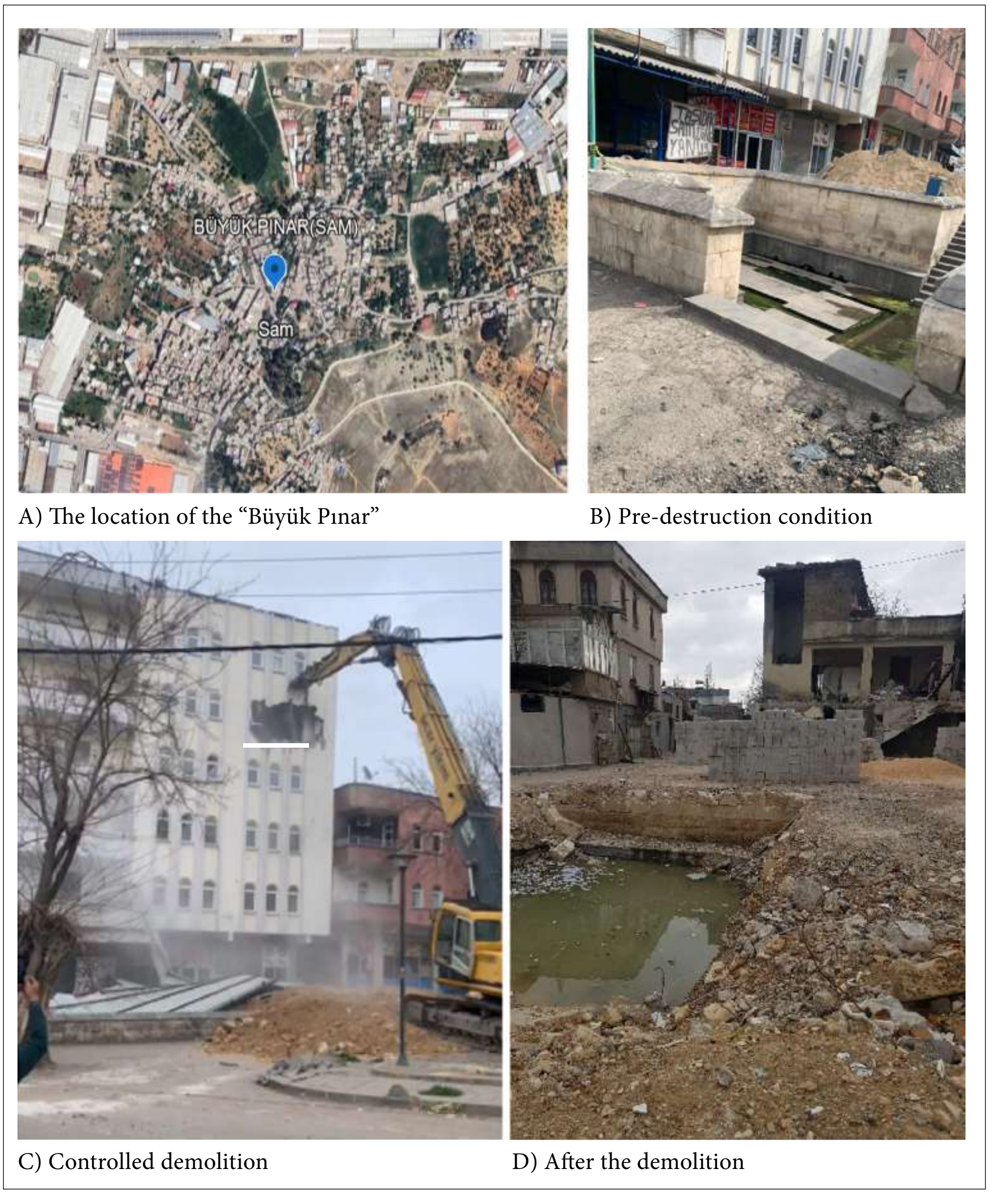
Another traditional underground water structure in Gaziantep, commonly referred to as "sweet water-bitter water" by the local population, is the ancient cistern located at the lowest level of the Gaziantep Castle, known to be connected to livas lines (Beyazlar, 2003). Experts conducting damage assessments for the castle have stated that, in addition to the clearly visible damage observed on the surface, no definitive assessment has yet been made regarding the condition of the sweet water-bitter water source and the well inside the castle[3] (Figure 7).

There are no post-disaster reports available for the livas connected to the kastels in Gaziantep. According to a report by Hacettepe University Department of Civil Engineering related to the earthquake, "due to the earthquakes, there are cave collapses, slope movements, and rock falls in and around the city center of Gaziantep." This risk could also be considered for livas formations intersecting with caves. Even if collapses occur in the lines in the city center, their effects may not be immediately noticeable. This situation is one of the most significant challenges encountered with underground water systems. Field studies carried out on these kastels after the earthquake did not reveal any deterioration in their physical condition. The main reason for this is that the structures are generally carved into the rock. However, to cite this as a reason, there is a need for comparison with similar examples.

