

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

ASSESSMENT OF DAMAGED WATER SUPPLY NETWORKS
DURING FEBRUARY 6TH KAHRAMANMARAŞ EARTHQUAKES:
THE CASE OF ADIYAMAN

ADEM EREN ŞENTÜRK

A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF CIVIL ENGINEERING

ADVISOR: PROF. DR. SELÇUK TOPRAK

JANUARY 2025

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

ASSESSMENT OF DAMAGED WATER SUPPLY NETWORKS
DURING FEBRUARY 6TH KAHRAMANMARAŞ EARTHQUAKES:
THE CASE OF ADIYAMAN

ADEM EREN ŞENTÜRK

A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF CIVIL ENGINEERING

ADVISOR: PROF. DR. SELÇUK TOPRAK

JANUARY 2025

T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

6 ŞUBAT KAHRAMANMARAŞ DEPREMLERİNDE
ZARAR GÖREN SU ŞEBEKELERİNİN
DEĞERLENDİRİLMESİ: ADIYAMAN ÖRNEĞİ

ADEM EREN ŞENTÜRK

YÜKSEK LİSANS TEZİ
İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI

DANIŞMAN: PROF. DR. SELÇUK TOPRAK

OCAK 2025

MASTER of SCIENCE JURY APPROVAL FORM

A thesis submitted by Adem Eren ŞENTÜRK defended on 29/01/2025 before the jury formed with the 20/01/2025 date and 2025/06 numbered decision of the GTU Graduate Administration Board, has been accepted as a MASTER of SCIENCE thesis in the Department of Civil Engineering.

JURY

MEMBER

(THESIS ADVISOR) : Prof. Dr. Selçuk TOPRAK

MEMBER

: Assoc. Prof. Dr. Hadi KHANBABAZADEH

MEMBER

: Assist. Prof. Dr. Engin NACAROĞLU

APPROVAL

Gebze Technical University Graduate Administration Board
...../...../..... date and/..... numbered decision.

SIGNATURE/SEAL

*To my
lovely wife*

ABSTRACT

The Kahramanmaraş-centered earthquakes of February 6, 2023, with magnitudes of Mw 7.7 and Mw 7.6, caused extensive destruction in southeastern Türkiye and northern Syria. In Türkiye, 11 cities were affected by the earthquake. The earthquake sequences resulted in the loss of over 50,000 lives, the collapse of thousands of buildings and the complete or partial destruction of critical infrastructure systems, causing billions of dollars in economic damage. Consequently, the financial and psychological impacts persisted for two years following the event.

Adıyaman is one of the most devastated cities within the impacted area by the earthquakes in Kahramanmaraş on 6th of February and the subsequent aftershocks. The water supply system of the Adıyaman city center, including both transmission lines and distribution networks, sustained significant damage during the earthquake. Notably, severe damage occurred in the transmission pipelines and the repair of these damages and the reactivation of the system were carried out under challenging conditions. As a result of these circumstances, there was no water supply within the first 4 days after the earthquake. Furthermore, damage assessment efforts on the transmission and distribution lines, which remained incomplete nearly two years after the earthquake, continue to cause occasional disruptions in the city's water supply.

Within the scope of this thesis, the seismic performance of water supply systems in Adıyaman, which is one of the most affected cities by the 2023 February Kahramanmaraş earthquakes, will be thoroughly examined. Throughout the study, visits were made to the specified region and a series of site investigation were conducted. Additionally, discussions were held with authorized agency personnel and efforts continue to collect information such as pipe damage locations, types of damage, pipe material properties and diameters to create a database. In detail, one of the aim of this study is performing efforts to present damage relationships of the pipeline failures occurring in transmission and distribution lines from various perspectives such as landslide effects, faulting effects, seismic parameters etc. Besides, results are presented with the assistance of GIS. Moreover, the acquired values are used for some case studies that are examined through numerical analysis. Shortly, the generalized objective of the study is attaining for the results to provide valuable insights and aid in developing strategies to reduce potential damages. Furthermore, it is aimed that improving the overall resilience of water supply systems in areas susceptible to seismic activities.

Keywords: Damage Relationships, Kahramanmaraş Earthquakes, Pipelines

ÖZET

6 Şubat 2023 tarihinde Mw 7.7 ve Mw 7.6 büyüklüğündeki Kahramanmaraş merkezli depremler, Türkiye'nin güneydoğusunda ve Suriye'nin kuzeyinde geniş çaplı yıkıma neden olmuştur. Türkiye'de 11 şehir bu depremlerden etkilenmiştir. Deprem silsileleri, 50.000'den fazla insanın hayatını kaybetmesine, binlerce binanın yıkılmasına ve hayati önem taşıyan altyapı sistemlerinin tamamen veya kısmen tahrip olmasına yol açarak milyarlarca dolarlık ekonomik zarara neden olmuştur. Sonuç olarak; depremin maddi ve manevi etkileri, olaydan sonraki iki yıl boyunca devam etmiştir.

Adıyaman, 6 Şubat'ta Kahramanmaraş'ta meydana gelen depremler ve ardından gelen artçı sarsıntılar nedeniyle bölgede en çok zarar gören şehirlerin başında gelmektedir. Adıyaman şehir merkezinin su temin sisteminde hem isale hatları hem de dağıtım şebekeleri deprem sırasında ciddi hasar almıştır. Özellikle isale hatlarında meydana gelen ağır hasarlar, zorlu koşullar altında onarılmış ve sistem bu zorlu koşullar altında yeniden devreye alınmıştır. Söz konusu durumların bir sonucu olarak, depremden sonraki ilk 4 gün boyunca su temini mümkün olmamıştır. Ayrıca, depremden sonraki yaklaşık iki yıl süre içerisinde isale ve şebeke hatlarındaki tamamlanamayan hasar tespit çalışmaları şehirde su temini noktasında zaman zaman aksamalara neden olmaya devam etmektedir.

Bu tez kapsamında, Kahramanmaraş depremlerinden en çok etkilenen şehirlerden biri olan Adıyaman'daki su temin sistemlerinin sismik performansı ayrıntılı bir şekilde incelenecektir. Çalışma süresince, çalışma bölgesine ziyaretler gerçekleştirilmiş ve bir dizi saha incelemesi yapılmıştır. Ayrıca, yetkili kurum personelleri ile görüşmeler gerçekleştirilmiş; boru hasar yerleri, hasar türleri, boru malzeme özellikleri ve çapları gibi bilgiler toplanarak bir veri tabanı oluşturulmaya çalışılmıştır. Bu çalışma doğrultusunda; isale ve şebeke hatlarında meydana gelen boru arızalarının hasar ilişkileri heyelan etkileri, faylanma etkileri, sismik parametreler gibi çeşitli perspektiflerden değerlendirilmiştir. Elde edilen bulgular CBS (Coğrafi Bilgi Sistemleri) yardımıyla sunulmuştur. Ayrıca, elde edilen veriler, gelecekte sayısal analizler yoluyla incelenecek bazı vaka çalışmaları için kullanılacaktır. Çalışma kapsamında, potansiyel hasarları azaltmaya yönelik stratejilerin geliştirilmesine yardımcı olacak değerli bilgileri sağlamak ve buna bağlı olarak sismik aktivitelere meyilli bölgelerdeki su temin sistemlerinin genel dayanıklılığının artırılmasını sağlamak hedeflenmektedir.

Anahtar Kelimeler: Hasar İlişkileri, Kahramanmaraş Depremleri, Boru Hatları

ACKNOWLEDGEMENTS

I would like to extend my heartfelt gratitude to my esteemed advisor, Prof. Dr. Selçuk TOPRAK, for his invaluable guidance, profound knowledge and immense contributions to the planning, execution and realization of this thesis. I am deeply thankful to him not only for being a thesis advisor but also for imparting life lessons that go beyond academia.

Additionally, I am grateful to Assoc. Prof. Dr. Hadi KHANBABAZADEH, for participating in the thesis evaluation committee and sharing his valuable insights with me. I also wish to express my sincere appreciation to Assist. Prof. Dr. Engin NACAROĞLU, who shared his extensive expertise with me during fieldwork and academic studies throughout the thesis process and contributed as a member of the thesis evaluation committee.

I also would like to express my gratitude to Dr. Muhammet CEYLAN and Res. Assist. Oğuz DAL for their support throughout the thesis process.

I also would like to express my gratitude to Res. Assist. Serhat POLAT his support throughout the thesis process.

I extend my heartfelt gratitude to my beloved mother, Ayşe ŞENTÜRK, my esteemed father, Bekir ŞENTÜRK, my brother and my sister for their lifelong support and unwavering encouragement.

Lastly, but most importantly, I would like to express my deepest gratitude to my beloved wife, Tuba Miray ŞENTÜRK. I am endlessly thankful for her patience and unwavering support throughout the challenging thesis journey, fieldwork and publication process. Undoubtedly, I could not have overcome the difficulties of life's challenges without her by my side.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	vi
ÖZET	vii
ACKNOWLEDGEMENTS	viii
TABLE OF CONTENTS	ix
LIST OF SYMBOLS AND ABBREVIATIONS	x
LIST OF FIGURES	xii
LIST OF TABLES	xiv
1. INTRODUCTION	1
1.1. Importance of the Study	2
2. LITERATURE REVIEW	5
3. FEBRUARY 6 TH KAHRAMANMARAŞ EARTHQUAKES	12
3.1. Mechanisms of the Earthquakes	13
3.2. The Cost Assessment of the Earthquakes	16
3.3. Earthquake-Related Circumstance of Adıyaman	20
4. GEOLOGICAL, GEOTECHNICAL AND SEISMIC PROPERTIES OF THE STUDY AREA	28
4.1. Geological Properties	28
4.1.1. Adıyaman Group (PlQa)	29
4.1.2. Germav Formation (Ktg)	30
4.1.3. Hoya Formation (Teh)	30
4.1.4. Şelmo Formation (Tmş)	30
4.1.5. Alluvial Deposits (Qal)	31
4.2. Seismic Properties	31
4.3. Geotechnical Properties	35
5. WATER SUPPLY SYSTEM IN ADIYAMAN CITY CENTER	44
6. WATER SUPPLY SYSTEM DAMAGES IN ADIYAMAN CITY CENTER	51
6.1. Damages in Transmission Lines	51
6.2. Damages in Distribution Lines	64
6.3. Damages in Reservoirs	64
7. METHODOLOGY AND ANALYSIS	68
8. CONCLUSIONS	76
REFERENCES	79
BIOGRAPHY	86
PUBLICATIONS AND PRESENTATIONS FROM THE THESIS	87

LIST OF SYMBOLS AND ABBREVIATIONS

α	: Acceptable Margin of Error
β_c	: Confidence Interval
Φ	: Pipe Diameter
$\phi^{-1}(\beta_c)$	: Standard Normal Deviate
x	: Sampling Length
AC	: Asbestos Cement
AFAD	: Disaster and Emergency Management Agency
AI	: Arias Intensity
ASKİM	: Adıyaman Water and Sewerage Directorate
CI	: Cast Iron
DI	: Ductile Iron
DSHA	: Deterministic Seismic Hazard Assessment
DSİ	: General Directorate of State Hydraulic Works
DSF	: Dead Sea Fault
EAF	: East Anatolian Fault
EAFZ	: East Anatolian Fault Zone
FRIT	: The EU Facility for Refugees in Turkey
GASKİ	: Gaziantep Water and Sewerage Directorate
GIS	: Geographic Information System
HDPE	: High-Density Polyethylene
İLBANK	: Bank of Provinces
İÖİ	: Special Provincial Administrations
LADWP	: Los Angeles Department of Water and Power
MADAD	: EU Regional Trust Fund
MMI	: Modified Mercalli Intensity
MTA	: Mineral Research and Exploration Institute
Mw	: Moment Magnitude
MWD	: Metropolitan Water District
NAF	: North Anatolian Fault
PE	: Polyethylene
PGA	: Peak Ground Acceleration
PGD	: Permanent Ground Deformation
PGV	: Peak Ground Velocity
PSHA	: Probabilistic Seismic Hazard Assessment
PVC	: Polyvinyl Chloride
QGIS	: Quantum GIS
REMI	: Refraction Micro Tremor
RR	: Repair Rate
SA	: Spectral Acceleration
SBO	: Presidency Strategy and Budget Office
SCADA	: Supervisory Control and Data Acquisition
SI	: Spectrum Intensity
SPT	: Standard Penetration Test
SPT-N	: Number of Blows Required for 30 cm Penetration
SRTM	: Shuttle Radar Topography Mission
T_o	: Predominant Period
TGD	: Transient Ground Deformation

TÜİK : Turkish Statistical Institute
USGS : United States Geological Survey
 V_{s30} : Average Shear-Wave Velocity for Upper 30-m Depth

LIST OF FIGURES

	<u>Page</u>
Figure 2.1: A schematic representation of various PGD mechanisms affecting pipelines [Toprak et al, 2024a].	9
Figure 3.1: The map illustrating the area where a state of emergency was proclaimed in the aftermath of the Kahramanmaraş earthquakes [Toprak et al., 2024c].	12
Figure 3.2: Representation of Türkiye’s tectonic structure and the epicenters of the Kahramanmaraş earthquakes [USGS, 2023].	13
Figure 3.3: The spatial distribution of seismic activities in the region that focuses on the first main shock location.	15
Figure 3.4: The histogram of the seismic activities which belong to the region that focuses on the first main shock location.	15
Figure 3.5: The map illustrating the seismic aspect of Adıyaman city center.	21
Figure 3.6: The locations of strong ground motion stations.	22
Figure 3.7: Demolished building inventory of Adıyaman city center [Tekin and Akcan, 2023].	23
Figure 3.8: Satellite images of the city center: (a) before the earthquake, (b) after the earthquake.	24
Figure 3.9: Damaged buildings in Adıyaman city center.	26
Figure 3.10: Collapsed buildings in Adıyaman city center.	27
Figure 4.1: The general geology of the Adıyaman city center surroundings [Herece, 2008].	29
Figure 4.2: The distribution of geological units within the study area [Adıyaman Municipality, 2023].	32
Figure 4.3: Fault lines located in the vicinity of Adıyaman city center.	32
Figure 4.4: The spatial distribution of seismic activities around the Adıyaman city center for a 100-year period.	33
Figure 4.5: The histogram of the seismic activities for Adıyaman city center for a 100- year period.	34
Figure 4.6: The histogram of the seismic activities for Adıyaman city center for two years after Kahramanmaraş earthquakes.	35
Figure 4.7: Groundwater table level map of Adıyaman city center [Adıyaman Municipality, 2023].	38
Figure 4.8: V_{s30} map of Adıyaman city center based on seismic refraction test [Adıyaman Municipality, 2023].	39
Figure 4.9: V_{s30} map of Adıyaman city center based on REMI method [Adıyaman Municipality, 2023].	40
Figure 4.10: Shear wave velocity distribution map with respect to map in Adıyaman city center [Adıyaman Municipality, 2023].	41
Figure 4.11: Predominant period distribution map of soil group in study area [Adıyaman Municipality, 2023].	42
Figure 4.12: Soil amplification map of study area [Adıyaman Municipality, 2023].	43
Figure 5.1: Spatial overview of the water sources of Adıyaman city center.	44
Figure 5.2: The map illustrating the regional topography and transmission lines.	45

Figure 5.3: A basic overview of the distribution networks of Adıyaman city center.	46
Figure 5.4: The photo of Gürlevik DI (left) and Gürlevik 2 from site observations.	49
Figure 5.5: Implementation photographs of MADAD and FRIT II frameworks.	50
Figure 6.1: An example from field studies conducted on the Havşeri transmission line [Adıyaman Municipality, 2024].	52
Figure 6.2: Repair process of the damaged Φ 700 mm steel pipe.	53
Figure 6.3: The crossing of existing fault line with Havşeri transmission line.	54
Figure 6.4: Distribution of landslide cases Adıyaman and nearby cities superimpose with landslide probability model.	56
Figure 6.5: Distribution of landslide cases along with transmission line for Adıyaman city center superimpose with landslide probability model.	57
Figure 6.6: Damages in Gürlevik 2 transmission line.	58
Figure 6.7: Damages in steel section of Gürlevik 1 transmission line.	60
Figure 6.8: Damages in Gürlevik DI and 2 transmission lines due to rock falls.	61
Figure 6.9: Different types of damages in Adıyaman: a) Local buckling failure b) Joint failure.	63
Figure 6.10: Different types of damages in Adıyaman: a) Tension failure b) Bending failure.	64
Figure 6.11: Some examples from distribution line problems in Adıyaman city center (ASKİM personal communication).	65
Figure 6.12: Damages in Gürlevik source due to rock falls.	66
Figure 6.13: The spatial distributions of landslides, Gürlevik water supply networks relevant damages.	67
Figure 7.1: PGV distribution map of Adıyaman city center and nearby districts.	70
Figure 7.2: Comparison of damage data from Gürlevik 2 with the literature.	72
Figure 7.3: Details of the terrain where Gürlevik 2 transmission line passes.	73
Figure 7.4: The correlation of RR and slope degree for Gürlevik 2 line.	75

LIST OF TABLES

	<u>Page</u>
Table 2.1: Some case studies examining the impact of earthquakes on infrastructure systems.	5
Table 2.2: Details of studies related with relevant earthquakes.	6
Table 3.1: Estimated impact assessment of the earthquake's damage to water and sewage systems.	18
Table 3.2: The distribution of grant amounts by cities and water systems.	19
Table 3.3: The detail of amount of investments for projects undertaken by İLBANK.	20
Table 3.4: Strong ground motion data for some stations in Adıyaman province with respect to the first earthquake (Mw 7.7).	22
Table 4.1: Detailed information about conducted tests.	36
Table 4.2: Soil composition of geologic units round Adıyaman city center.	37
Table 4.3: Soil composition details and soil types in Adıyaman city center.	37
Table 4.4: Detailed parameters of fine grained soil types in Adıyaman city center.	38
Table 4.5: Geophysical test results for Adıyaman city center.	43
Table 5.1: Information regarding the sources and their associated transmission lines [Toprak et al., 2024c].	45
Table 5.2: Operational details of ASKİM related with water supply [Toprak et al., 2024c].	47
Table 6.1: Lithological information along the Gürlevik 2 line.	56
Table 6.2: Information about damage point locations along Gürlevik 2 line.	59
Table 7.1: Corresponding PGV values for water supply networks.	70
Table 7.2: Distribution of PGV intervals for each transmission line.	71
Table 7.3: RR values for Gürlevik 1 and 2 lines with respect to PGV intervals	71
Table 7.4: Topographic information of damage points along the Gürlevik 2 line.	74
Table 7.5: RR calculations for damage points along the Gürlevik 2 line with respect to slope intervals.	75

1. INTRODUCTION

As a natural disaster, earthquakes are among the most powerful and devastating natural phenomena capable of causing serious damage and substantial loss of life. Earthquakes, affect negatively the post-disaster management mechanism by causing significant damage to superstructure and infrastructure systems such as buildings, bridges, water transmission and distribution lines and electricity networks in urban areas. These system damages caused by natural disasters delay emergency actions and extend the time required for community life to return to normal. As a result, countries and their societies experience long term challenges for both economical and psychological.