The Impact of Earthquakes on Traditional Underground Water Systems: The Case of Persian qanats and The Bam Earthquake

Numerous studies have shown that earthquakes in regions with high seismic activity affect traditional underground water supply networks. For example, it has been found that traditional underground water systems, such as "qanat," lead to collapses and cracks in the underlying soil layers due to disruptions in their geotechnical structure (Pellet et al., 2005; Smerzini et al., 2009; Ebrahimi et al., 2019). These damages can sometimes directly affect the traditional underground water heritage or indirectly impact nearby structures, leading to collapses and damages caused by falling rock fragments on the heritage.

Examining World Heritage Sites with livas and similar underground water distribution systems in affected areas would be beneficial for better understanding the earthquake impacts on traditional underground water systems. Before the destructive Bam earthquake on December 26, 2003, it was already known that qanat systems are sensitive to seismic events. The most significant observed impact was the collapse of qanats and damage to water transmission lines. Additionally, the secondary effect of the earthquake caused the collapse of hidden qanats under living corridors, thereby damaging roads and buildings on the surface (Ambraseys & Melville, 2005). The impact of the Bam earthquake on qanat systems extended beyond surface collapses, also causing pits in the deep layers where qanats are located (Figure 8). These collapses disrupted water flow to palm groves in Bam, affecting a significant part of the cultural landscape connected to the traditional underground water system and



A) The location of the "Büyük Pınar"   B) Pre-destruction condition

C) Controlled demolition   D) After the demolition

Figure 6. The condition of a structure near the Kastel of Büyük Pınar in Gaziantep/Sam Village during its controlled demolition after the earthquake (Kaslıgil Archive[2]).

causing economic losses for the country. Pits under main roads complicated the efforts of emergency response teams trying to reach the affected area in the first 48 hours after the disaster (Amini et al., 2004).

A study in Tehran province reported a series of collapse events in horizontal tunnels near areas where Kariz tunnels had collapsed due to long-term gravitational effects (Rayhani & El Naggar, 2007). According to post-earthquake reports, the collapse of garden walls or other structures onto the surface distribution channels of qanat systems led to these channels being covered with debris. Consequently, the vital water sources for local communities in villages near fault lines were obstructed (Nadim et al., 2004). The relationship between fault lines and qanat routes offers important lessons for local administrators, especially in urban planning. The Persian Qanat World Heritage Site Risk Management Plan indicates that significant damage did not occur during earthquakes (UNESCO, 2019). However, the nomination file prepared in 2015 shows an increase in restoration activities, especially after 2003, and new decisions in management mechanisms. The report also states that areas designated as "Buffer Zones" are defined to protect the qanat and water supply system against possible natural, environmental, cultural, and landscape hazards. This definition aims to prioritize the protection of the system against earthquake effects. Therefore, the most critical section where the qanat route passes through dense urban and settlement areas has been designated as a buffer zone extending 50 meters on

Figure 7. Gaziantep Castle tunnels lead to the bitter water-freshwater junction, and on the right, the view of the hill leading to the castle corridors after the earthquake (Umut Almaç[3]).

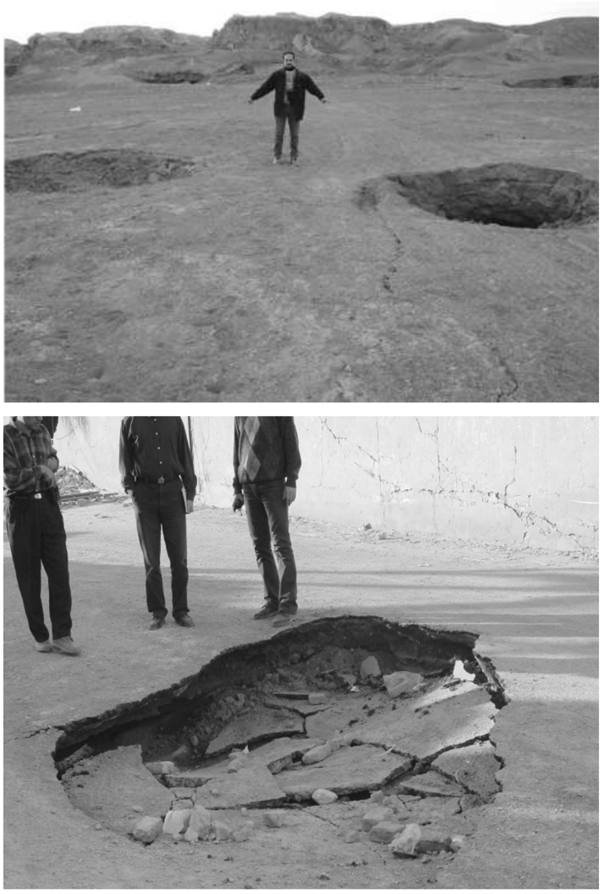


Figure 8. Ground voids and tension cracks formed after the collapse of a shallow qanat in Iran after the earthquake (Pellet et al., 2005).

either side of the route. Approvals for urban developments in these areas are granted by ICHHTO, the central institution responsible for matters related to qanats, based on detailed zoning plans (UNESCO, 2015).

Reports based on observations in the affected regions indicate:

- Changes in the water regimes of some qanats were observed,
- The north-south orientation of fault lines and the east-west orientation of qanat routes reduced the level of collapse in qanats,
- Collapses in qanats occurred at intersections of fault lines,
- Qanats passing over wide alluvial deposits suffered more damage during the earthquake.

Regarding measures taken for earthquakes and qanat systems:

- After the earthquake, cracks in qanats were filled with a soft clay and water mixture according to traditional methods by experts,
- Well entrances passing through urban areas were sealed with stone materials to prevent foreign objects from falling into the channels,
- The Bam Cultural Heritage Rescue Project (RPBCH) was implemented after the earthquake. This project aimed to map the routes of qanat main wells and exit points to gather all information about qanats.

Compared to the Gaziantep case, the primary damage observed in the qanat system can be attributed to the lines directly passing over fault lines, even though the systems were created using similar techniques under similar geographical conditions. Since there is no definitive report on the condition of the livas systems in Gaziantep, it is unknown whether collapses occurred. Identifying risky points of lines, particularly those related to soil structure, can help prevent similar incidents to the qanat example from happening in the future and contribute to the existing literature.

CONTRIBUTION OF TRADITIONAL UNDERGROUND WATER SYSTEMS TO RESILIENCE CAPACITY IN TIMES OF DISASTER

Globally faced earthquakes, climate crises, and related disasters such as floods, landslides, and fires emphasize the importance of "resilience." Traditional underground water systems, as man-made structures and systems throughout history, stand out not only for their cultural, historical, and archaeological values but also for their contributions to building resilient communities and cities. For instance, challenges related to water supply are encountered both instantly and after earthquakes. In regions with modern water distribution networks, water supply is intentionally cut off during earthquakes. This is because water leaking from damaged or broken pipes can cause trapped individuals under debris to drown. Moreover, leaking water coming into contact with already weakened structural elements of buildings can accelerate the collapse of damaged structures (Yıldız, 2019). This water cutoff complicates disaster victims' access to clean water, jeopardizes hygiene conditions, and increases the risk of epidemics threatening public health in the disaster area. This raises questions about potential water supplies in settlements during disaster scenarios and whether the relationship between traditional underground water heritage and disasters is significant. These questions are aimed at exploring whether traditional underground water systems can serve as potential water sources for vulnerable communities in emergencies.

The earthquakes experienced on February 6th, 2023, in Kahramanmaraş underline the challenges faced in accessing basic needs such as clean drinking water and water for personal hygiene during and after the event, further emphasizing the importance of this topic. After the earthquakes, it was observed that local people, especially those living in rural areas, experienced water shortages and used water for drinking and cleaning purposes from the Kastel of 'Küçük Pınar' in the village center (Figure 9).

Another example regarding the potential use of traditional underground water systems after the earthquake is the Historic Bath of Naib, which is connected to livas and is still actively used today. According to information provided by the hamam's operator, the hamam did not suffer damage after the earthquake, and it is mentioned that it could accommodate around 50-60 people from nearby residences for approximately 10 days (NTV, 2023). The strongest evidence of the contribution of traditional groundwater systems to water security is that in the critical first three days after the earthquake disaster, which affected some 11 provinces, water supply was actively provided by historic water systems in both urban and village centers.

As seen, water, which is a basic necessity in daily life, becomes even more crucial during disasters, especially earthquakes. To support this research in defining the resistance parameter, studies of the use of traditional groundwater systems after earthquakes are also being evaluated.

Figure 9. The post-earthquake situation in Sam Village, Gaziantep and the reference to "Küçük Pınar".

Contribution of Traditional Underground Water Heritage to Resilience in Disaster Situations: International Cases

Molden (2019) argues that underground water heritage extends beyond being merely a temporary alternative, a water museum, or a universal solution for modern problems (UNESCO, 2015). Traditional underground water systems should be considered not only as cultural assets but also as systems that have served numerous purposes. They may be used as temporary options, can remain functional, and should not be considered obsolete until their potential is fully understood. They may not be completely compatible with modern needs due to their physical condition but can be somewhat stable (Molden, 2019). Disasters worldwide have shown the need to analyze water structures within vulnerability and resilience parameters, integrating this aspect into disaster management as a fundamental input. The connection between various types of disasters and traditional underground water structures in different regions worldwide has been examined in numerous studies. For example, in Rome, which has traditional aqueducts, historical water aqueducts like Acqua Vergine and Acqua Paola have been identified as having the water capacity to support firefighters due to the dense building concentration and fire risk in the historical city center, indicating they could be used during or after disasters (Okubo, 2016).