The protection of cities, which possess high population density, an increasing number of large residential areas and buildings, significant trade networks, industrial activities and importance with respect to political and administrative issues, against earthquakes is a critical concern [Pitilakis et al., 2006].

Lifeline systems, encompassing aspects such as the provision of energy and potable water, wastewater treatment, transportation infrastructure and communication services, have critical importance for humanity. Within the global trend of urbanization, the protection of urban areas against earthquakes has become increasingly significant under the concepts of seismic safety and seismic reliability. [Kameda, 2000].

Water systems are extensive and complex networks that span diverse geological formations and hazard-prone areas, making them susceptible to damage and service disruptions when impacted by the widespread effects of an earthquake. Therefore, the performance of water systems under seismic loads plays a vital role in ensuring the resilience of the communities they support [Davis, 2014].

Transmission lines that transport water from sources located kilometers outside the city to urban areas may be exposed to earthquake-induced geo-hazards as they pass through regions with varying geographic characteristics. These effects can result in damages to pipelines such as ruptures, buckling and cracking. Additionally, engineering structures like reservoirs and valve chambers may sustain damage to the

extent of collapse during an earthquake. In the distribution networks responsible for delivering water from transmission lines to urban areas, ground responses caused by the propagation of seismic waves can lead to breaks, fractures, and buckling in the pipelines. Furthermore, damage can also occur at the connection points of subscriber systems.

Water supply systems are considered an indication of the quality of urban living standards due to their role in satisfying fundamental human needs. In this context, it is evident that any disruptions in the functionality of these water systems will adversely impact daily life. Considering all these factors, it is crucial for water supply systems to maintain their functionality under the impact of earthquakes.

1.1. Importance of the Study

Pipelines, one of main components in the term of lifelines, are laid across extensive distances and encountering various geo hazards such as fault rupture, landslides, liquefaction and lateral spreading as they pass through diverse geographical regions [Toprak et al., 2015].

Water supply infrastructures, including pipelines, treatment plants and pumping stations, are at significant risk of serious damage during earthquake shaking, which could disrupt water supply and negatively affect water quality [Toprak et al., 2024a]. For this reason, it is imperative to assess the causality of damages caused by or potentially arising from earthquakes in seismically active regions. Based on these evaluations, establishing the necessary damage correlations and integrating these findings into appropriate disaster management strategies is crucial. In this regard, Geographic Information Systems (GIS) serve as a valuable tool in developing these relationships. The ability to conduct spatial analyses and overlay diverse datasets to derive meaningful correlations constitutes one of the most significant advantages offered by GIS.

GIS which creates, manages, analyzes and maps numerous types of data plays a crucial role in various engineering applications owing to its capability. Especially in recent years, the performance of infrastructure systems during earthquakes that impact extensive residential areas has been studied by using GIS.

Studies conducted by geoscientists generally centered on primarily geological and geophysical characteristics of the earthquakes as main topic. Additionally, earthquake-related works primarily focus on the behavior structures and structural elements such as buildings, bridges, dams, transportation systems under the effect of an earthquake from a civil engineering perspective. However, the studies which specifically focus on the impact of earthquakes on the behavior of pipeline systems are relatively much fewer in the literature. Furthermore, the seismic behavior of buried pipeline systems and the influence of factors on it have been comparatively less studied from a geotechnical viewpoint.

As part of the study, the damages in the water supply systems in the city center of Adıyaman which are resulted in following the February 2023 Kahramanmaraş earthquakes are addressed. These damages, which will be elaborated upon in detail for next chapters, have significantly impacted the residents of Adıyaman's city center, subjecting them to severe hardships. During this period, the inability to access potable water, coupled with the inoperability of the sewerage system, exposed the population to substantial public health risks.

Additionally, the raw data utilized in the study were analyzed and spatially interpreted using GIS tools. Efforts were made to parametrically correlate the damages observed in the pipelines supplying water to the Adıyaman city center with specific damage relationships. The findings were presented through the use of tables and maps to facilitate clarity and comprehension.

Although the city center of Adıyaman benefits from various water sources, these sources can only meet the city's water demand within certain limits, particularly due to drought conditions during the summer months. In addition to drought, despite the ongoing efforts to modernize the city's water distribution infrastructure, the persistently high rates of water loss and leakage in transmission lines pose a significant risk of water scarcity for Adıyaman in the future. Ruptures, fractures, and corrosion that have occurred in the transmission lines over time were exacerbated by the impact of the February 2023 Kahramanmaraş earthquakes, turning these issues into more severe problems. In the post-earthquake period, significant repairs and improvements were undertaken in the transmission lines supplying water to the city center, requiring extraordinary efforts.

The city center of Adıyaman, located at a relatively short distance from active fault lines, is also traversed by several thrust faults situated near the urban area, which have been the subject of certain studies. To enhance the city's resilience to earthquakes, it is imperative to always consider the reality of seismic activity and integrate this factor into urban planning policies. Undoubtedly, achieving earthquake resistance in Adıyaman requires the sustainable operation of its infrastructure systems.

The analyses conducted within the scope of this study aim to present the current state of Adıyaman's infrastructure system in terms of earthquake resilience, while also identifying necessary improvements to enhance the system. Through numerous field visits and official consultations carried out as part of this study, the objective is to increase the earthquake resilience of the city's water supply system in collaboration with relevant local authorities. The findings obtained in this regard are expected to make a significant contribution to the existing literature. The data collected during the study will also be utilized in future research and, subject to approval from the relevant authorities, shared with appropriate units to support collaborative efforts that benefit the city of Adıyaman.

2. LITERATURE REVIEW

Seismic activities have had a profound impact on infrastructure systems during numerous earthquakes throughout history. Notable examples of major earthquakes from the 20th and 21st centuries include the 1985 Michoacán earthquake, the 1989 Loma Prieta earthquake, the 1994 Northridge earthquake, the 1995 Kobe earthquake, the 1999 Kocaeli earthquake, the 1999 Chi-Chi earthquake, the 2011 Christchurch earthquake and the 2016 Kumamoto earthquake [Toprak et al., 2024a; 2024b].

Case studies conducted following each earthquake in world history have provided significant contributions to the literature from many aspects. In this context, studies conducted following certain earthquakes in the past and current centuries have contributed to raising awareness of the behavioral mechanisms of infrastructure systems, particularly buried pipelines, under seismic loading [e.g. Ayala and O'Rourke, 1989; Isenberg et al., 1991; Hamada et al., 1996; O'Rourke and Toprak, 1997; Chen et al., 2002; Kaya et al., 2017; Wham et al., 2017; Toprak et al., 2019]. These studies have provided valuable examples to the literature, thereby supporting the development of resilient infrastructures, which are fundamental to the creation of disaster-resistant cities. **Table 2.1** and **Table 2.2** highlights earthquakes that have contributed to the literature, while also providing examples of studies that examine the impacts of these earthquakes on infrastructure systems.

Table 2.1: Some case studies examining the impact of earthquakes on infrastructure systems.

Earthquake	Year	Mw	Country	Study
Michoacán	1985	8.0	Mexico	Ayala and O'Rourke [1989]
Loma Prieta	1989	6.9	USA	Isenberg et al. [1991]
Northridge	1994	6.7	USA	O'Rourke and Toprak [1997]
Kobe	1995	7.2	Japan	Hamada et al. [1996]
Kocaeli	1999	7.4	Türkiye	Kaya et al. [2017]
Chi-Chi	1999	7.7	Taiwan	Chen et al. [2002]
Christchurch	2011	6.2	New Zealand	Toprak et al. [2019]
Kumamoto	2016	7.0	Japan	Wham et al. [2017]

Table 2.2: Details of studies related with relevant earthquakes.

Earthquake	Study	Notes
Northridge Earthquake (1994)	O'Rourke and Toprak (1997) Toprak (1998) O'Rourke et al, (1998)	-Damage at 15 locations across three transmission lines. -LADWP distribution pipeline network experienced 1,013 damage points. -74 damage sites were identified in the water trunk lines.
Kobe Earthquake (1995)	Chung (1996)	-About one million households without water. -Within three weeks, 70% of the water system was restored for residential use. -A total of 10 damages were reported in two steel transmission lines.
Kocaeli Earthquake (1999)	Erdik (2001) Ansal et al. (2008)	-The primary damage occurred in the distribution systems, mainly due to the brittle AC pipes. -Ground deformations caused by liquefaction and the softening of alluvial sediments are main factors. -Severe damage to distribution pipes caused by fault ruptures and liquefaction.
Chi-Chi Earthquake (1999)	Shih and Chang (2006)	-Significant vertical displacements occurred, with values reaching up to 10 meters. -Water treatment facilities and underground pipelines sustained extensive damage. -Approximately 2,800 instances of pipeline damage were documented.
Christchurch Earthquake (2011)	O'Rourke et al, (2012) Milashuk and Crane (2012) O'Rourke et al. (2014) Nacaroğlu (2017) Toprak et al. (2020)	-The total number of repairs to main pipelines was 1502. -Repairs to the submain pipeline system were documented at 2000 locations. -69% of pipeline damages occurred in AC pipes, with 15% of these damages observed in areas where liquefaction did not occur. -Total economic loss of 30 billion New Zealand Dollars.

The 1994 Northridge earthquake (Mw 6.7) is one of the earliest events to provide significant contributions to the literature. The earthquake caused substantial disruptions to Los Angeles's water supply system. The earthquake caused damage at 15 locations across three transmission lines supplying water from Northern California. Additionally, the Los Angeles Department of Water and Power (LADWP) distribution

pipeline network experienced 1,013 damage points, while 74 damage sites were identified in the water trunk lines [Toprak, 1998].

In 1995 Kobe earthquake, the earthquake left one million households without water. Within three weeks, 70% of the water system was restored for residential use. A total of 10 damages were reported in two steel transmission lines supplying water to the city of Kobe. Despite the high percentage of earthquake-resistant pipes with robust damage-resistant features, about 1800 pipe damages occurred in the transmission lines. The damage mechanism involved joint failure and separation, which was speculated to result from lateral spreading caused by liquefaction [Chung, 1996].

Ansal et al. [2008] reported that the water pipeline system in city of Adapazari suffered significant damage in 1999 Kocaeli earthquake (Mw 7.4). The primary damage occurred in the distribution systems, mainly due to the brittle AC pipes used in the system, compounded by ground deformations caused by liquefaction and the softening of alluvial sediments. In steel transmission lines, there were reported damages in some regions which locate surface fault rupture points. The water supply in cities, particularly Gölcük, Adapazari and Sapanca, was disrupted for an extended period due to severe damage to distribution pipes caused by fault ruptures and liquefaction. Additionally, there were some damages in water tanks and reservoirs during the earthquake [Erdik, 2001].

During the Chi-Chi earthquake (Mw 7.7), significant vertical displacements occurred, with values reaching up to 10 meters. The earthquake caused rupture along more than 100 kilometers of the fault. In the disaster-affected region, water treatment facilities and underground pipelines sustained extensive damage. Approximately 2,800 instances of pipeline damage were documented across numerous cities in the area. In the earthquake, it was reported that 48% of water pipeline damages were caused by ground shaking, 16% by vertical ground movement, 9% by lateral ground movement, 11% by ground failure 10% by surface cracks and fissures, 2% by liquefaction and 4% by the others [Shih and Chang, 2006].

In 2011 Christchurch earthquake (Mw 6.2), the earthquake caused substantial damage to the pipelines. The 2010-2011 Canterbury earthquake sequence remains one of the most extensively documented earthquake events to date. The total number of repairs to main pipelines was 1502 [Toprak et al., 2020]. During the Christchurch

earthquakes, repairs to the submain pipeline system were documented at 2000 locations [Milashuk and Crane, 2012]. In the Christchurch earthquake, 69% of pipeline damages occurred in AC pipes, with 15% of these damages observed in areas where liquefaction did not occur [O'Rourke et al., 2012]. The majority of pipeline damages occurred in soil liquefaction areas where differential settlements and lateral strains affected the pipelines adversely. Although service was restored to approximately half of the households within a few days after the earthquake, the overall recovery required considerable time. Due to the Christchurch earthquake, liquefaction occurred over an extensive area of approximately 90 km² within the city of Christchurch. As a result of liquefaction, approximately 60,000 residential properties were damaged, and a significant portion of the city's infrastructure systems was severely affected. Of the total economic loss of 30 billion New Zealand Dollars, half is directly attributed to damage caused by liquefaction [Nacaroğlu, 2017].

Pipeline damages resulting from seismic effects are classified into three primary categories in the literature: permanent ground deformation (PGD), transient ground deformation (TGD) and secondary damage formation. PGD refers to irreversible ground displacements triggered by earthquakes, including those caused by fault movements, landslides, liquefaction and lateral spreading [Toprak and Yoshizaki, 2003]. **Figure 2.1** exemplifies PGD mechanisms for buried pipelines. TGD refers to the dynamic response of the soil during the propagation of seismic waves and can result in soil cracks and fissures caused by strong motion pulses that surpass the soil's shear strength near the surface [O'Rourke, 1998]. Although, PGD typically affects specific locations within pipeline systems, it has a significantly high potential to cause damage to pipelines. In contrast, TGD impacts a larger portion of pipeline systems compared to PGD. Various studies have demonstrated that both types of deformation result in damage to infrastructure systems [Nair et. al, 2018].

Damage relationships developed to assess pipeline fragility are not only critical for robustness and reliability analyses but also play a fundamental role in future seismic damage estimation studies [Toprak et al., 2011]. The repair rate (RR) parameter is widely utilized in the literature for calculating damage relationships, as it normalizes damage based on pipeline length and provides a reliable measure of fragility [Toprak et al., 2009]. Pipeline damage relationships are typically established by correlating RR with various parameters, including horizontal and vertical displacements, peak ground

acceleration (PGA), peak ground velocity (PGV), Modified Mercalli Intensity (MMI) and the PGV^2/PGA ratio. The PGV^2/PGA ratio was first proposed by **Pineda-Porras and Ordaz [2007]**.

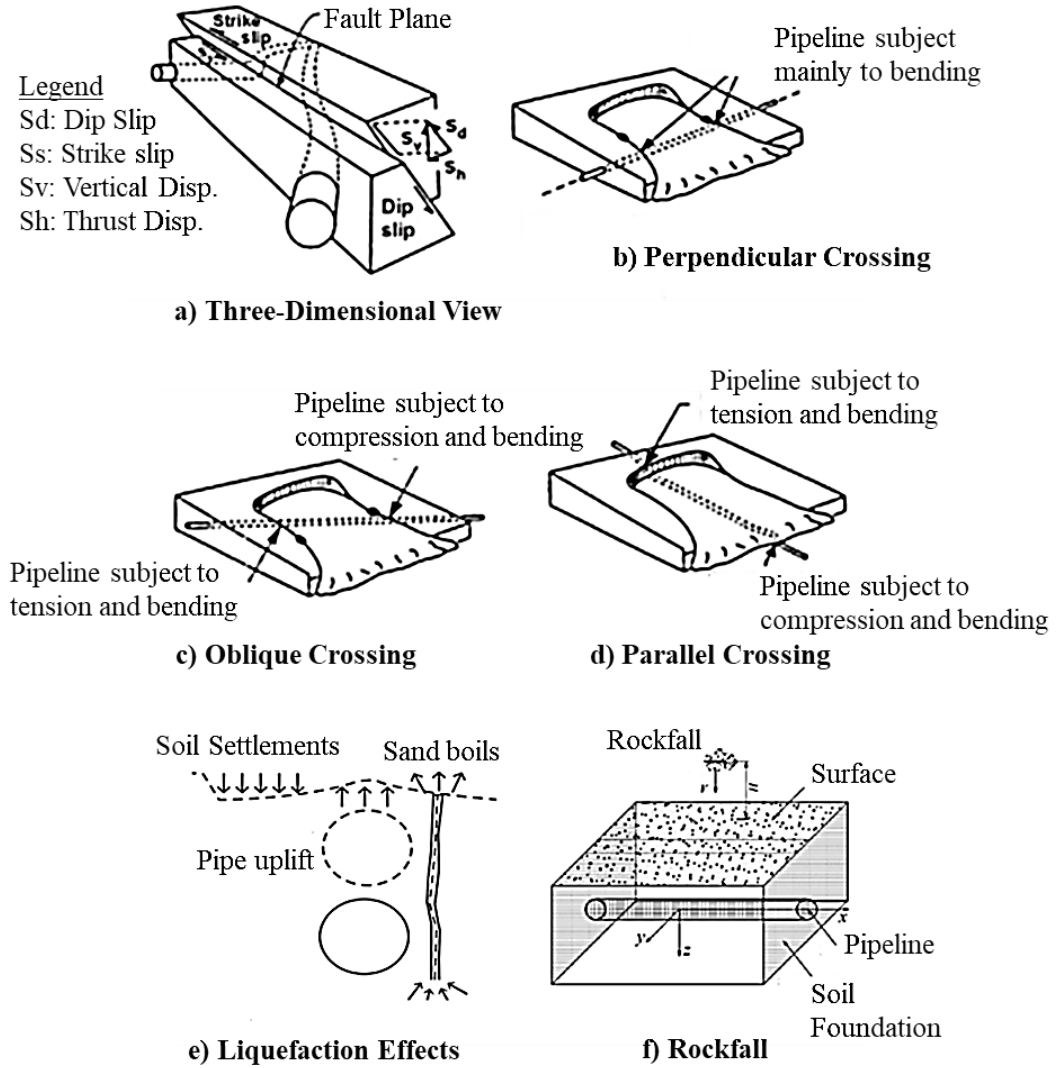


Figure 2.1: A schematic representation of various PGD mechanisms affecting pipelines [Toprak et al, 2024a].

Toprak [1998] and **Toprak ve Taşkın [2007]** presents a detailed literature review on historical development process of pipeline damages. In the literature, damage relationships are correlated with various seismic parameters as previously mentioned. Additionally, these approaches have been extensively analyzing for pipelines made from different material types, such as asbestos cement (AC), ductile iron (DI), steel, cast iron (CI), PVC and polyethylene (PE).

The study by **Katayama et al. [1975]**, which utilized the PGA seismic parameter, is considered one of the earliest works to establish the relationship between pipeline damage and seismic parameters. They calculated damage relationships for AC and CI pipelines using the PGA parameter across six different earthquake scenarios.

O'Rourke et al. [1998] and **Toprak [1998]** revealed that the correlation between PGV and RR provided the most accurate results among the damage relationships developed for parameters such as MMI, PGA, peak ground displacement, Arias Intensity (AI), Spectral Acceleration (SA) and Spectrum Intensity (SI) in the water transmission pipelines managed by the LADWP and the Metropolitan Water District (MWD) via using GIS following the 1994 Northridge earthquake. **Toprak [1998]** also identified a relationship between pipeline diameters and the extent of damage sustained. The influence of seismic hazards on buried pipelines was analyzed in two distinct categories as PGD and TGD.