A similar situation is observed in Japan. Studies have shown that underground water wells provided significant benefits during earthquakes in Japan. For instance, fires following the 1995 Hanshin-Awaji earthquake damaged many wooden cultural heritages. Considering the high risk of continuing earthquakes, the benefits of traditional water management inherited from the Shirakawa-go and Gujyo-Hachiman communities began to be researched. The traditional water system consisting of urban canals and reservoirs provided clean drinking water and met the necessary water requirements, especially for extinguishing fires in emergencies (Kobayashi, 2003).

An older example of this system is found in the case of San Francisco, which experienced a major earthquake disaster in the spring of 1906. Following the earthquakes, the city was completely destroyed by fire disasters. As a solution, it was suggested to build cisterns based on traditional knowledge at certain points underground in city centers. Today, 175 underground cisterns lined with circular red bricks are kept ready in the city center for use in case of earthquakes and subsequent fire disasters (Atlas Obscura, n.d.) (Figure 10). After surviving the 7.8 magnitude earthquake in San Francisco, interviews with survivors brought up another significant issue related to water heritage. Immediately after the event, the meeting place for people to gather was known as Lotta's Fountain, "Lotta’s Foundation." Since then, it has become a memorial space where people gather annually to remember the 1906 disaster and the lost lives. Today, the fountain is preserved for its place in the city's image and its ritual value (ABC7 News, 2023).

In Japan, a "national emergency underground water well registration system program" was launched in 2015. This law introduced regulations on the efficient use of underground water for emergency water supply during disasters (Table 1).

Jigyasu (2015), in his example on the role of traditional water systems in natural disaster situations using the case of Nepal, emphasized their contribution to forming resilient communities (Figure 11). Water tank systems or wells in the historical urban fabric of the Kathmandu Valley met the city's water needs in emergencies. Jigyasu (2015) mentioned that these systems are currently facing pressure from intense urbanization. This not only accelerates the disappearance of cultural resources but also increases the fragility of communities against natural disasters by disrupting the local ecological balance (Jigyasu, 2015).

The stages that follow a disaster can be identified as,

Figure 10. An example from the underground cistern on Sanchez Street (Atlas Obscura, n.d.).

Figure 11. The traditional water supply system in the Kathmandu Valley is utilized for both daily needs and emergencies (Jigyasu, 2015).

- Emergency aid,
- Rehabilitation, and
- Reconstruction phase (Limoncu, 2004; Yıldız, 2019).

A review of examples from around the world and from Turkey can provide a general framework for the potential use of traditional groundwater systems during disasters (Table 2).

Table 1. Different amounts and qualities of water were used depending on the location after the Tohoku earthquake in Japan. (Tanaka, 2016).

Water Source	Quantity	Quality	Remarks
River, lake and pond water	Large amount	Different depending on water source	Transportation is necessary
Sea water	Large amount	Treatment is necessary for freshwater usage	Transportation is necessary
Groundwater	Amount will be affected place to place	Pollution of shallow groundwater is a factor	Need and supply locations can coincide; Water table decline is possible; water pollution is possible, set of hand pumps is needed
Rainwater	A water tank set is necessary to provide 0.22-2,000 m^3	Possibly clean but treatment is necessary sometimes	Need and any supply locations can coincide

Table 2. Traditional Underground Water Systems' Potential for Use During Earthquakes

Method of Use	Rural Area	City Center
Drinking Water	Emergency Response and Recovery Phase	Emergency Response and Recovery Phase
In Preventing Secondary Disasters	-	First 24 Hours (Emergency Assistance)
Sanitation	Emergency Response and Recovery Phase	-
Assembly Point	At the Moment	At the Moment

According to the United Nations Office for Disaster Risk Reduction (UNDRR), resilience is "the ability of a system, community or society exposed to hazards to withstand, absorb, accommodate, adapt to, transform and recover from the effects of hazards in a timely and efficient manner, including through the maintenance and recovery of its essential basic structures and functions" (UNDRR, n.d.). Literature-based research has demonstrated the potential use of traditional underground water systems in disaster situations, contributing positively to resilient cities and communities. They have provided protection against secondary disasters that can occur in both rural and urban centers, met the urgent need for drinking water, served hygiene needs in the first 3 days when water was cut off, and in some cases, because of their place in the memory of the city, have acted directly as assembly points.

PRESERVATION AND PLANNING OF TRADITIONAL UNDERGROUND WATER SYSTEMS IN THE POST-EARTHQUAKE RECONSTRUCTION PHASE

It is important to study and monitor the impact of the 6 February earthquakes on cultural heritage. This section of the study explains the parameters to be considered in urban planning decisions and the measures to be implemented during the post-earthquake reconstruction phase. Any disruption in the underground water transmission lines can cause water to seep into the soil and soften it, if it still carries water. This condition can lead to vertical deflection in the buildings, affecting their foundation settlement (Arun, 2019).

In considering the impact of the Iran-Bam earthquake on qanats, it is noted that qanats are generally buried in the ground and are sufficiently stable during earthquakes and ground shaking. However, it is emphasized that the characteristics of the ground should be taken into account during the post-earthquake reconstruction phase (UNESCO, 2019). Similarly, in the case of Gaziantep, the potential impact of the earthquake on livas and kastels was investigated based on the soil characteristics.

Risk Assessment for Kastels and Livas Based on Soil Properties

In the initial phase of damage assessment studies following the 6 February earthquakes, observational assessments were carried out on the Gaziantep kastels and livas, which are part of the UNESCO World Tentative Heritage Site. During the preparation phase of these initial assessments, damage assessment studies carried out at the Iran Bam World Heritage Site, which suffered significant earthquake damage to its historic settlement and has a similar traditional system, served as a guiding reference. The damage assessment conducted after the Iran Bam earthquake identified breaks and collapses in the lines of the traditional underground water systems (Rayhani & El Naggar, 2007; UNESCO, 2015). These findings indicate the need to assess similar damage risks for Gaziantep's traditional underground water systems, which have a similar structure. The fact that both historical systems are part of the Outstanding Universal Value emphasizes the importance of not only assessing the physical damage but also the potential loss of value due to this damage.

In order to preserve this heritage and prepare for future risks, it is essential to understand the long-term effects of the earthquake on underground water structures and to identify which parts may be affected. In contrast to the Iranian example, the impact of the earthquake on Gaziantep's traditional groundwater heritage was felt differently, as fault lines do not cross the city center and its surroundings. Therefore, identifying areas with high sensitivity to earthquake effects due to soil properties is an important step in the long term[4].

Underground water structures located within the soil can develop different responses in the absence of any earthquake threat and during an earthquake. In areas with alluvial soil properties, liquefaction or soil softening can be observed under the impact of an earthquake (Gaziantep IRAP, 2021). Soil liquefaction is defined as the significant reduction in shear strength and stiffness of cohesionless or low-cohesion soils below the groundwater level up to a depth of 20 m under earthquake shaking, parallel to the increase in pore water pressure (Türkiye Bina Deprem Yönetmeliği, 2018). The risk of liquefaction, being predictable beforehand, is an important input that should be considered in design decisions and urban planning parameters. Liquefaction also damages the stability of underground structures (Mian et al., 2013) (Figure 12). Liquefaction areas generally manifest themselves in coastal regions, river surroundings, lake/swamp areas, and their surroundings (Bulut Üstün et al., 2023).

It is known that the "kastels" part of the traditional underground water system in the Gaziantep sample area and the nearby livas lines connected to these kastels are located in the layer 20 meters deep from the surface (Altan & Arun, 2019). The depths of the structures from north to south are as follows: İmam Gazali 13.75 meters, Kozluca 2.65 meters, Şeyh Fethullah 3 meters, Pişirici 5.80 meters, İhsanbey 5.5 meters, and Ahmet Çelebi 8.75 meters. The depths of the livas lines reaching from the source point to the city center vary, with some depths identified as deep as 50 meters (e.g., under the American Hospital) and others as shallow as 1 meter from the surface (e.g., around the Pancarlı source point). Another parameter affecting liquefaction is the soil PGA (Peak Ground Acceleration) value. According to the Turkey Earthquake Hazard Map, when the PGA 475 value is greater than 0.1, the risk increases, and liquefaction is expected to intensify (JMO, 2021). PGA values for Gaziantep were examined based on coordinates entered on the AFAD Earthquake Hazard Map. Three different points in the region were researched: firstly, the area where the urban "kastels" are clustered, secondly, the Pancarlı region mentioned as the starting point of the livas line in sources, and lastly, Sam Village, which was damaged during the earthquake. Accordingly, the lowest PGA 475 value of 0.165 was recorded in the