Toprak and Taşkın [2007] examined the vulnerability of city of Denizli drinking water distribution networks to seismic hazards using GIS. In this study, seismic hazards were analyzed under two categories: transient ground deformation effects and permanent ground deformation effects such as surface ruptures caused by strong ground motion parameters (PGA, PGV), liquefaction and landslides. The study assessed the damage to drinking water networks in Denizli city caused by two seismic sources with high potential to generate hazards, using four scenario earthquake magnitudes (Mw 6.0, 6.5, 7.0, 7.5). The findings revealed that significant damage to the drinking water distribution networks is likely to occur in the event of potential earthquakes in Denizli, making the network non-functional. They came up with the results of some recommendations. Proposals include risk reduction recommendations, replacing of asbestos cement and concrete pipes in areas exposed to liquefaction, and surface rupture, with ductile materials such as steel or PE pipes, as well as improving the seismic resilience of soils where pipelines are embedded.

In this context, studies conducted in the aftermath of the Christchurch earthquake, which occurred on February 22, 2011, with a magnitude of Mw 6.2, have offered critical insights into the relationship between pipeline damage and seismic events. The large-scale horizontal and vertical ground movements caused by widespread liquefaction resulted in severe damage to the infrastructure systems in the region. The Christchurch earthquake is widely regarded by many researchers as one of the seismic

events that caused significant damage to infrastructure systems. Post-earthquake investigations identified 1502 instances of damage assessment within approximately 1730 kilometers of the drinking water distribution network across the entire region [Ceylan, 2020].

In 2014, **O'Rourke et al. [2014]** performed a wide in scope study focused on damage relationships. They analyzed the performance of Christchurch, New Zealand's water supply, wastewater, and natural gas pipeline networks during the 2011 Canterbury earthquake sequence. The study utilizes damage reports from brittle water supply pipelines, they established fragility relationships based on peak ground velocity (PGV), defined as the geometric mean of the peak ground velocities from two orthogonal recordings. They also analyzed the impact of horizontal and vertical ground movements on pipeline damage in the region. The study emphasized the considerable performance of the pipeline networks, primarily composed of highly ductile high-density polyethylene (HDPE) pipes.

Bouziou [2015] examined the relationship between the principal strain axis and the pipe axis in Christchurch's drinking water pipeline system, associating this relationship with pipe orientation. The study also incorporated a comprehensive dataset related to the earthquake in question.

3. FEBRUARY 6TH KAHRAMANMARAŞ EARTHQUAKES

On February 6, 2023, at 04:17 and 13:24 local time (Türkiye), two earthquakes with magnitudes of Mw 7.7 and Mw 7.6 occurred, with their epicenters located in the Pazarcık and Elbistan districts of Kahramanmaraş Province, Turkey. The earthquakes have occurred within the depth of 8.6 and 7 km for the first and the second shocks, respectively [AFAD, 2023a].

After February 6 Kahramanmaraş earthquakes a state of emergency was pronounced across 11 provinces. The state of emergency comprises Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye and Şanlıurfa. The relevant earthquakes also affected some provinces outside of these 11 and Disaster and Emergency Management Agency (AFAD) declared to the public that the provinces of Batman, Bingöl, Kayseri, Mardin, Niğde, and Tunceli were identified as 'Disaster Area with Major Impact on Public Life' as a result of the damage assessment works in addition to mentioned 11 provinces, on April 3, 2023 [AFAD, 2023b]. **Figure 3.1** illustrates related information about Kahramanmaraş Earthquake sequences [Toprak et al., 2024c].

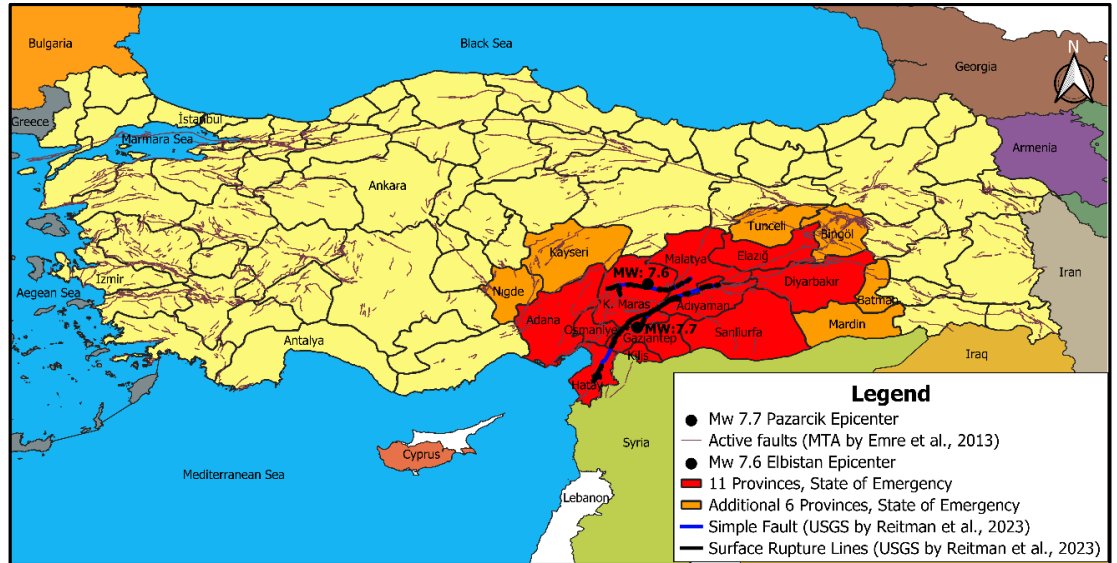


Figure 3.1: The map illustrating the area where a state of emergency was proclaimed in the aftermath of the Kahramanmaraş earthquakes [Toprak et al., 2024c].

The Kahramanmaraş earthquakes on February 6, 2023 impacted a region of 120,000 square kilometers, directly affecting 11 provinces in Turkey that are vital for agriculture and industrial production, while also being culturally, historically, and touristically significant. These earthquake sequences caused significant destruction, affecting approximately 14 million people living in these provinces. As a result of the earthquakes, 53,537 people lost their lives, and 107,204 individuals were injured [SBO, 2024].

3.1. Mechanisms of the Earthquakes

The first earthquake (Mw 7.7) is located in the zone that is quite close distance to the triple junction formed by the Arabian and African plates and the Anatolian block. It was on nearly East Anatolian Fault Zone (EAFZ). The second earthquake (Mw 7.6) was taken place on the Sürgü fault (also attributed as Ekinözü and Çardak fault) which was existing in the west of the East Anatolian Fault (EAF). **Figure 3.2** depicts epicenters of aforementioned earthquake sequence and major faults of Türkiye [USGS, 2023].

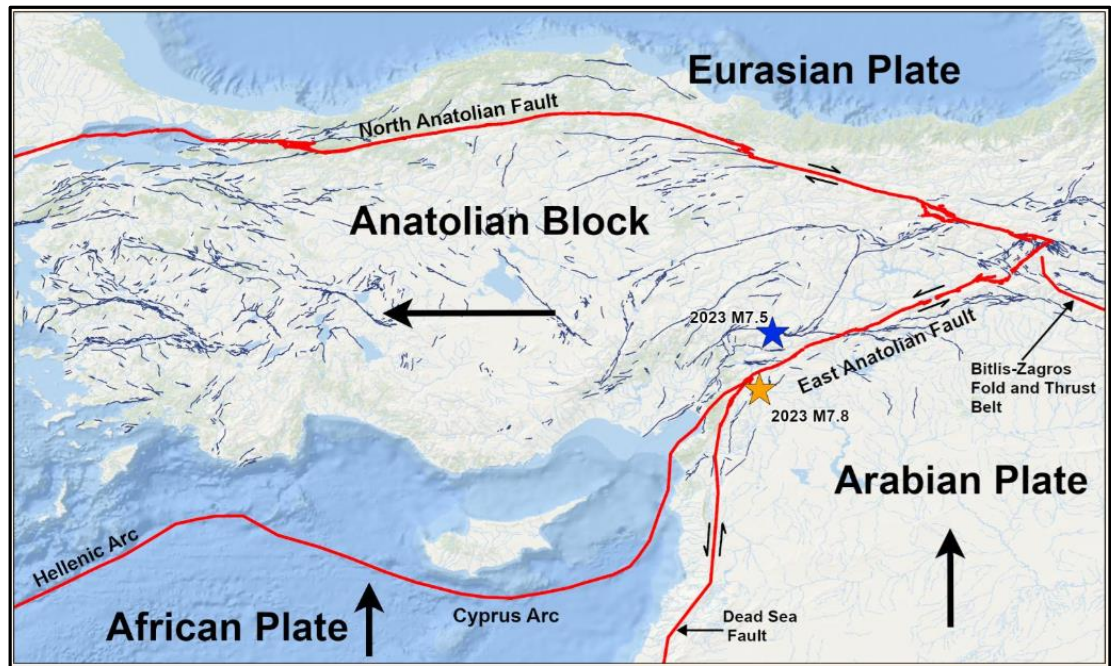


Figure 3.2: Representation of Türkiye's tectonic structure and the epicenters of the Kahramanmaraş earthquakes [USGS, 2023].

The East Anatolian Fault Zone (EAFZ) lies along NE to SW direction and divided many segments. Additionally, EAFZ displays an active left-lateral fault characteristic [Duman and Emre, 2013]. EAFZ is one of most active transform fault zones on the Earth and locates between the Arabian plate and the Anatolian plateau. It plays a key role on leading the westward movement of the Anatolian plate which was arisen from the continental collision between the Arabian and Eurasian plates during the Late Miocene [Lyberis et al., 1992]. Besides, the Arabia peninsula has a northward movement with respect to the African plate via the Dead Sea fault (DSF) [Figure 3.2].

Reitman et al. [2023] detected that Kahramanmaraş earthquake sequences resulted in more than 500 km fault rupture totally within the combination of approximately 345 km along the EAF for the first earthquake (Pazarcık, Mw 7.7), 175 km along the Çardak fault for the second earthquake (Elbistan, Mw 7.6) and some additional secondary fault ruptures.

Figure 3.3 illustrates the spatial distribution of aftershocks that occurred within approximately two years following the February 6 Kahramanmaraş earthquakes [AFAD, 2024]. The figure depicts earthquakes that occurred within a region extending up to 100 km from the epicenter of the initial earthquake (Pazarcık, Mw 7.7). In the figure, earthquake locations, active faults, and Türkiye Seismic Hazard Map provided by AFAD are superimposed.

In this region, the number of seismic events with a magnitude of 4.0 or greater within approximately two years has been calculated as 411. This calculation was based on the 'Instrumental Earthquake Catalog' portal provided by AFAD. Figure 3.4 presents a histogram illustrating the seismic activity of the region in question. It should also be noted that numerous aftershocks occurred along the EAFZ outside this reference region following the two main earthquakes.

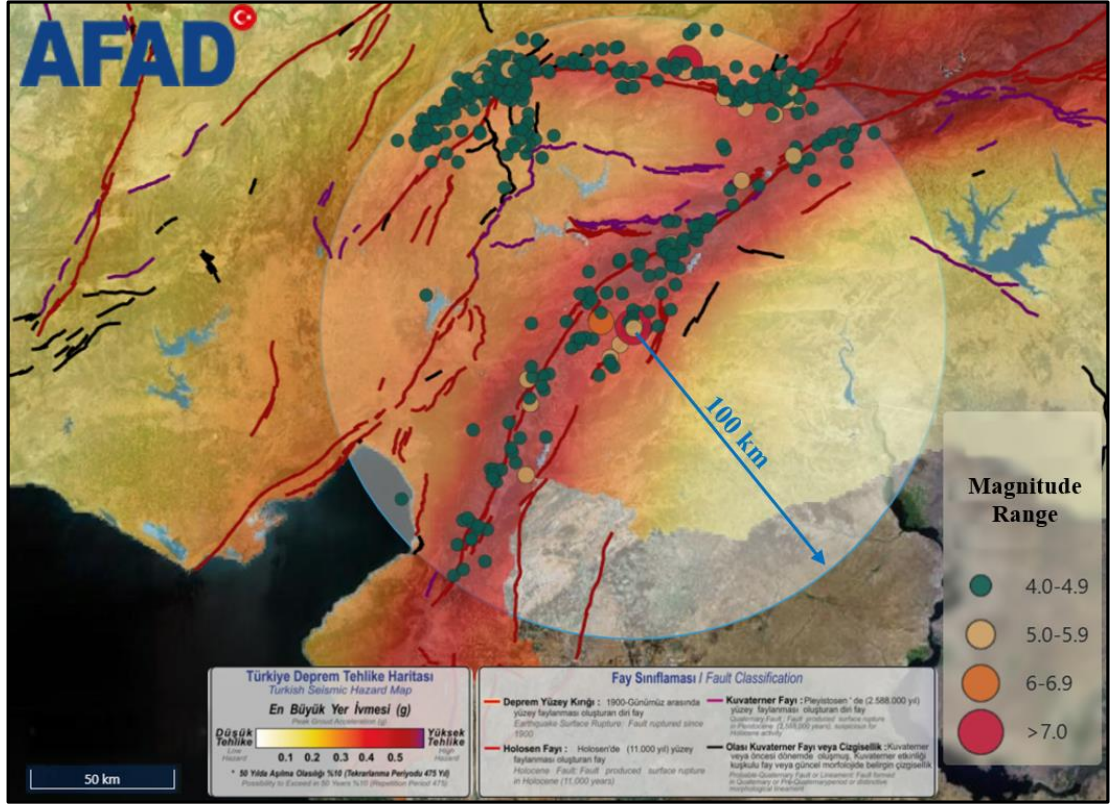


Figure 3.3: The spatial distribution of seismic activities in the region that focuses on the first main shock location.

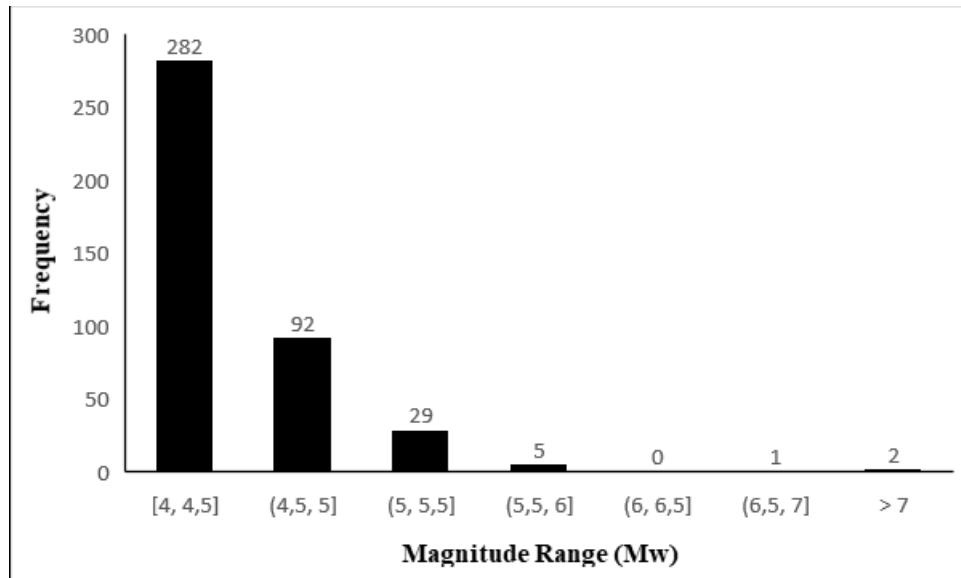


Figure 3.4: The histogram of the seismic activities which belong to the region that focuses on the first main shock location.

3.2. The Cost Assessment of the Earthquakes

According to releasing information to the public, the damage assessment studies conducted in the 11 provinces affected by the earthquakes have been revealed that, from among 2258622 buildings totally, 39361 (1.7 %) have collapsed, 21191 (0.9 %) are in immediate danger of collapse, 202571 (9 %) are heavily damaged, 43344 (1.9 %) are moderately damaged and 1,952,155 (86.4 %) are either lightly damaged or non-damaged by the date of January 22, 2024.

In the disaster area, disruptions and interruptions have occurred in infrastructure services such as water, wastewater, gas, electricity, telecommunications and transportation, ranging from a few hours to several months in duration. Most of disruptions were directly related to earthquake based damage while some interruptions were implemented by the relevant authorized associations as precautionary measures (such as controlled water and natural gas line cuts in certain locations). In particular, the aforementioned system disruptions had a huge negative impact on the first few days which are the most vital period immediately after the disaster. Therefore, this circumstance led the delays in search and rescue and first aid operations in the short term, also a long-term process in which the community experienced adverse effects, both mentally and physically. For this reason, recovery process was further extended.

The report published by Presidency Strategy and Budget Office (SBO) on March 17, 2023, outlined the extent of the losses and damages that were identifiable in the initial stage following the earthquakes. The report estimates that the cost of the devastation to the Turkish economy could be as high as 103.6 billion dollars (1995 billion TL) based on the initial information and data collected from the disaster area. The largest portion of the total cost is consisted of residential building damages amounting to 56.9 billion dollars. public sector damages including infrastructure costs are following amounting to 12.9 billion dollars followed by damages related with private sector with amounts to 11.8 billion dollars. The total estimated cost corresponds to approximately 9% of the national income for 2023 calendar year.

After the earthquake, although loss and leakage rates vary from city to city. Official institutions have confirmed that there has been a significant and unequivocal increase in the rate of water loss and leakage through inter-agency consultations in the region. In fact, the rate of water loss and leakage immediately following the earthquake ranged

between 60% and 85% in some cities in the disaster area according to statements from official institutions related with water works.

Since potable water and sewage infrastructure facilities are generally buried underground, damage assessment to these structures is particularly challenging. Some municipalities with their subsidiary, notably GASKİ (Gaziantep Water and Sewerage Directorate), possess advanced SCADA (Supervisory Control and Data Acquisition) systems. While these municipalities can more accurately acquire water loss, leakage, and consumption rates on a regional basis, municipalities without advanced SCADA systems, such as ASKİM, provide these rates as roughly estimations. Nevertheless, damage assessments and estimations on water loss, leakage rate have been attempted by the relevant institutions to the extent permitted by available technical capabilities.

According to data from the Presidency of Strategy and Budget, the total cost of damage to potable water and sewage infrastructure estimated at approximately 15.1 billion TL (798.8 million USD) as initially identified via post-earthquake damage assessment studies. **Table 3.1** presents the cost details of water and sanitation works for the disaster area [SBO, 2023].

The data were provided through field studies conducted by the General Directorate of State Hydraulic Works (DSİ), which is responsible for the supply of potable water to settlements; the Bank of Provinces (İLBANK), which is responsible for municipal infrastructure investments; and Special Provincial Administrations (İÖİ), which oversee rural infrastructure investments. However, it should be noted that relevant damage assessment efforts had not been fully completed as of the report's publication date, March 17, 2023. Thus, the SBO declared it was supposed that the related cost would be relatively higher after actual repair and renewal works.

Indeed, it was stated that a total funding of 70.2 billion TL (approximately 2.3 billion USD) which was provided by the World Bank, Japan International Cooperation Agency, Islamic Development Bank, European Bank for Reconstruction and Development, European Investment Bank, and French Development Agency, was given away as non-repayable aid through İLBANK for projects under the responsibility of municipalities in the report titled "Reconstruction and Development Report of Kahramanmaraş and Hatay Earthquakes" published by the same institution on February 6, 2024.

Table 3.1: Estimated impact assessment of the earthquake's damage to water and sewage systems.