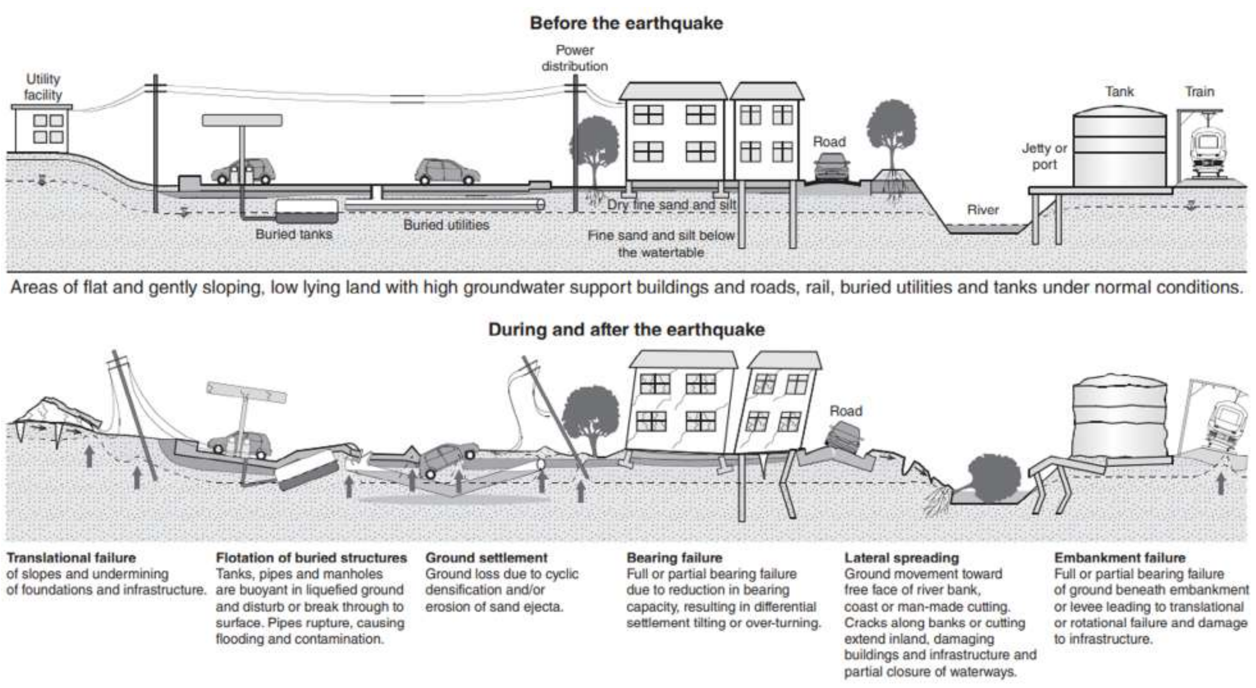


Figure 12. Soil liquefaction and its impact on underground structures (Mian et al., 2013).

urban kastels area, while the highest PGA 475 value of 0.217 was observed in the Pancarlı water source area. In Sam Village, this value was calculated as 0.210. These values are essential data for identifying high-risk areas (AFAD, n.d.) (Figure 13). According to the "Gaziantep Earthquake-Based Sensitivity Analysis," the area around the Alleben stream, including the kastels and livas lines, as well as the Çıksorut and Şehreküstü neighborhoods in the city center, are at risk of liquefaction due to the alluvial nature of the soil. This situation may pose a risk of damage to the region's old structures (Gaziantep IRAP, 2021).

According to the Gaziantep Micro-zoning Suitability Map, the suitability of land for settlement has been assessed based on geological calculations and seismicity characteristics and divided into sub-categories. Some of the most important categories affecting the groundwater system are Significant Areas 5.1 (SA - 5.1) and Precautionary Areas 2.4.A (SA 2.4.A). SA 5.1 includes areas with an alluvial structure, while SA 2.4.A includes areas composed of limestone units. It is worth noting that these areas may contain artificial caves dug by humans in the past and that collapses may occur as a result of these caves coming into contact with water (Gaziantep Metropolitan Municipality, 2023). The passage of livas carved from the rock through these areas could increase the risk of collapse.

A risk map was developed (Figure 14) based on a combination of current faulting maps, data from the Gaziantep Central Microzonation—Residential Suitability Map, PGA values obtained from the AFAD Seismic Vulnerability Map, based on designated points outside the city, and the authors' assessment of Gaziantep's groundwater resources.

According to the map prepared for the protection of Gaziantep Kastels and Livas against earthquake hazards, it is seen that the areas where the Kastel of Ahmet Çelebi, the Kastel of İhsanbey, and the Kastel of Pişirici, whose locations are known in the city center, are located could be affected by problems due to karstic voids according to the soil properties. Even without an earthquake, structures in this area could face collapse risks due to cave formations and soil properties. Therefore, special measures should be taken in the vicinity of the kastels located in these areas. Another risky area shown in orange on the map is the alluvial soils, specifically the areas around the Alleben stream where the city livas line passes. In these areas, during an earthquake, the risk of liquefaction or soil softening increases, and cracks and fractures may be observed in underground livas attempting to move through liquefied soil within 20 meters of the surface. This situation also damages the system's stability (Mian et al., 2013). Considering the PGA values in the Pancarlı Source Point and Sam Village, where the livas line first emerges on the surface and where damage occurred, it is understood that the risk of liquefaction is also valid for these areas. The map prepared based on the soil characteristic parameter highlights the points that should be prioritized in interventions for the system's protection and maintenance after earthquake hazards.