Facility	Unit	Quantity	Cost (TL)	Data Source
Water Transmission Line	km	169	1.595.000.000	DSİ
Water Treatment Plant	m ³ /day	135.000	25.000.000	DSİ
Reservoir	m ³	10.000	50.000.000	DSİ
Water Transmission Line	km	185	2.119.000.000	İLBANK
Water Treatment Plant	piece	2	1.765.000.000	İLBANK
Reservoir	piece	23	112.900.000	İLBANK
Water Distribution Line	km	488	1.405.000.000	İLBANK
Sewage	km	1842	6.262.000.000	İLBANK
Waste Water Treatment Plant	piece	7	1.595.000.000	İLBANK
Pumping Station	piece	5	51.000.000	İLBANK
Water Distribution Line	km	241	29.000.000	İÖİ
Catchment	piece	5	800.000	İÖİ
Reservoir	piece	22	71.000.000	İÖİ
Total	-	-	15.080.700.000	-

The completed or planned projects encompass activities such as the rehabilitation of drinking water and waste water infrastructure, the construction and repair of treatment plants, the construction of drinking water reservoirs, and storm water network systems within the funding. The distribution by province is provided in **Table 3.2**.

For the 11 provinces affected by the earthquakes, the total investment in drinking water sector projects undertaken by DSİ amounts to 6.6 billion TL (215.7 million USD). These efforts aim to rehabilitate structures such as transmission lines, treatment plants, storage facilities, and pumping stations. As part of the projects undertaken by İLBANK in the earthquake-affected region, approximately 2 billion TL (65 million USD) has been invested in potable water and sewage works.

Table 3.2: The distribution of grant amounts by cities and water systems.

Province	Potable Water	Sewage	Rain Water	Waste Water	Total Investment Cost (TL)
Adana	x	x	x	-	3.766.060.000
Adıyaman	x	x	x	-	6.778.906.000
Diyarbakır	x	x	x	-	3.331.357.000
Elazığ	-	-	-	x	689.866.000
Gaziantep	x	x	x	-	7.825.034.000
Hatay	x	x	-	x	15.482.686.000
Kahramanmaraş	x	x	-	-	11.591.094.000
Kilis	x	x	-	-	1.380.889.000
Malatya	x	x	-	x	5.355.021.000
Osmaniye	x	-	-	-	4.623.691.000
Şanlıurfa	x	-	-	-	3.341.921.000
All Provinces	Investigation, Project, Planning				6.075.587.000
Total					70.222.112.000

A portion of this investment has been utilized, while the remaining funds continue to be allocated to ongoing projects. Efforts to assess and deal with earthquake-related damages are still ongoing as of the end of 2024. The data sources are DSI and İLBANK. The provincial and category-based detailing of the data is presented in **Table 3.3**.

Table 3.3: The detail of amount of investments for projects undertaken by İLBANK.

Province	Potable Water	Sewage	Waste Water	Total Investment Cost (TL)	2023 Expenditure Cost (TL)
Adana	x	-	-	11.189.589	11.189.589
Adıyaman	x	x	-	569.636.893	435.059.537
Diyarbakır	x	-	-	806.910.000	199.290.780
Hatay	x	x	x	4.215.421.514	1.188.898.701
Kahramanmaraş	x	x	-	1.413.315.769	333.314.285
Malatya	x	x	x	630.112.026	355.227.218
Osmaniye	x	-	-	53.839.430	19.080.230
Şanlıurfa	x	-	x	867.256.727	143.988.786
All Provinces	Investigation, Project, Planning			1.092.432	-
Total				8.568.774.380	2.686.049.126

3.3. Earthquake-Related Circumstance of Adıyaman

The city center of Adıyaman is located about 122 km from the epicenter of the first earthquake (Mw 7.7) and 100 km from the epicenter of the second earthquake (Mw 7.6), both originating from Kahramanmaraş. The total area of the Adıyaman city center is 1,814 km², with an elevation of about 700 meters. Additionally, the city center of Adıyaman is located approximately 27 km and 32 km away from the nearest surface fault ruptures to the north and northwest of the city, respectively. The map in **Figure 3.5** illustrates the relative spatial location of the city center of Adıyaman in relation to the epicenters of the Kahramanmaraş earthquakes and the fault lines.

According to the Turkish Statistical Institute's year-end population records for 2023, the population of Adıyaman's city center decreased from 316,140 at the end of 2022 to 284,839 by the end of the year in which the earthquake occurred, reflecting a decline of about 10% [TÜİK, 2023]. The city center of Adıyaman comprises a total of 33 neighborhoods. Undoubtedly, the infrastructure and superstructure damages occurring in the city play a significant role in the emergence of this situation.

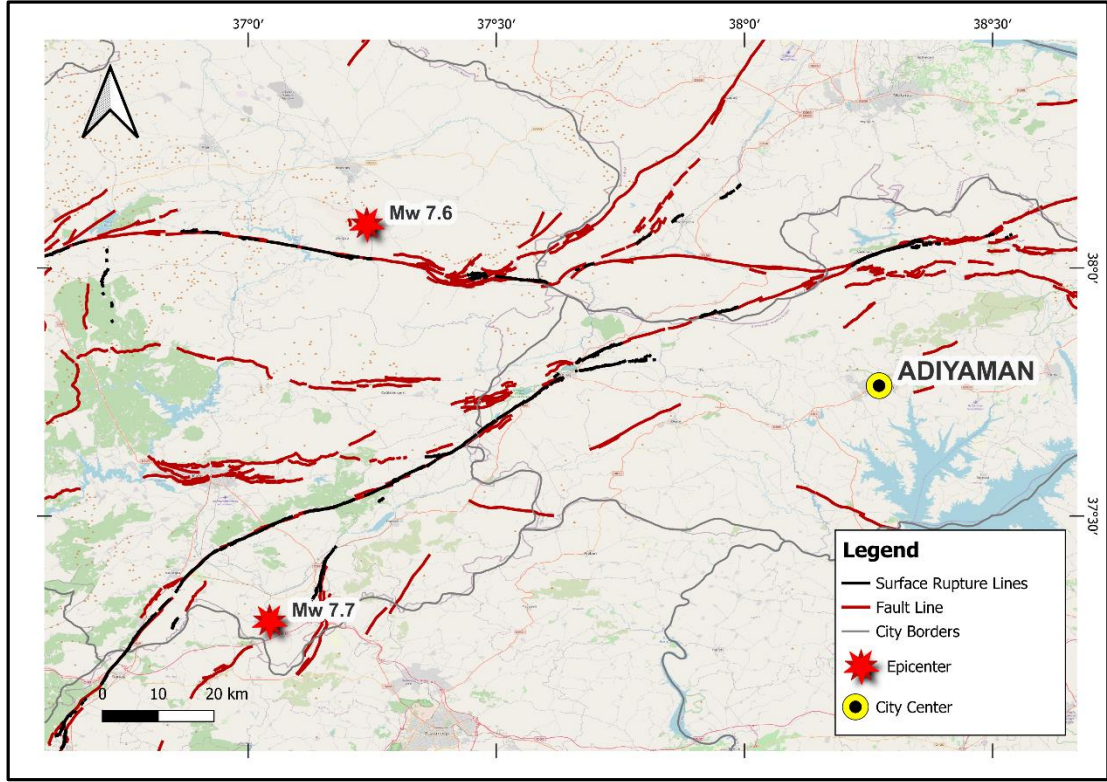


Figure 3.5: The map illustrating the seismic aspect of Adiyaman city center.

In the immediate aftermath of the earthquake, structural damage in the city center of Adiyaman was extensive. Thousands of individuals were trapped under debris and thousands of buildings were either collapsed, assessed as severely damaged or designated for immediate demolition. Data obtained from some strong motion stations located in the province of Adiyaman are presented in **Table 3.4** with respect to the first earthquake (Mw 7.7). The table was derived from **Işık et al. [2023]**. Additionally, the locations of the stations are given within earthquake epicenters in **Figure 3.6**.

The station data presented in **Table 3.4** are obtained from stations affiliated with AFAD. According to these data, the maximum PGA value in Adiyaman province was recorded at the station with code 0201, located in the city center of Adiyaman within the first earthquake (Mw 7.7). The PGA values at this station were measured as 879.95 cm/s^2 , 474.12 cm/s^2 and 318.97 cm/s^2 in the E-W, N-S, and U-D directions, respectively. Additionally, **Akcan et al. [2024]** performed a probabilistic seismic hazard assessment (PSHA) and a scenario-based deterministic seismic hazard assessment (DSHA) for Adiyaman province. According to the analysis, the PSHA results ended up with that the predicted ground motion levels at the center of Adiyaman are approximately 0.6 g PGA for a 475-year return period and 0.8 g PGA for a 2475-

year return period. Besides, through scenario analysis (DSHA) of the Pazarcık and Elbistan earthquakes, the PGA values at the center of Adıyaman were calculated as 0.8 g and 0.7 g, respectively.

Table 3.4: Strong ground motion data for some stations in Adıyaman province with respect to the first earthquake (Mw 7.7).

District	Station Code	Long.	Lat.	PGA (cm/s ²)			R (km)	
				NS	EW	UD	Rrup	Repi
Besni	2713	37.4925	37.6241	0.03	2.98	0.03	126.0	56.2
Gölbaşı	208	37.7869	37.6528	30.20	14.00	16.97	147.4	77.3
Tut	213	37.7968	37.9296	242.28	171.69	291.29	166.8	96.5
Center	201	37.7612	38.2674	474.12	879.95	318.97	190.0	120.1
Center	210	37.7672	38.2866	65.91	61.37	42.13	191.8	122.0
Çelikhan	214	38.0283	38.2260	61.68	54.38	69.91	203.1	131.7
Sincik	215	38.0300	38.5563	61.40	108.13	28.82	227.0	156.7
Sincik	216	38.0309	38.5571	20.44	38.58	22.58	227.1	156.8
Sincik	217	38.0300	38.5563	13.05	17.90	17.47	227.0	156.7

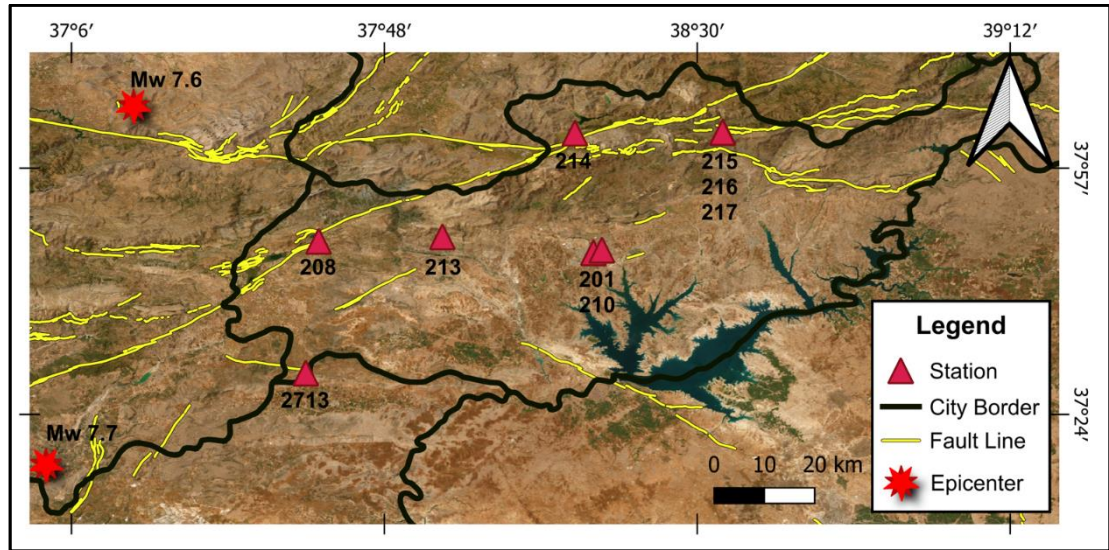


Figure 3.6: The locations of strong ground motion stations.

According to building stock data obtained from the Adıyaman Municipality, there are approximately 34,000 buildings across 33 neighborhoods. The Ministry of Environment, Urbanization and Climate Change has reported that approximately 2000 buildings in Adıyaman have been destroyed. Additionally, the number of severely damaged buildings has been determined as 4085, while the number of buildings requiring urgent demolition is 538. **Figure 3.7** showcases the destroyed building inventory of Adıyaman city center [Tekin and Akcan, 2023]. In addition to these data,

a total of 110,354 buildings were present in Adıyaman province and 38,666 of them remain undamaged, 38,576 are slightly damaged, 4,629 are moderately damaged, 20,201 are heavily damaged, 2,329 require urgent demolition and 5,953 have already been demolished [Akcan et al., 2024].

The destruction in the city center of Adıyaman is illustrated in **Figure 3.8**. The figure contains satellite images of the city center before and after the earthquake. **Figure 3.9** and **Figure 3.10** give some examples from the earthquake devastation in Adıyaman city center.

Following the Kahramanmaraş earthquakes, the tremors were felt with great intensity both across the Adıyaman province and the city center of Adıyaman. Due to structural damages and the pipeline failures in the water supply system such as pipe ruptures, tears and cracks, the supply of drinking water was systematically halted by the Adıyaman Water and Sewerage Directorate (ASKİM) authorities as a precautionary measure immediately following the earthquake.

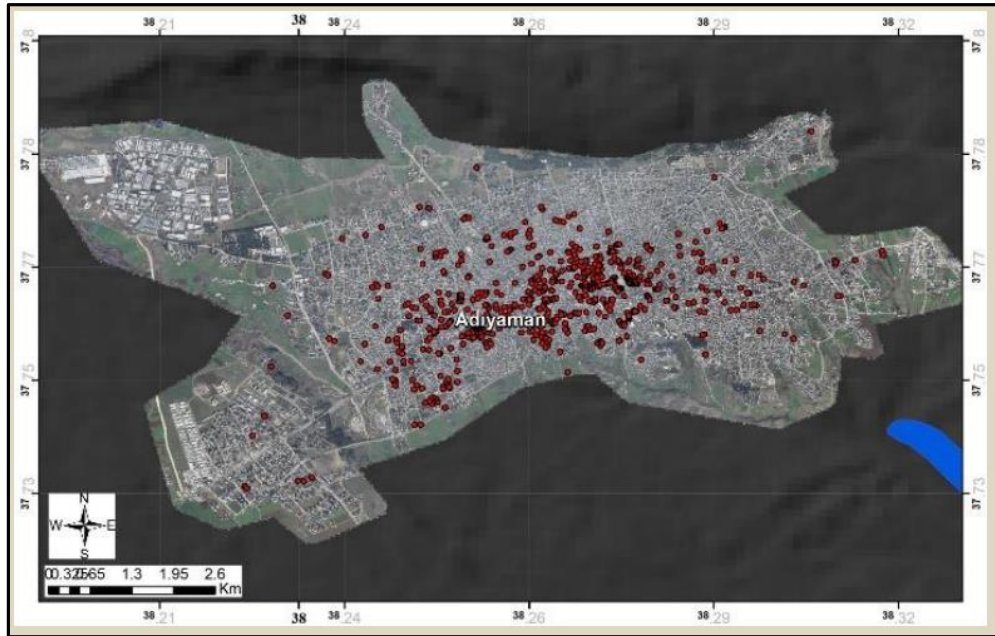
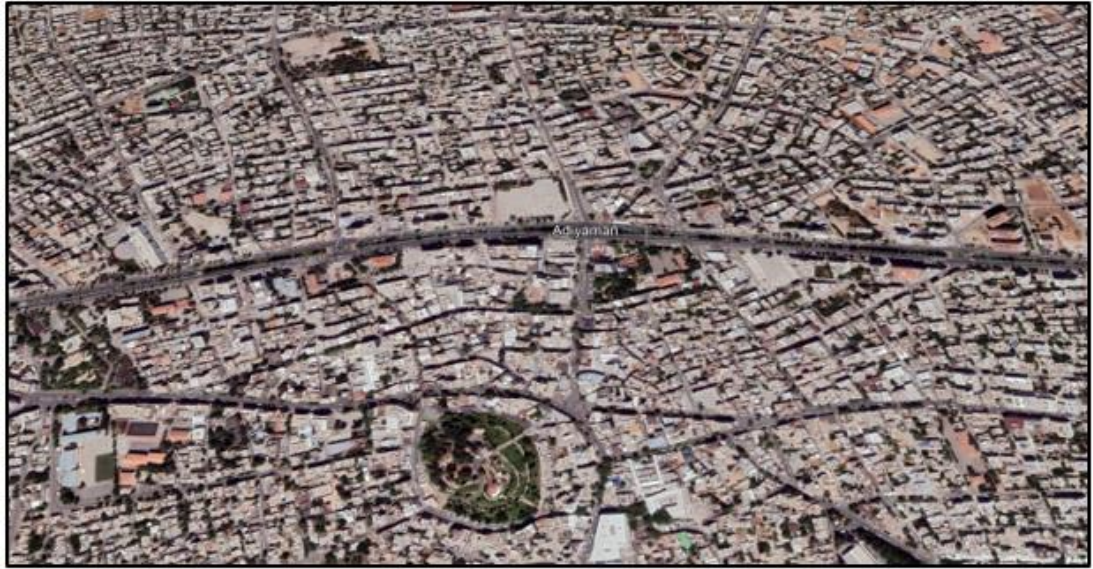


Figure 3.7: Demolished building inventory of Adıyaman city center [Tekin and Akcan, 2023].



a)



b)

Figure 3.8: Satellite images of the city center: (a) before the earthquake, (b) after the earthquake.

The first supply of drinking water to the city center was provided on the fourth day after the earthquake to the Altınşehir neighborhood. Altınşehir which is also referred to as the "university neighborhood" features a relatively newer infrastructure and superstructure system.

Consequently, it is one of the neighborhoods where comparatively less damage was observed in the city center. Within the scope of the FRIT project, the water distribution system was renewed using PE pipes and almost no earthquake-related damage to the network was observed in this neighborhood. This situation demonstrates that regions

where infrastructure and superstructure systems are renewed through appropriate technology and engineering services become more resilient to earthquakes, thereby minimizing potential material and spiritual losses during the critical post-disaster period.

Following the initial water supply to the Altınşehir neighborhood, the process was gradually and systematically initiated to the rest of the city center in the subsequent days. However, controlled water interruptions are still occasionally implemented due to the existence of unrepaired infrastructure damage caused by the earthquake as of December 2024 (approximately 22 months after the earthquake). The majority of these controlled disruptions are necessitated because of maintenance and repair work on the aforementioned transmission lines, as well as water network renewal efforts conducted under the scope of the FRIT project.

In September 2022, 257 damage reports were recorded, whereas by September 2023, this number had risen to approximately 3000 according to ASKİM. This significant increase highlights the urgent need for improvements in the earthquake-damaged infrastructure system of Adıyaman city center. Efforts to repair these damages were undertaken by a field personnel team consisting of about 25 members. However, this workforce was insufficient to handle the extensive damage caused by the disaster. Consequently, ASKİM received support from both various state institutions and field staff affiliated with other municipal administrations during the emergency response period following the earthquake. Field teams from DSİ and İLBANK assisted ASKİM personnel in the repairment and renewal process for the damages sustained by the transmission lines supplying the central district of Adıyaman. Additionally, field teams from several metropolitan municipalities including Erzurum, Şanlıurfa, Diyarbakır, Manisa, Sakarya, and İzmir provided repair support to Adıyaman Municipality for damages to the water distribution system.