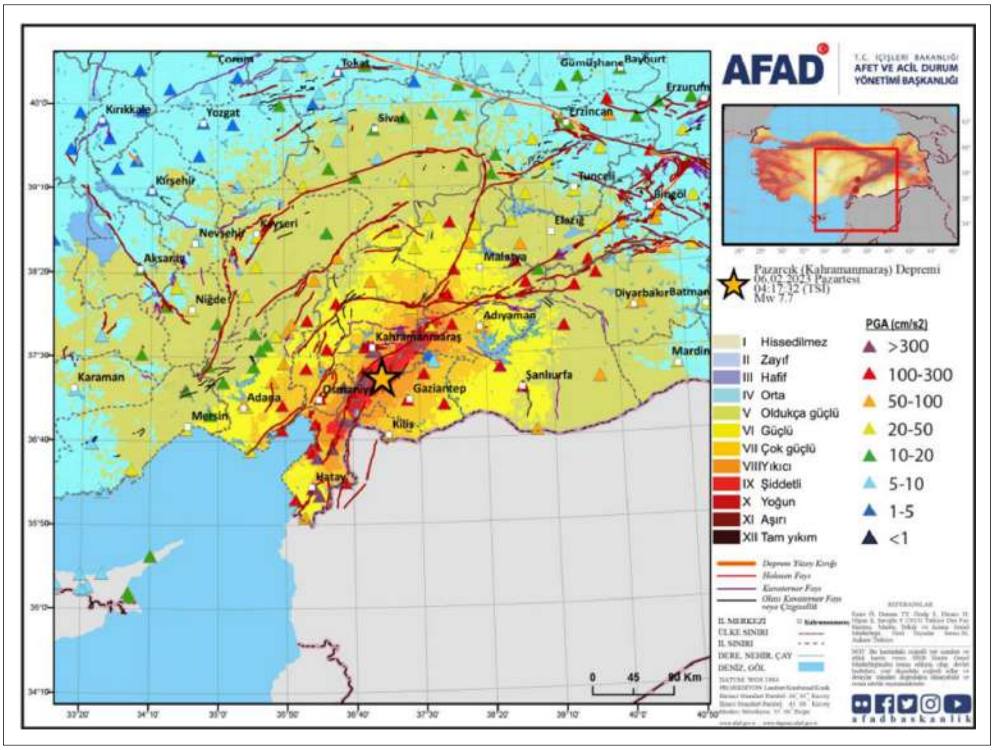
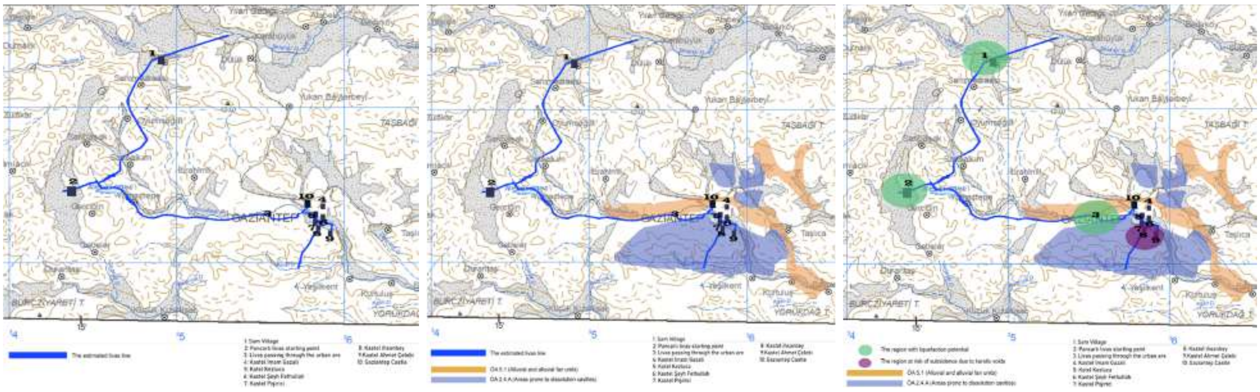


Figure 13. The AFAD-RED estimated intensity map for the Mw 7.7 earthquake (AFAD, 2023).



The Map of Estimated Livas Lines (made by the authors based on information from the OBRUK cave team and Zafer Okuyucu in September 2022).

Overlay of the estimated fault line with the Gaziantep Microzoning Suitability Map for Seismic Vulnerability Points.