Figure 3.9: Damaged buildings in Adıyaman city center.



Figure 3.10: Collapsed buildings in Adiyaman city center.

4. GEOLOGICAL, GEOTECHNICAL AND SEISMIC PROPERTIES OF THE STUDY AREA

The city of Adıyaman is located in the Southeastern Anatolia region, bordered by the provinces of Malatya, Gaziantep, Kahramanmaraş, Şanlıurfa, and Diyarbakır. The city is situated near the EAFZ. Due to its location in an active seismic region, Adıyaman was among the provinces most severely impacted by the February 6 Kahramanmaraş earthquakes. The destruction reached significant levels, particularly in the city center district. Many lives were lost, and extensive damage to infrastructure and superstructures severely disrupted the city's critical systems, with recovery expected to take many years. The city's seismic characteristics, geological diversity and geotechnical properties played a significant role in the magnitude of this outcome. Additionally, this section presents specific elements of the comprehensive report prepared by the Ministry of Environment, Urbanization and Climate Change which encompasses geological and geotechnical analyses conducted over an area of approximately 6000 hectares as part of efforts to revise the zoning plan for Adıyaman's central district, severely impacted by the earthquake. Furthermore, the geological and geotechnical maps presented within the scope of the report are also included in this section. This section focuses on geological, seismic and geotechnical properties of relevant city center mainly.

4.1. Geological Properties

Adıyaman city center poses a diverse and complex geological framework. The area is largely formed by accumulated quaternary-aged alluvial units and sedimentary rocks dating back to the Neogene, Paleogene, and Mesozoic eras. The geological composition primarily consists of limestone, conglomerate, marl, and chalk.

The study area primarily consists of five geological formations: Adıyaman Group, Germav Formation, Şelmo Formation, Hoya Formation, and alluvial deposits. **Figure 4.1** presents a general view of Adıyaman city center and its surroundings with geological descriptions [Herece, 2008].

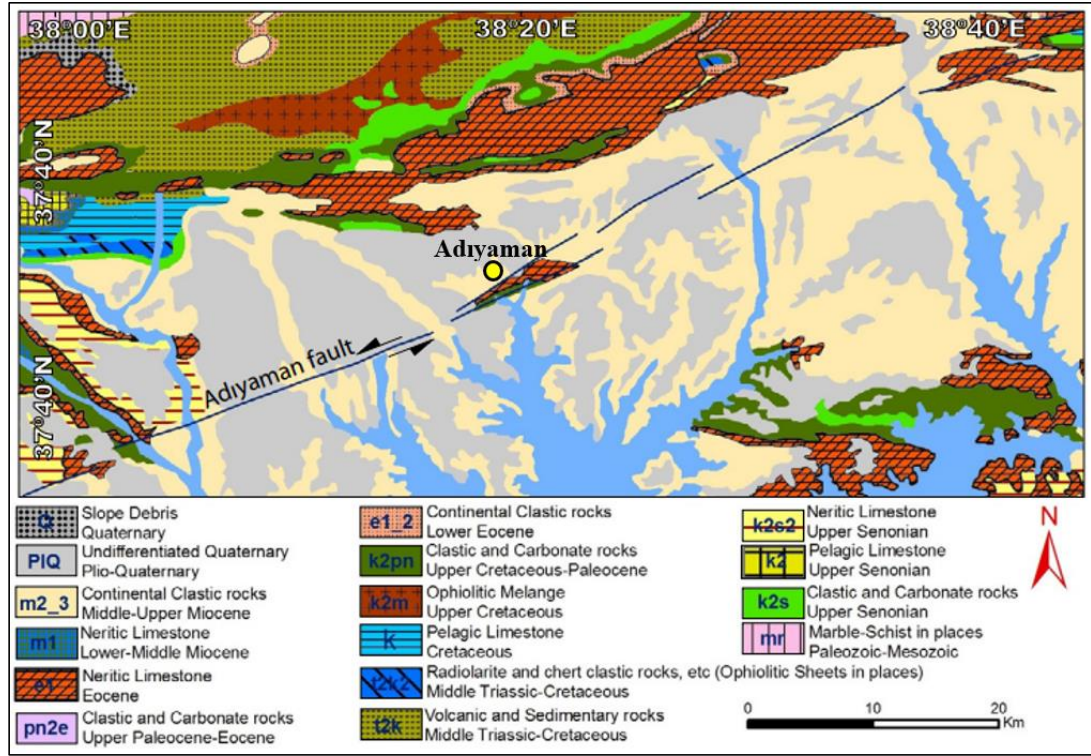


Figure 4.1: The general geology of the Adiyaman city center surroundings [Herece, 2008].

4.1.1. Adiyaman Group (PIQa)

The Adiyaman Group is composed of two distinct formations: The Karaboğaz Formation and the Sayındere Formation [Mülayim et al., 2024]. Although some researchers classify the Adiyaman Group as a formation due to its structure, it is generally recognized as a group composed of subordinate formations. The Adiyaman Group refers to Pliocene-Quaternary-aged terrestrial deposits composed of conglomerate, sandstone, and mudstone. This nomenclature was first used by Bolgi [1964] and Tuna [1973] to describe Middle-Late Miocene-aged deposits in the region and by İlker [1972] and Sungurlu [1974] for Late Miocene-Pliocene-aged deposits. The formation is extensively distributed to the south of the east-west-trending mountain ranges located north of the Adiyaman city center, as well as across the flat plains of the Adiyaman basin. It is prominently present throughout the city center, encompassing the areas where both the main water transmission lines and distribution networks are located. The unit typically exhibits a thickness ranging between 30 and 50 meters.

4.1.2. Germav Formation (Ktg)

The Germav Formation, consisting of sandstone, shale, siltstone, marl, and clayey limestone with occasional conglomerate interbeds, was first described by **Maxson [1936]**. This formation exhibits varying lithological characteristics across the study area. In the northern parts of the region, sandstone, siltstone, and conglomerate are more dominant, while in the southern sections, the formation is primarily composed of marl, claystone, siltstone, clayey limestone, and shale. It extends from the Middle to Late Maastrichtian through the Early Eocene, with some sections suggested to have originated in the Campanian [**Köylüoğlu, 1986**].

The Germav Formation is widely distributed throughout the region, with surface exposures identified in several areas of the study, including Palanlı neighborhood where the Kuru-Palanlı water transmission line passes, as well as Yaylakonak and Dandırmaz villages along the Gürlevik transmission line, and the northern parts of Adıyaman city center. The thickness of this unit within the study area varies significantly, ranging from 150 to 1500 meters.

4.1.3. Hoya Formation (Teh)

Perinçek [1978] identified the Hoya Formation as a carbonate unit distinguished by its thin to thick bedding and massive structure. Composed mainly of limestones and dolomites, the formation is dated to the Early Eocene to Early Oligocene based on fossil evidence, including benthic and planktonic foraminifera [**Duran et al., 1988**]. The Hoya Formation generally consists of Nummulite-bearing limestone, dolomitic limestone, marl, and siltstone. This formation is predominantly found in the northern parts of the region, with its thickness varying between 25 and 650 meters within the study area.

4.1.4. Şelmo Formation (Tmş)

The Şelmo Formation was laid down in the Adıyaman Basin, which formed during the late Miocene under a compressional tectonic regime that prevailed from the early Miocene through the late Pliocene [**Türkmen et al., 2010**]. The outcrops of the formation are composed of braided river deposits at the base, representing the lower

alluvial unit, followed by lacustrine and deltaic deposits in the middle, forming the lacustrine unit, and capped by low-sinuosity river and alluvial deposits, which constitute the upper alluvial unit in Adıyaman region [Taşgım et al., (2011)].

The unit which primarily consist of conglomerate, sandstone, claystone, siltstone, tuff and travertine was named as the Şelmo Formation by **Bolgi (1961)**. It comprises a composition of sandstone, siltstone, shale, mudstone, and occasional white-colored gypsum deposits. This formation is widely distributed across Adıyaman province and is particularly concentrated in the western and southern parts of the city center. The thickness of the unit reaches up to approximately 1400 meters and is considered to be of Middle-Late Miocene age.

4.1.5. Alluvial Deposits (Qal)

Alluvial deposits in the study area consist of gravel, sand, clay and silt accumulated along the valley floors of streams and creeks. In the Adıyaman urban region, this unit is relatively less extensive compared to other formations. The alluvium exhibits heterogeneous characteristics, with a transitional composition of gravel, sand, clay, and silt intergrading into one another.

Figure 4.2 was obtained from the comprehensive study which is fore mentioned in this section, depicts the dominant geological units within a 60 km² portion of the study area. In the figure, the presented region constitutes a portion of Adıyaman city center and thus the study area borders correspond to in the coverage area of city center.

4.2. Seismic Properties

The boundaries of Adıyaman province contain the Pazarcık, Erkenek, and Pütürge segments of the East Anatolian Fault (EAF), the Gerger and Narince segments of the Southeastern Anatolian Thrust, as well as sections of the Besni, Bozova, and Sürgü Faults. EAFZ, a left-lateral strike-slip fault marking the boundary between the Arabian Plate and the Anatolian Block, represents a major seismic hazard for the region [Figure 4.3]. It converges with the North Anatolian Fault (NAF) in the northeast near Karlıova and with the Dead Sea Fault (DSF) in the southwest near Kahramanmaraş. Extending roughly 580 km in length, the EAF follows a predominantly northeast-southwest orientation [Emre et al., 2013].

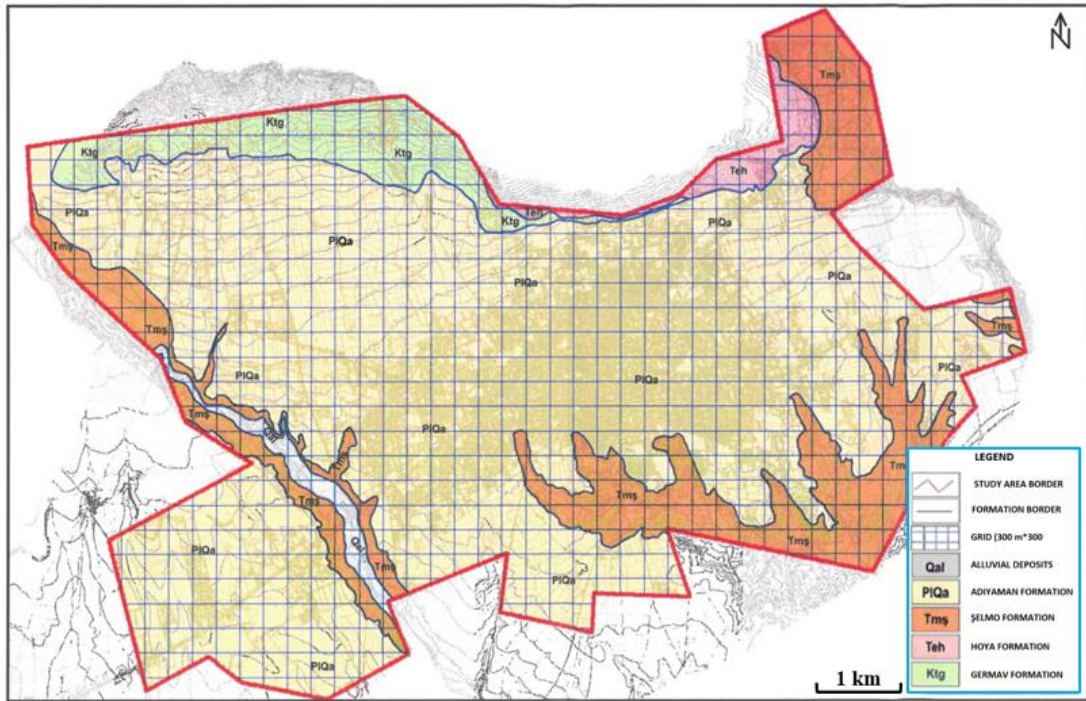


Figure 4.2: The distribution of geological units within the study area [Adiyaman Municipality, 2023].

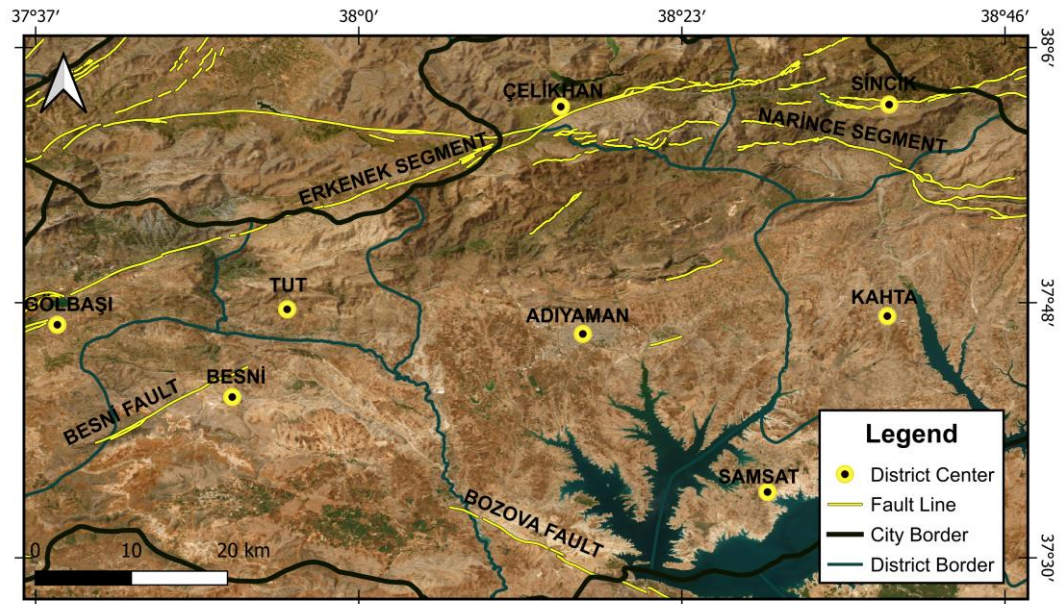


Figure 4.3: Fault lines located in the vicinity of Adiyaman city center.

The EAF, characterized by left-lateral strike-slip motion, is divided into six segments: Karlıova, Ilıca, Palu, Pütürge, Erkenek, Pazarcık, and Amanos. In Adiyaman province, the Erkenek, Pazarcık, and Pütürge segments of the EAF span approximately 70 km, 63 km and 23 km, respectively. Furthermore, around 60 km of the Gerger segment and

the entirety of the Narince segment, both associated with the Southeastern Anatolian Thrust, are located within the province's boundaries [Emre et al., 2018].

While the Adıyaman Fault near the city center is not highly active, it has recently been the subject of investigation by researchers due to its potential for reactivation [Khalifa et al., 2021; Şentürk et al., 2019]. Additionally, the districts of Çelikhan and Sincik are situated in the region traversed by the Pütürge Segment of the EAF. Besni district contains the Besni Fault, which passes through its boundaries, whereas Gölbaşı district is located in the area crossed by the Erkenek and Pazarcık segments of the EAF.

Figure 4.4 depicts the spatial distribution of seismic events recorded over a span of nearly 100 years, from 1923 up to the Kahramanmaraş earthquakes on February 6 [AFAD, 2024]. The figure represents earthquakes occurring within a 100 km radius of Adıyaman city center, overlaying earthquake locations, active fault lines, and the Türkiye Seismic Hazard Map provided by AFAD.

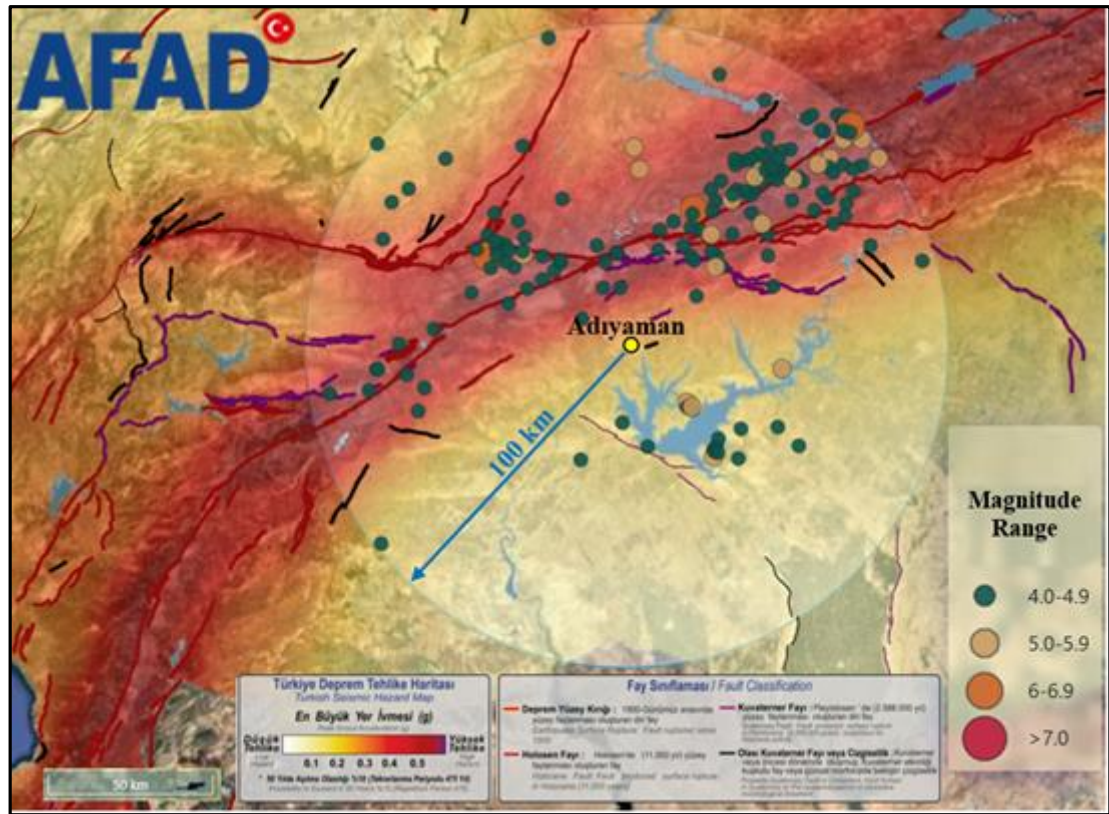


Figure 4.4: The spatial distribution of seismic activities around the Adıyaman city center for a 100-year period.

Figure 4.5 presents a histogram and it represents seismic activities of the region encompassing an area approximately 100 km around the Adıyaman city center within a 100-year time period up to immediately before the Kahramanmaraş earthquakes. **Figure 4.6** also presents a histogram of same region and it comprises seismic activities which occurred in a period of roughly 2 years with starting from the first excitation of February Kahramanmaraş earthquakes.

According to the histogram in **Figure 4.5**, there were 168 seismic activities with magnitudes of $M_w \geq 4.0$, while the histogram in **Figure 4.6** indicates that this number increased to 336. In other words, in the same region, the number of seismic activities that occurred over the last 100 years has doubled within just two years following the Kahramanmaraş earthquakes, and aftershocks from these events are still ongoing. Factors such as the recurrence interval of the earthquake, the magnitudes of the events, and the characteristics of the fault releasing the energy have played a significant role in this phenomenon. This underscores the necessity of detailed analysis of fault systems that have remained dormant for extended periods yet possess high potential for generating major earthquakes, as well as the importance of conducting seismic hazard assessments (both probabilistic and deterministic).

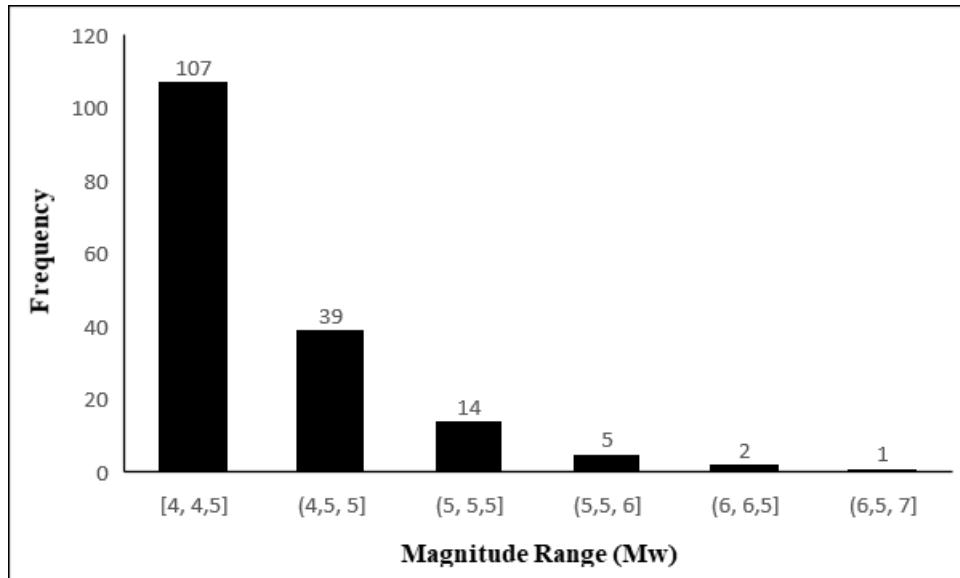


Figure 4.5: The histogram of the seismic activities for Adıyaman city center for a 100-year period.

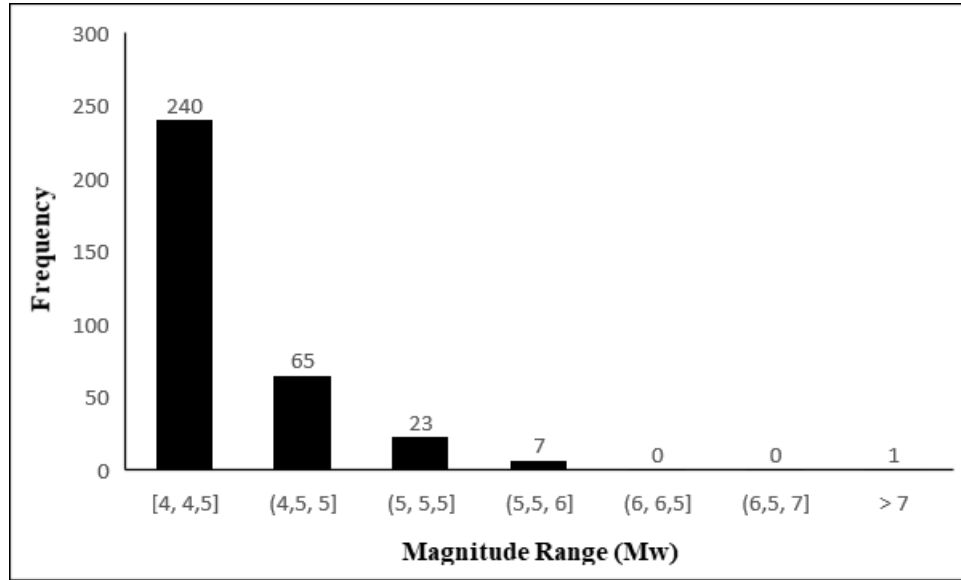


Figure 4.6: The histogram of the seismic activities for Adıyaman city center for two years after Kahramanmaraş earthquakes.

4.3. Geotechnical Properties

The geotechnical, rock mechanics, and geophysical experiments conducted in the study area have provided the primary data used to determine the physical and mechanical properties, as well as the behavioral characteristics, of the units within the study area. These experimental data have been evaluated with consideration of the geological units.

In the comprehensive study conducted for the Adıyaman city center, covering an area of 60 km², a total of 660 boreholes were drilled [Adıyaman Municipality, 2023]. Approximately 92% of the borehole investigations were carried out in soil layers, while 8% were conducted in rock formations. As part of the laboratory studies, soil mechanics and rock mechanics tests were performed using disturbed (SPT), undisturbed (UD) and core (CR) samples collected from the borehole investigations. Detailed information on the field and laboratory tests conducted in the study area is provided in **Table 4.1**. The Standard Penetration Test (SPT) is one of the suitable in-situ test methods used to determine the relative densities and strength parameters of soil layers encountered during the drilling of boreholes. Within the study area, a total of 6913 SPT tests were conducted, including 6073 tests in the soils of the Adıyaman

formation, 125 tests in the alluvial units, and 715 tests in the soils of the Şelmo formation.

Table 4.1: Detailed information about conducted tests.

Experiment Type	Number of Test
Drilling	660
SPT	6913
Seismic Refraction	660
REMI	660
Micro-tremor	660
Pressuremeter	160
Water Content	1636
Sieve Analysis	1636
Atterberg Limit	1636
Hydrometer	204
Triaxial test	813
Direct Shear	1506
Consolidation	607
Unit Weight	1506

SPT is one of the suitable in-situ test methods used to determine the relative densities and strength parameters of soil layers encountered during the drilling of boreholes. Within the study area, a total of 6913 SPT tests were conducted, including 6073 tests in the soils of the Adıyaman formation, 125 tests in the alluvial units, and 715 tests in the soils of the Şelmo formation.

To perform a geotechnical assessment of a region, it is essential to determine the dynamic-elastic engineering parameters of the soil. In this context, geophysical surveys are utilized. For this purpose; seismic refraction, refraction micro tremor (REMI) and micro tremor tests were conducted in the study area. These tests provide a range of parameters such as stratification, subsurface velocity structure, soil classifications, site amplifications, and fundamental soil resonance periods. As a result of the studies conducted in the investigation area, the soil and rock composition of the geological units constituting the area is presented in the **Table 4.2**.

The SPT results conducted on soil groups within the study area revealed that the SPT-N values for soils along the Şelmo Formation range between 12 and 50. In alluvial soils, the SPT-N values vary between 8 and 50 while the value range for soil groups along the Adıyaman Formation is positioned between 15 and 50. Furthermore, in many locations across the study area, the SPT test resulted in "refusal" when the N-value exceeded 50 for any 15 cm drive at various depths.

Table 4.2: Soil composition of geologic units round Adıyaman city center.

Formation	Composition	
	Soil	Rock
Alluvial Deposit (Qal)	x	
Adıyaman Group (PlQa)	x	x
Şelmo Formation (Tmş)	x	x
Hoya Formation (Teh)		x
Germav Formation (Ktg)		x

The SPT results conducted on soil groups within the study area revealed that the SPT-N values for soils along the Şelmo Formation range between 12 and 50. In alluvial soils, the SPT-N values vary between 8 and 50 while the value range for soil groups along the Adıyaman Formation is positioned between 15 and 50. Furthermore, in many locations across the study area, the SPT test resulted in "refusal" when the N-value exceeded 50 for any 15 cm drive at various depths.

Table 4.3 presents the composition of the soil in the central district of Adıyaman. Upon examination of the table, it is evident that fine-grained soil groups dominate significantly in the city center. In the Adıyaman Formation, which covers a substantial portion of the city center, the fine-grained content is calculated to be 86.2%. The Şelmo Formation, which represents the second most prevalent distribution, has a fine-grained content of 84.6%, while the alluvial units, found in limited amounts along certain valleys and riverbeds within the city, exhibit a fine-grained content of 51.1%. Across the city, CH and CL type soils are predominantly encountered.

Table 4.4 presents the plasticity, consistency and compression index values of the specified soils. According to the table; the fine-grained soils in the central district of Adıyaman exhibit high plasticity characteristics. In terms of consistency, they are classified as stiff to very stiff and they fall within the medium to high range in terms of compressibility.

Table 4.3: Soil composition details and soil types in Adıyaman city center.

Name of Formation	Average Soil Composition (%)			Soil Classification (%)			
	Gravel	Sand	Fine Content	CH CL	GC	MH	SC
Alluvial Deposits	19.9	29.0	51.1	15.4	7.7	15.4	61.5
Adıyaman Formation	5.5	8.3	86.2	82.3	1.2	13.6	2.9
Şelmo Formation	6.1	9.3	84.6	68.7	1.1	24.0	6.2

Table 4.4: Detailed parameters of fine grained soil types in Adıyaman city center.

Name of Formation	Plasticity Index		Consistency Index		Comp. Index	
	PI (%)	Definition	Ic	Definition	Cc	Definition
Alluvial Deposits	18-30	High	0.87-1.44	Stiff-Very Stiff	0.25-0.46	Medium-High
Adıyaman Formation	15-39	High	0.60-1.51	Stiff-Very Stiff	0.25-0.50	Medium-High
Şelmo Formation	19-36	High	0.73-1.49	Stiff-Very Stiff	0.25-0.52	Medium-High

In Adıyaman city center, the groundwater level varies seasonally but generally ranges between 3 meters and 16 meters. Typically, the groundwater level is at 7 meters or deeper, which minimizes potential issues associated with groundwater levels in this region. **Figure 4.7** illustrates the groundwater level conditions within the study area.

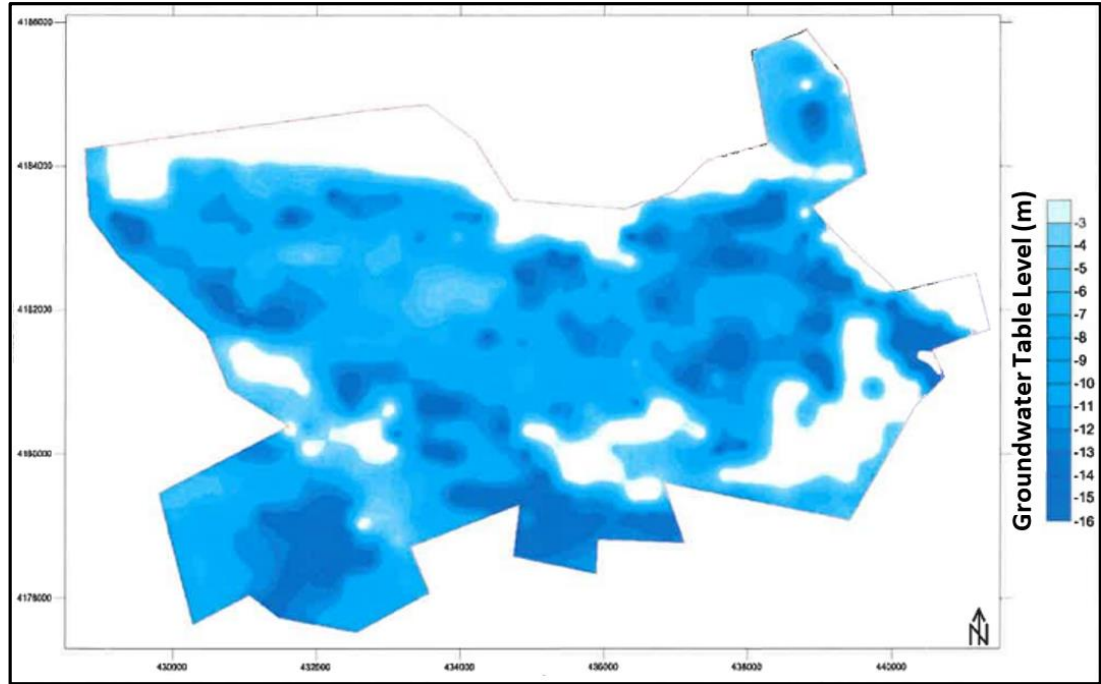


Figure 4.7: Groundwater table level map of Adıyaman city center [Adıyaman Municipality, 2023].

Based on the seismic refraction test results, the V_{s30} values were identified as ranging from 364 to 470 m/s for the alluvial deposits (Qal), 468 to 683 m/s for the Adıyaman Formation (PlQa), 481 to 677 m/s for the Şelmo Formation (Tmş), 714 to 726 m/s for the Hoya Formation (Teh) and 667 to 743 m/s for the Germav Formation (Ktg) [Figure 4.8].

The range of V_{s30} values were determined as 381–481 m/s for the alluvial deposits (Qal), 409–725 m/s for the Adıyaman Formation (PlQa), 406–739 m/s for the Şelmo Formation (Tmş), 665–731 m/s for the Hoya Formation (Teh) and 616–756 m/s for the Germav Formation (Ktg) as a result of the REMI studies [Figure 4.9].

Figure 4.10 presents the concentrations of shear wave velocity values at 5 m intervals. It is observed that the minimum shear wave velocity is approximately 250 m/s near the ground surface, increasing to around 1750 m/s in rock units at a depth of 30 meters, when analyzed layer by layer.

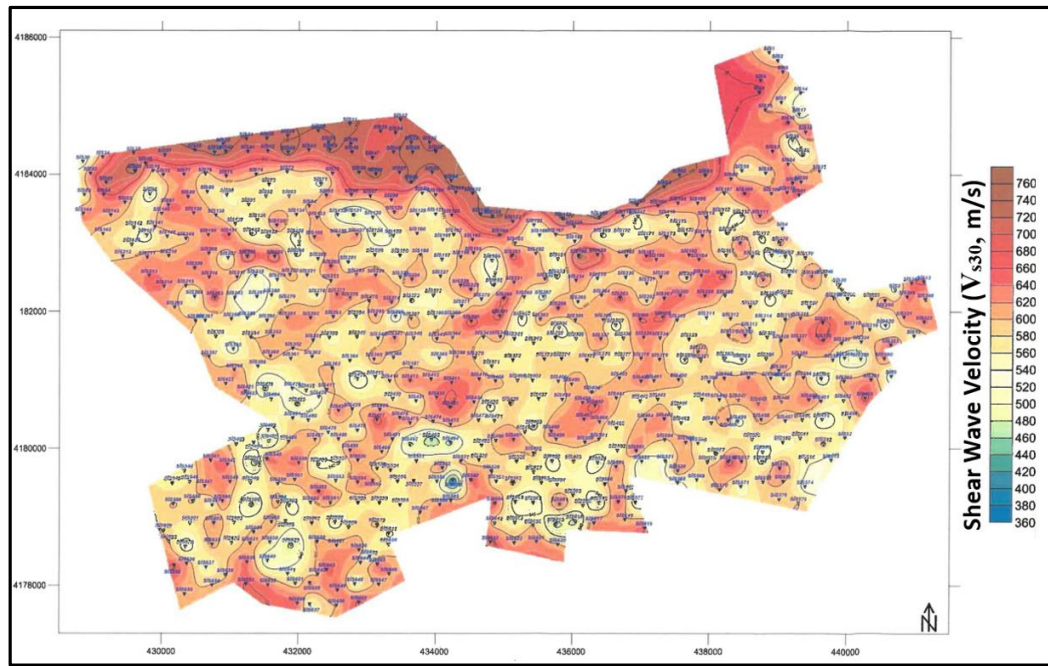


Figure 4.8: V_{s30} map of Adıyaman city center based on seismic refraction test [Adıyaman Municipality, 2023].

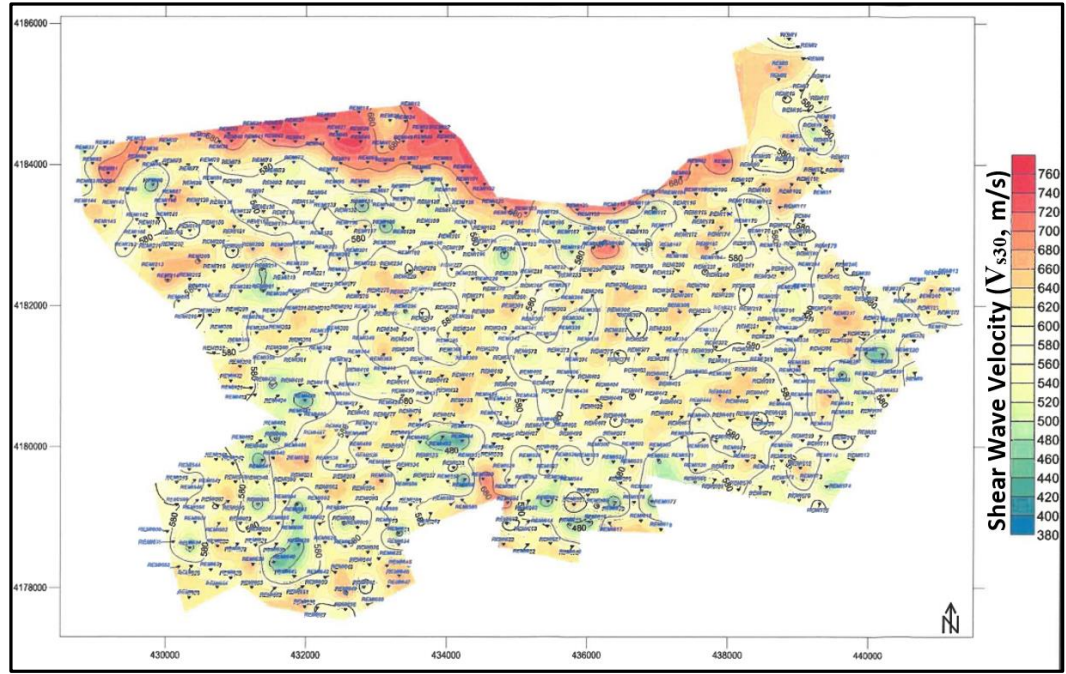


Figure 4.9: V_{s30} map of Adiyaman city center based on REMI method [Adiyaman Municipality, 2023].