The location of kastels and livas' in areas of potential liquefaction and karst collapse risk, as determined by the overlaid maps.

Figure 14. Traditional underground water structures located in areas with high earthquake damage risk (The estimated livas line map was created using the 2023 MTA (General Directorate of Mineral Research and Exploration) data generated by the authors and interviews conducted with the OBRUK Cave Team and Zafer Okuyucu).

CONCLUSION

This study was prepared to understand the status of traditional underground water systems after the February 6, 2023, Kahramanmaraş earthquakes. According to the evaluations, the traditional underground water systems in the affected city of Gaziantep were exposed to the secondary effects of the earthquake, suffering damage from surrounding debris rather than the direct impact of the earthquake itself. Furthermore, in the case of Gaziantep examined under the resilience parameter, in addition to the potential use of the systems during disasters, the likelihood of direct damage from disasters is generally low. It is concluded that the historical endurance of the systems and their function in preserving water sources have increased the level of resilience for the source and users and decreased the degree of vulnerability.

When evaluated in the context of resilience and protection parameters, better preservation of traditional underground water systems has been identified as an output that contributes to resilience in disaster situations. Therefore:

- Priority should be given to mapping historic groundwater pipes. Missing points should be completed as soon as possible.
- High-rise construction where the groundwater system comes to the surface and in its vicinity should be avoided.
- A detailed assessment of the collapse risk of buildings should be made where water pipelines cross areas of high seismic vulnerability, particularly in residential areas. This factor should be taken into account in land-use planning and development decisions.
- Historic underground water systems in rural areas should be re-established and made available to the local community. Local action can revitalize the system.
- Preparations of these systems should be made for use by disaster victims in case of emergency, especially in areas with a dense stock of wooden buildings in historic city centers, which increases resistance to fire risk.
- Preserving the intangible values of these historic systems is important. Especially the local communities living in the region should be educated and informed about the system.
- It is important to protect the technical knowledge of craftsmen familiar with the system and to teach them how to maintain these systems.

The field study revealed that historical underground water structures were not directly affected by earthquakes. However, significant risks are posed by the urban layer near the points where historic underground water structures emerge. The collapse of substandard structures near traditional underground water systems due to the earthquake's effect shows secondary effective damage to these historic water structures. Therefore, in future conservation and urban planning decisions, it is crucial to prevent multi-story constructions around the points where these structures emerge to protect these cultural assets. This provides important data in defining the conservation criteria for the Gaziantep Kastels and Livas in the UNESCO Tentative Heritage List and in determining the buffer zone.

Traditional systems have demonstrated their potential for emergency use during disasters, increasing urban resilience, providing drinking water, meeting sanitation needs, and mitigating secondary effects. Although not regularly recommended, their benefits in rural emergencies are supported by international examples (Hein et al., 2020; Celia López-Bravo et al., 2022; Blanco et al., 2019). The example of Küçük Pınar studied in Gaziantep could be an important case to address this issue. Therefore, the critical importance of Gaziantep's kastels and livas is not limited to their heritage value; their contribution to water security in the 21st century is also significant.

Examining the impact of earthquakes on qanats in Bam, Iran, has yielded valuable data for understanding the impact of the February 6 earthquake on traditional underground water systems. The collapse of qanat lines where fault lines passed and damage to main road lines due to breaks and collapses in underground qanats in Bam had widespread effects on the city. Main fault lines bypassing Gaziantep's livas prevented direct damage to the city center. In rural areas, the earthquake spared traditional underground water systems, except for the collapse of buildings on kastels. However, future secondary effects remain a concern. A soil-based risk map for Gaziantep pinpoints vulnerable areas for underground water systems post-earthquake. These areas signal collapse risks, both seismic and non-seismic. Further scrutiny is needed to prioritize action in these zones. To preserve these systems, collaborative efforts by expert hydrogeologists, geologists, civil engineers, environmental engineers, urban planners, archaeologists, and architects are needed to determine the long-term impact of risks.

In conclusion, the study confirms that traditional groundwater systems increase resilience and reduce vulnerability during disasters, contributing to 21st-century water security. It also suggests conservation strategies based on post-earthquake observations in the Kastels and Livas of Gaziantep.

NOTES

[1]The information provided is based on the interview conducted with Zafer Okuyucu on July 14, 2023.

[2]The information is provided by the personal archive of Sibel Karslıgil on May 03, 2024.

[3]The information provided is based on the interviews conducted with Assoc. Prof. Dr. Umut Almaç on May 18, 2023, and Architect Zafer Okuyucu on July 17, 2023.

[4]The discussions with Murat Ergenekon Selçuk, an Assistant Professor in the Department of Civil Engineering at YTU, have been utilized in the investigation of the earthquake's impact on underground structures based on soil properties.

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