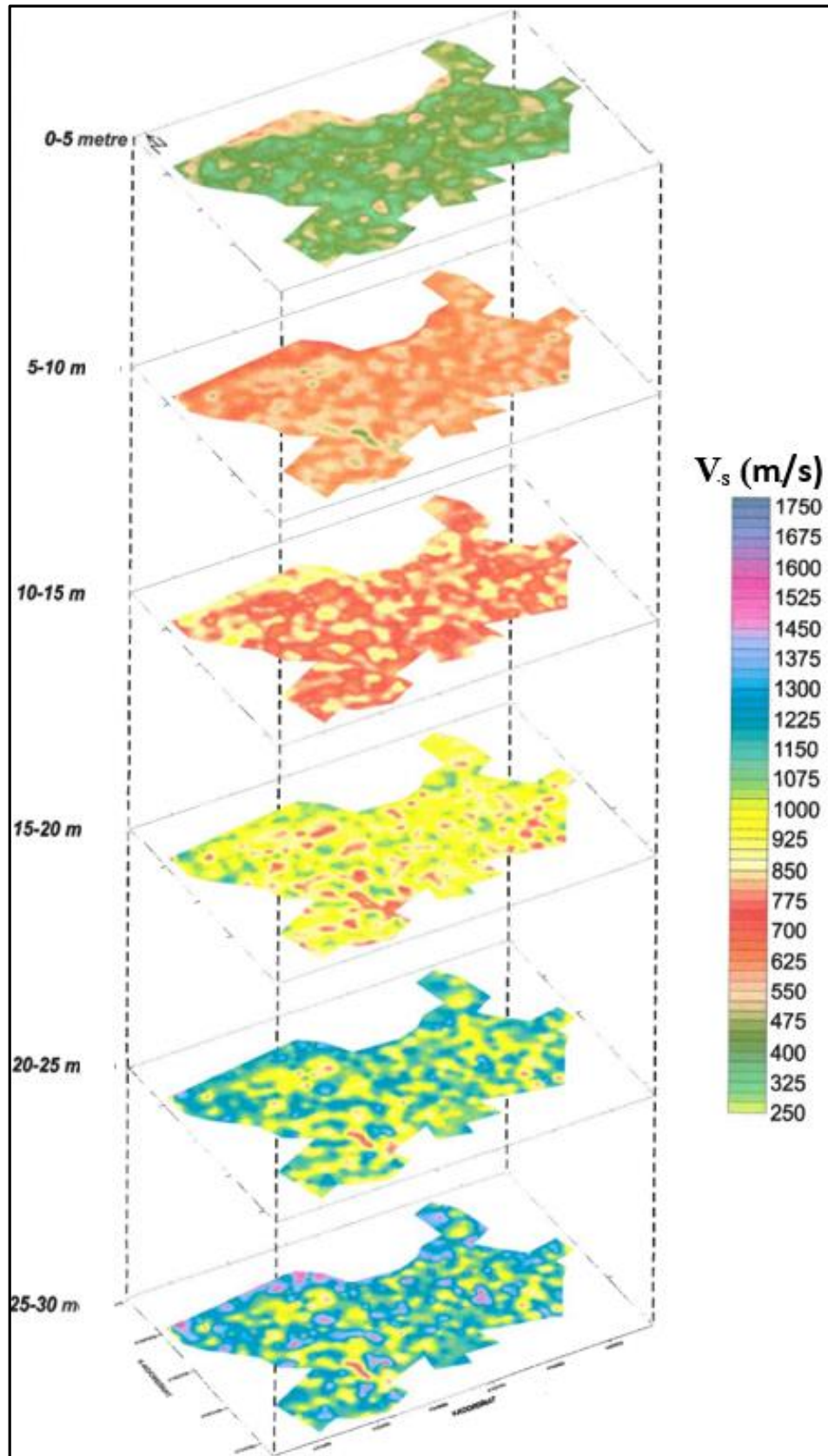


Figure 4.10: Shear wave velocity distribution map with respect to map in Adıyaman city center [Adıyaman Municipality, 2023].

Based on the micro tremor measurements, the predominant period (T_0) values of the soils and rocks have a range of 0.44–0.56 s for the alluvial deposits (Qal), 0.19–0.43 s for the Adıyaman Formation (PlQa), 0.19–0.21 s for the Şelmo Formation (Tmş), 0.14–0.15 s for the Hoya Formation (Teh) and 0.16–0.18 s for the Germav Formation (Ktg) [Figure 4.11].

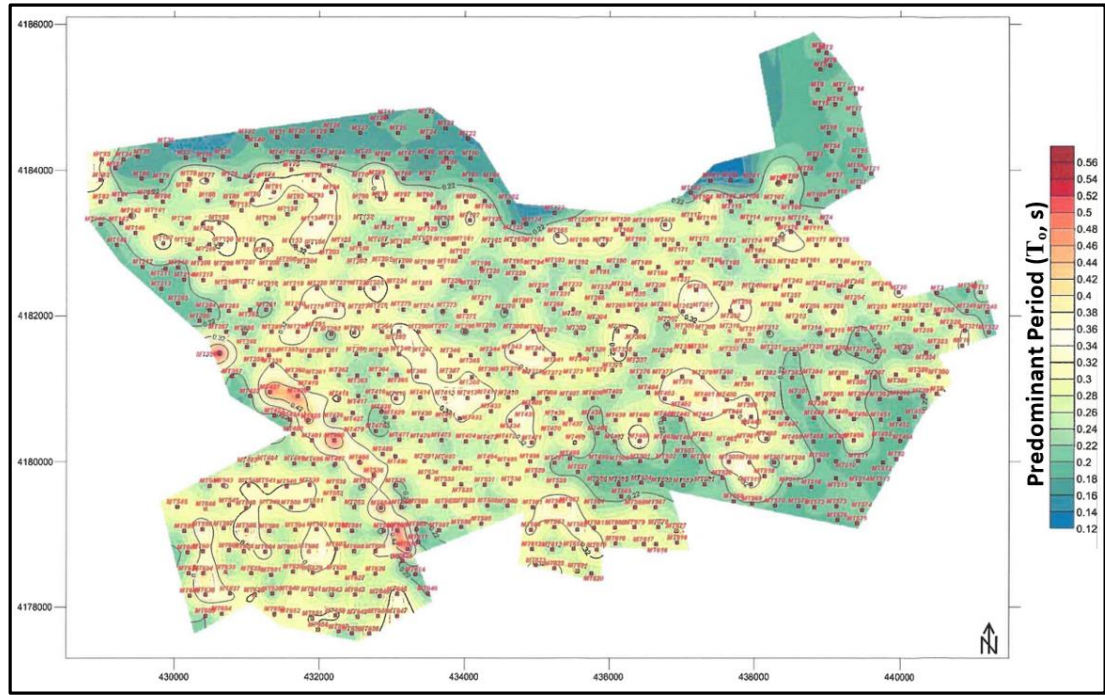


Figure 4.11: Predominant period distribution map of soil group in study area [Adıyaman Municipality, 2023].

Furthermore, the micro tremor measurements revealed site amplification (H/V) values of 2.64–4.68 for the alluvial deposits (Qal), 1.10–4.32 for the Adıyaman Formation (PlQa), 1.04–2.49 for the Şelmo Formation (Tmş), 1.25–2.49 for the Hoya Formation (Teh) and 1.12–2.21 for the Germav Formation (Ktg) [Figure 4.12]. All geophysical experiment results are given in Table 4.5.

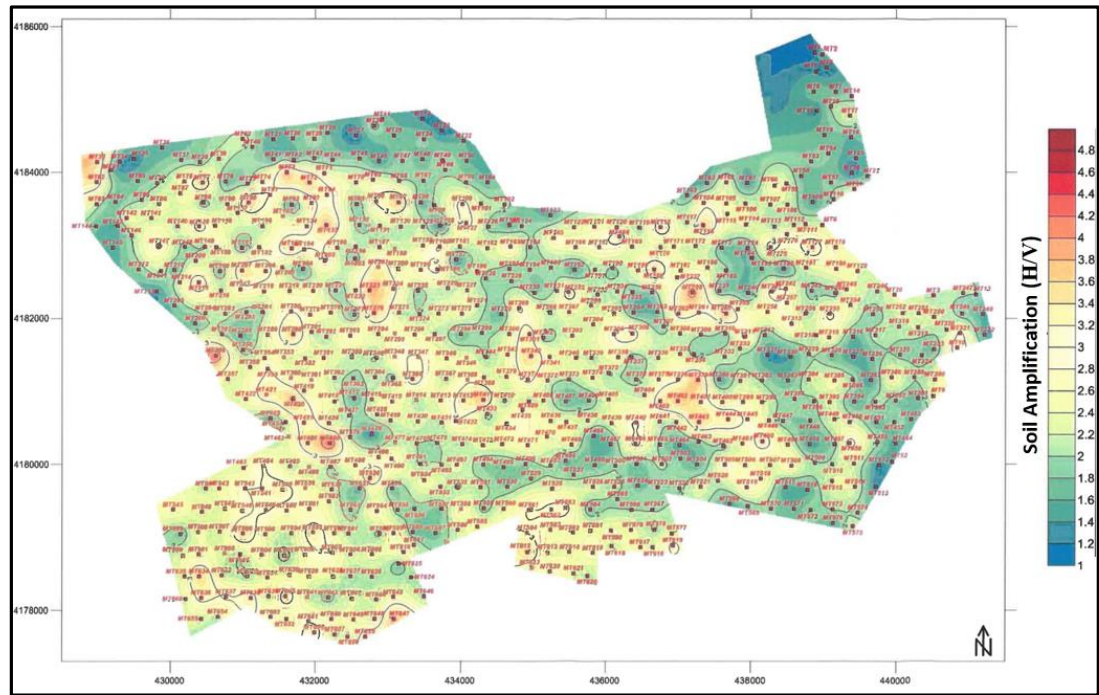


Figure 4.12: Soil amplification map of the study area [Adıyaman Municipality, 2023].

Table 4.5: Geophysical test results for Adıyaman city center.

Name of Formation	V_{s30} (SIS, m/s)	V_{s30} (REMI, m/s)	T_o (s)	H/V
Alluvial Deposits	364-470	381-481	0.44-	2.64-
			0.56	4.68
Adıyaman Formation	468-683	409-725	0.19-	1.10-
			0.43	4.32
Şelmo Formation	481-677	406-739	0.19-	1.04-
			0.21	2.49
Hoya Formation	714-726	665-731	0.14-	1.25-
			0.15	2.49
Germav Formation	667-743	616-756	0.16-	1.12-
			0.18	2.21

5. WATER SUPPLY SYSTEM IN ADIYAMAN CITY CENTER

The city center of Adıyaman is supplied with drinking water from various sources, including the Havşeri, Gürlevik, Tut-Medetsiz, and Koru-Palanlı sources [Toprak et al., 2024a]. These water sources are classified as spring water. The water is transported from these springs which exist at the foothills of the mountains to the city center via transmission lines [Figure 5.1]. Subsequently, it is distributed to the residents through the water network, making it accessible for public use.

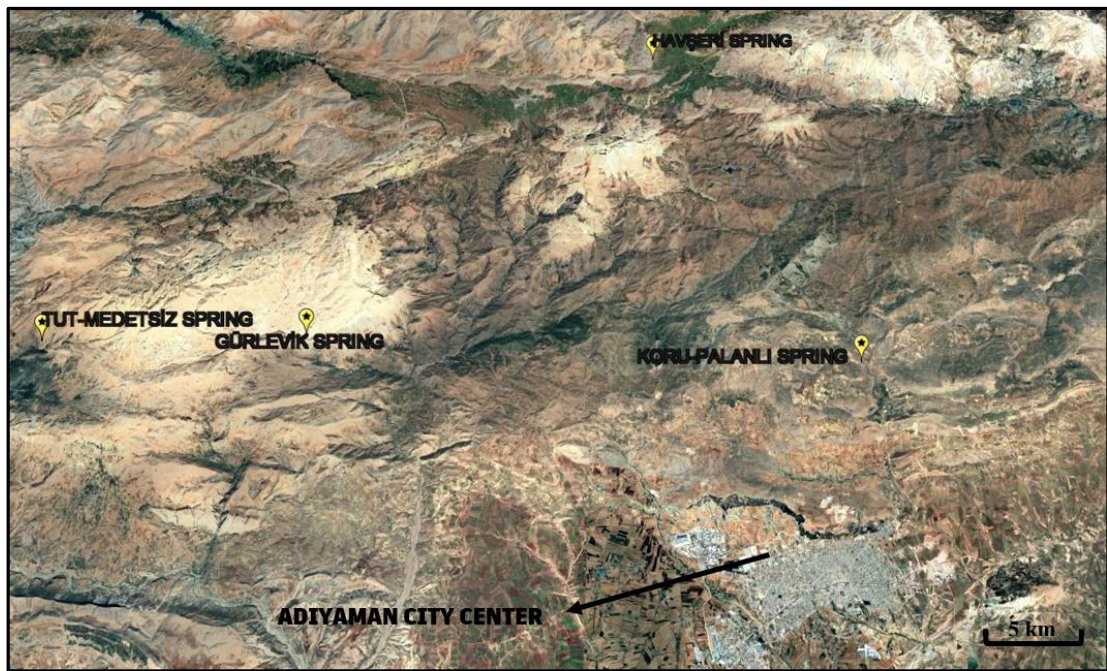


Figure 5.1: Spatial overview of the water sources of Adıyaman city center.

Table 5.1 indicates the detailed information about relevant water sources [Toprak et al., 2024c]. Among the transmission lines supplying water to the city center from these sources, the Gürlevik 1 line is the oldest. This approximately 27 km-long line, which has been in operation for nearly 50 years, consists of steel material for the first 15 km, while the remaining section is composed of asbestos cement (AC) pipes. Similarly, the Koru-Palanlı transmission line is made of both AC and steel pipes, with a greater prevalence of AC pipes. Potable water is transported to the city entirely through steel pipes via Gürlevik 2, Havşeri and Tut-Medetsiz sources. Additionally, the newly completed Gürlevik DI (Ductile Iron) pipeline was utilized for use following the

earthquake. In total, a 191 km-long transmission line network has been established to transport water from these sources to Adıyaman over the years. **Figure 5.2** visually presents the regional topography and the transmission lines that transport water from the mentioned sources to the city center.

Table 5.1: Information regarding the sources and their associated transmission lines [Toprak et al., 2024c].

Name of Transmission Line	Opening Year	Pipe Diameter (Φ , mm)	Material Type	Line Length (km)	Flow Rate (l/s)
Gürlevik 1	1973	250-300	Steel-AC	27	40
Gürlevik 2	1981	400-600	Steel	29	105
Havşeri	2011	800-1000	Steel	40	530
Tut-Medetsiz	2002	400-600	Steel	47	110
Koru-Palanlı	1998	400	AC-Steel	13	150
Gürlevik DI	2023	500-600	Ductile Iron	35	135

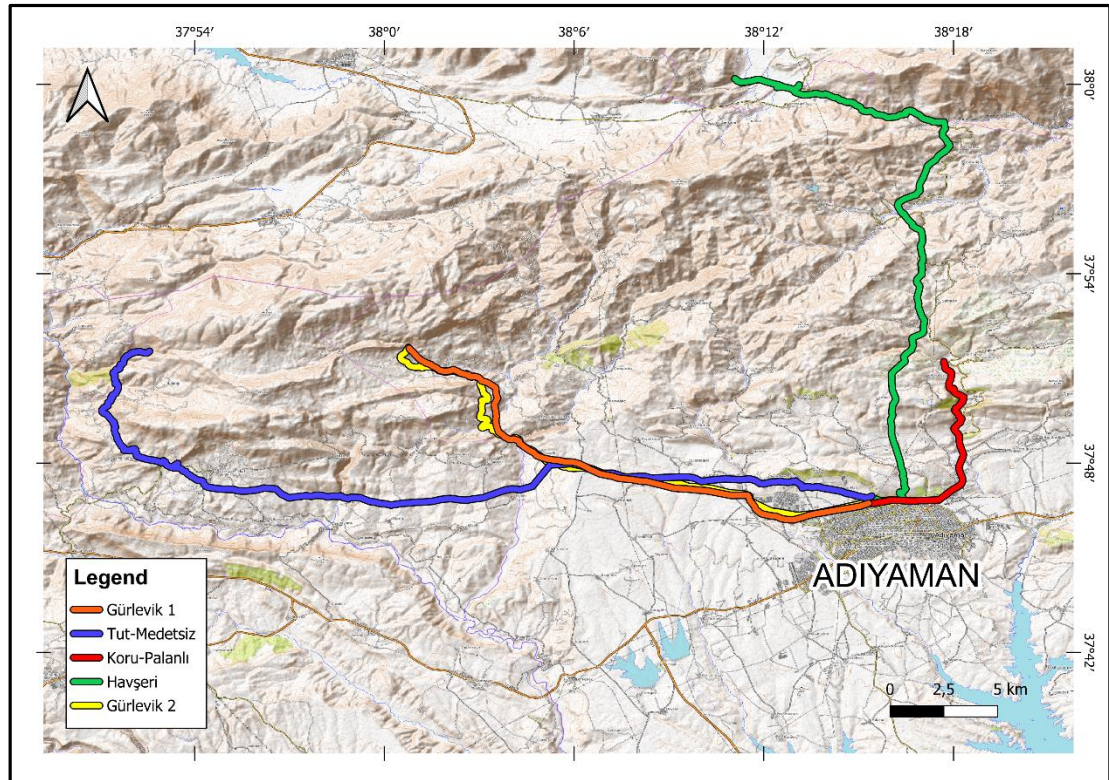


Figure 5.2: The map illustrating the regional topography and transmission lines.

Among these sources, the Havşeri water source and the Havşeri transmission line which transports water from this source to the city center, meet approximately 60% of the city's water demand. The Gürlevik water source, along with its associated transmission lines Gürlevik 1, Gürlevik 2, and the newly established Gürlevik DI (Ductile Iron) lines accounts for approximately 25% of the demand. Additionally, the Kuru-Palanlı and Tut-Medetsiz water sources contribute 8% and 7% of the city's water supply along with their respective transmission lines, respectively.

Adıyaman city has a total of 550 km of drinking water distribution pipelines, predominantly composed of AC, PVC and PE materials. The water distribution system operates primarily through gravity flow as highlighted by **Toprak et al. [2024c]**. **Figure 5.3** is an overview of the distribution networks map of Adıyaman city center.

The city center of Adıyaman is entirely supplied by a gravity-fed water flow system. Since no pumping is required, the cost of water supply for the city is relatively low. However, in a small number of residences where the gravitational flow is insufficient, hydro press systems are necessary. Furthermore, the city is supplied from the aforementioned sources without any treatment processes.

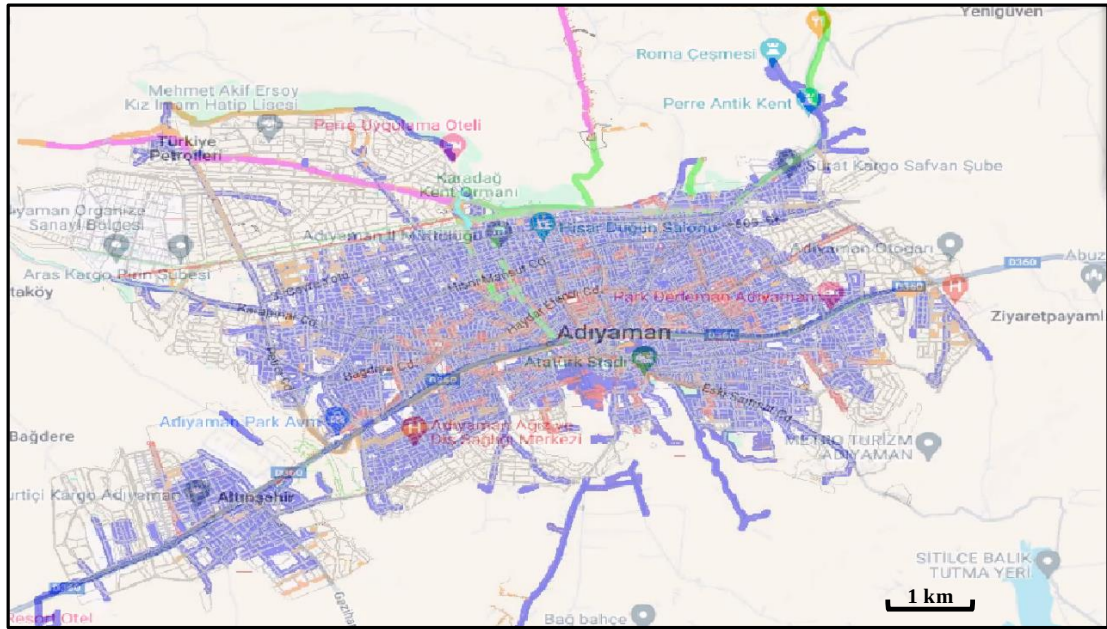


Figure 5.3: A basic overview of the distribution networks of Adıyaman city center.

In Adıyaman city center, water supply operations are managed under the responsibility of ASKİM which operates under the jurisdiction of the Adıyaman Municipality.

Detailed information regarding ASKİM is presented in **Table 5.2** with reference to **Toprak et al. [2024c]**.

Table 5.2: Operational details of ASKİM related with water supply [Toprak et al., 2024c].

ASKİM	
Population Served	316,140
Service Area (km ²)	1,814
Number of Cities/Towns Served	1
Number of Subscribers	82,000
Number of Employees	167
Water Quantity Supplied (m ³ /year)	22,075,200
Avg. Daily Water Supply (m ³)	60,480
Avg. Water Demand (l/s)	700
Drinking Water Pipeline Length (km)	550
Transmission Pipeline Length (km)	191

ASKİM operates four main water reservoirs with capacities of 15000 m³, 6000 m³, 4,000 m³, and 1,000 m³ respectively. The largest reservoir, with a capacity of 15000 m³, does not directly distribute water to the city but instead supplies the other three reservoirs. The 6000 m³ reservoir serves the southern areas of Atatürk Boulevard where roughly separates the city center into two part, while the 4000 m³ reservoir supplies the northern parts of the city. The 1000 m³ reservoir primarily provides water to new residential areas located further north and can also support the 4000 m³ reservoir when needed. In addition to these reservoirs, the construction of two new reservoirs with capacities of 10000 m³ and 20000 m³ is ongoing as part of the FRIT (the EU Facility for Refugees in Turkey) and MADAD (EU Regional Trust Fund) projects.

The water supply system in the city center of Adıyaman requires development and modernization. Both the transmission and distribution lines consist of outdated pipes with inadequate material properties. Since there are no flow meters in the city's network system, detailed consumption data cannot be obtained. Therefore, the absence of a SCADA system within the water supply infrastructure renders the current system far from meeting sustainability standards.

Several significant projects have been initiated with the aim of improving the existing infrastructure systems in the city center of Adıyaman. The FRIT is one of these projects. The Facility prioritizes delivering assistance in key domains, including

humanitarian relief, education, migration oversight, health services, urban infrastructure, and socio-economic advancement.

As a part of this support program, the city's drinking water network in Adıyaman will be modernized under the FRIT II Project, funded with a €22 million grant provided by the European Union. This amount represents the largest infrastructure investment in the history of Adıyaman. The title of the relevant project is 'Construction and rehabilitation of water supply and waste water systems and related soft measures to improve water management efficiency' [EU, 2024]. The project is funded by French Development Agency.

FRIT II framework involves renewing 550 km of the drinking water network, extending its length to 700 km, constructing reservoirs and establishing an advanced biological treatment facility. Within the scope of the project, the entire pipeline is being replaced with PE pipes. The buried depth of the pipelines varies between 1-2 meters. Additionally, the project includes plans to establish a SCADA center under ASKİM's management. As part of the FRIT project, the city water distribution network is being upgraded with PE pipes. As of March 2024, 30 km of the pipeline had been replaced with PE pipes and this production had increased to 75 km by July 2024.

The removal of AC-type pipes from the network system will constitute a significant advancement in terms of public health, water quality, and the adequacy of potable water. Furthermore, the project aims to integrate the renewed infrastructure system into an automation system, enabling the monitoring and management of drinking water networks. Consequently, the project is expected to enhance the quality of life for residents in the region, improve access to infrastructure services and lay the foundation for sustainable infrastructure management.

Another significant project implemented to establish sustainable infrastructure in the city center of Adıyaman is the MADAD project. The primary objective of the project is to modernize the aging pipeline infrastructure and minimize water losses in Adıyaman. The Gürlevik Drinking Water Transmission Line Construction Project, entirely financed by an EU grant, is being implemented by the Adıyaman Municipality under the framework of the MADAD.

Within the scope of this project, a new 35-km-long transmission line made of ductile iron was planned in addition to the aging Gürlevik 1 and Gürlevik 2 transmission lines which supply drinking water from the Gürlevik water source to the city center [**Figure 5.4**]. Additionally, the project included the construction of hydraulic structures such as flow meters and valve chambers, as well as a storage tank with a capacity of 20,000 m³.

A substantial portion of the project was completed just prior to the February 6 Kahramanmaraş-centered earthquakes. Because of this project, the damages that occurred in the Gürlevik 1 and Gürlevik 2 transmission lines which are discussed in later sections did not result in water supply disruptions to the city center. The Gürlevik DI transmission line which was largely completed as part of the project, was utilised using branch lines and allowed the continuous supply of water from the Gürlevik source to the city after the earthquake. Photographs are presented depicting the implementation of the aforementioned projects carried out in this context within the city center of Adıyaman in **Figure 5.5**.



Figure 5.4: The photo of Gürlevik DI (left) and Gürlevik 2 from site observations.



Figure 5.5: Implementation photographs of MADAD and FRIT II frameworks.

6. WATER SUPPLY SYSTEM DAMAGES IN ADIYAMAN CITY CENTER

Significant earthquake-induced infrastructure damages occurred in the central district which is Adıyaman's largest district by population. This section addresses the earthquake-induced infrastructure damage observed in this district of Adıyaman. Furthermore, it examines the factors contributing to the damage (rock falls, material properties, topography, seismic parameters etc.). Due to the damage occurred in the transmission and distribution network lines following the earthquake, prolonged water supply interruptions lasting for several months occurred in sequence.

6.1. Damages in Transmission Lines

Remarkable damages have taken place particularly in the transmission lines within the city center of Adıyaman during the February 6 Kahramanmaraş earthquakes. Various factors contributed to these damages; including the effects of landslides, rock falls, faulting, topography and the aging characteristics of pipe materials. Damage assessment efforts could not be completed immediately after the earthquake due to these severe damages. Even nearly two years later, these assessments have occasionally carried on along the transmission pipelines spanning various locations across the city.

For instance, in a public statement issued by the Adıyaman Municipality on 8th of October 2024, 20 months after the earthquake, it was stated that damage assessment efforts were still ongoing for the Havşeri transmission line which holds the largest share among the sources meeting the city's water needs. The statement further noted that buckling and fractures had been identified at four different points along the pipelines during the investigations and that, the repairs across the entire line would be completed as swiftly as possible within the consideration of seasonal conditions.

Figure 6.1 exemplifies the related field assessment [Adıyaman Municipality, 2024].

The Havşeri water source has a critical importance for Adıyaman city center, supplying approximately 60% of the city's water demand. This pipeline transports water from the Havşeri water source, located within the Çelikhan district boundaries

approximately 28 km away from the central district of Adıyaman in a straight line, to the city center. The total length of the pipeline is approximately 40 km.



Figure 6.1: An example from field studies conducted on the Havşeri transmission line [Adıyaman Municipality, 2024].

A series of significant transmission line failures along the Havşeri pipeline were identified immediately after the earthquake, as the pipeline's flow rate dropped by nearly half. **Figure 6.1** indicates that still water losses caused by damage have occurred at certain points along the transmission line.

The existing pipeline traverses vast plains and intersects with the faulting zone where the Sürgü and Pötürge segments of the East Anatolian Fault Line are located. Therefore, it is estimated that faulting and soil amplifications occurring in the vast plains have played a significant role in the damages observed, particularly along the initial kilometers of the pipeline.

Figure 6.2 includes photographs of a damage point along this pipeline. At this location, a Φ 700 mm diameter steel pipe was severely bent at its elbow joint due to the impact of the earthquake. The damage point is approximately 400 meters from the source and directly intersects with the mentioned fault line. It is evident that fault movement caused the damage at this location. Furthermore, for approximately 800 meters following the damage point, the pipeline runs in close proximity and parallel to the fault line.



Figure 6.2: Repair process of the damaged Φ 700 mm steel pipe.

Figure 6.3 illustrates the anticipated ground movement. Accordingly, the pipeline passes through a wide plain, with a sloped rocky terrain located nearby. Ground movement induced by the left-lateral EAF portion was occurred and resulting in damage to the existing pipeline by bending it at its elbow joint. Further along the same pipeline, at the 2.3-kilometer mark from the source, the pipeline intersects with a surface rupture. The deformation is approximately 2 m at the location of damage point due to fault rupture. It should also be noted that this pipeline, along its 40-km route, traverses steep terrains, areas with slope variations, and regions with high landslide potential, transporting water to the city through topographies ranging from approximately 1300 meters to 720 meters in elevation.

In various regions worldwide, buried pipelines are essential for crossing high-risk landslide zones to minimize pipeline length and reduce engineering expenses. However, in such scenarios, seismic landslides can cause severe accidents by inducing substantial plastic deformations at critical points along the pipeline [Darvishi et al., 2024].

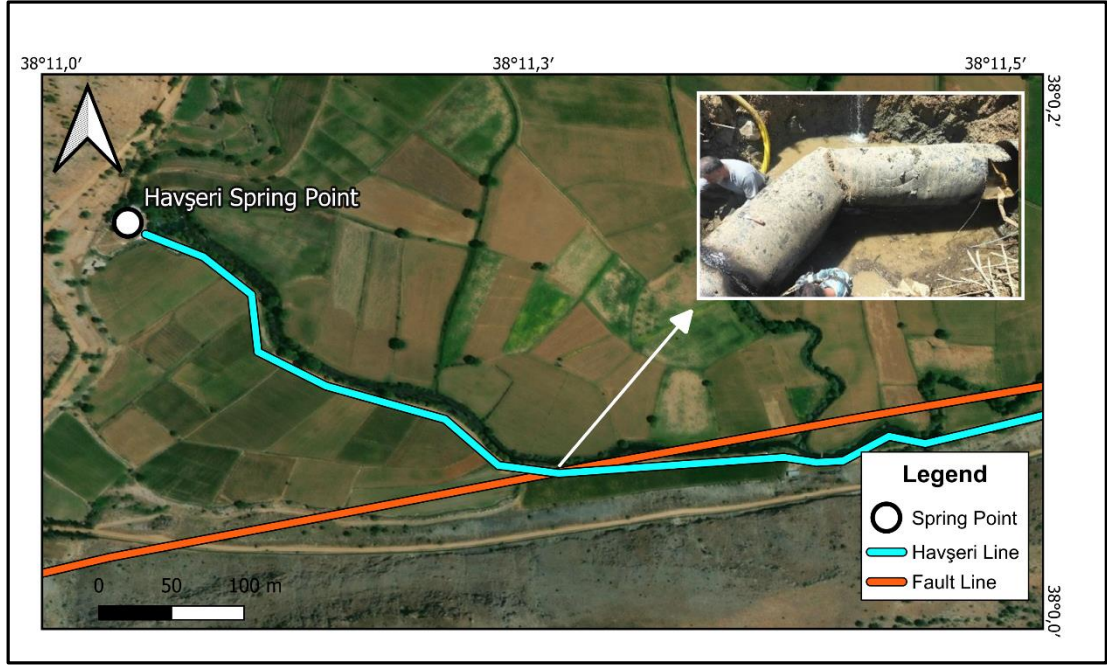


Figure 6.3: The crossing of existing fault line with Havşeri transmission line.

In earthquake-affected region, the landslides significantly affected water supply systems situated in areas of the region prone to such events. This effect was particularly pronounced where water transmission pipelines, which are vital for transporting water from rivers or mountain springs to urban centers, crossed these vulnerable zones. Rock falls and translational slides are the most frequently occurring types of landslides in these areas [Toprak et al., 2024a].

The potable water from the Gürlevik water source is transported to the city center via the Gürlevik 1, Gürlevik 2 and Gürlevik DI transmission lines. Various types of damage have occurred along these lines. Although the water transmission lines carrying water from Gürlevik do not intersect with a fault along their route, damages observed in the three aforementioned pipelines and they are generally associated with landslide activities triggered by the earthquake. These pipelines traverse landslide-prone terrains to transport water to urban areas.

Landslides occur more frequently in areas where lithological differences are observed; therefore, it is essential to consider lithological variations in analyses as elaborated by Komac [2006]. The Gürlevik transmission lines passes through diverse lithological formations that are highly susceptible to landslides. Recognizing this susceptibility is crucial for assessing risks and devising effective mitigation strategies. For instance, Table 6.1 presents the geological units traversed along the route of the Gürlevik 2

transmission line affected by the landslide, along with the lithological details of these geological units with reference to 1:500000 scale maps generated by the Mineral Research and Exploration Institute (MTA) [Toprak et al., 2024a]. MTA Hatay map section indicates that the 29-km pipeline route passes through six distinct lithological formations [MTA, 2002]. These lithological structures differ in terms of soil composition and rock types, which adversely affect the stability of sloped terrain. Therefore, recognizing these differences is crucial for the design, upkeep and repair of the transmission line to enhance its resilience to landslide occurrences.

Site investigations and ASKİM personnel statements indicate that the aforementioned landslide activities primarily exhibited shallow, surface-level characteristics rather than being deep-seated. Additionally, observations showed that pipelines affected by landslides were often located at the base of unstable slopes. Moreover, the Gürlevik 1, 2 and DI transmission lines run parallel to each other along certain mountainous roads which locate the base of the slopes.

According to Görüm et al. [2023], the Kahramanmaraş earthquakes generated ground motions capable of triggering landslides. In their study, they identified over 3,500 landslides throughout the entire earthquake-affected region within the analysis of high-resolution satellite images, aerial photos, and site investigations. Additionally, they determined that 70% of these landslides occurred at elevations between 800 m and 1400 m and on slopes with gradients ranging from 20 to 45 degrees. The study also highlighted that the most predominant type of landslide in the region was rock falls. Görüm et al. [2023] noted that the study presented landslides identified using remote sensing-based methodologies, but due to some limitations inherent in this approach, the actual number of landslides could be higher.

Figure 6.4 illustrates the landslide incidents that have occurred in Adıyaman province and its surrounding regions. The incident locations were sourced from Görüm et al. [2023] and the landslide incidents have been overlaid with the landslide susceptibility model presented by Nowicki Jessee et al. [2018] on the map. The model utilizes logistic regression to analyze the relationship between earthquake-induced landslide occurrences and factors such as lithology, spatially distributed ground shaking estimates, land cover types and topographic slopes. By examining this overlap, it can be observed that the model aligns with the documented landslide incidents, thereby demonstrating its reliability.

Table 6.1: Lithological information along the Gürlevik 2 line.

No.	Lithological Information	Symbol	Distance Covered by Pipeline (km)
1	Middle Triassic - Cretaceous / Volcanic and Sedimentary Rocks	t ₂ k	5.5
2	Upper Cretaceous – Paleocene / Clastic and Carbonate Rocks	k ₂ pn	5.9
3	Quaternary / Undifferentiated Quaternary	Q	0.6
4	Cretaceous / Pelagic Limestone, Clastic Rocks, Radiolarite, Chert etc.	k	2.0
5	Middle - Upper Miocene / Continental Clastic Rocks	m ₂₋₃	9.3
6	Plio – Quaternary / Undifferentiated Continental Clastic Rocks	plQ	6.2

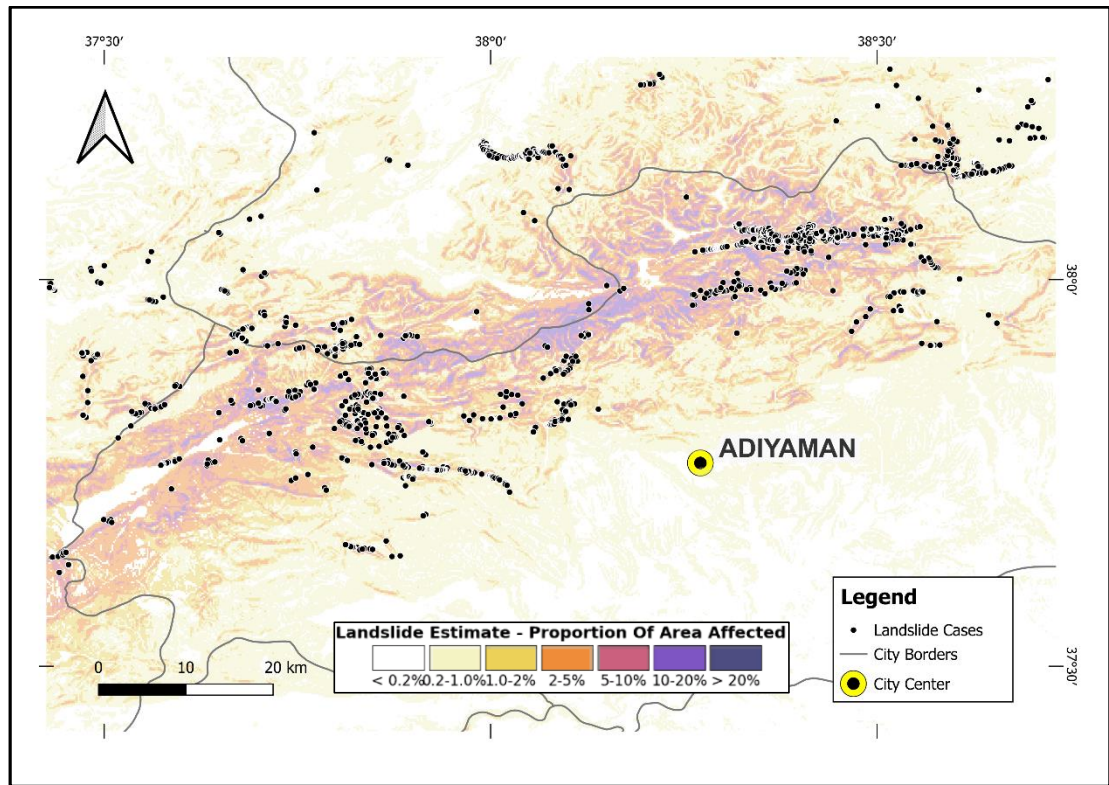
**Figure 6.4:** Distribution of landslide cases Adiyaman and nearby cities superimpose with landslide probability model.

Figure 6.5 is derived by overlaying the transmission lines supplying water to the Adiyaman city center onto the same map. According to the figure, landslide incidents are observed in certain areas along the Havşeri transmission line, near the source points of the Gürlevik 1 and Gürlevik 2 lines and within the first few kilometers of the Tut-

Medetsiz line. In contrast, no landslide incidents and overlaps with high landslide susceptibility zones are observed along the Kuru-Palanlı transmission line.

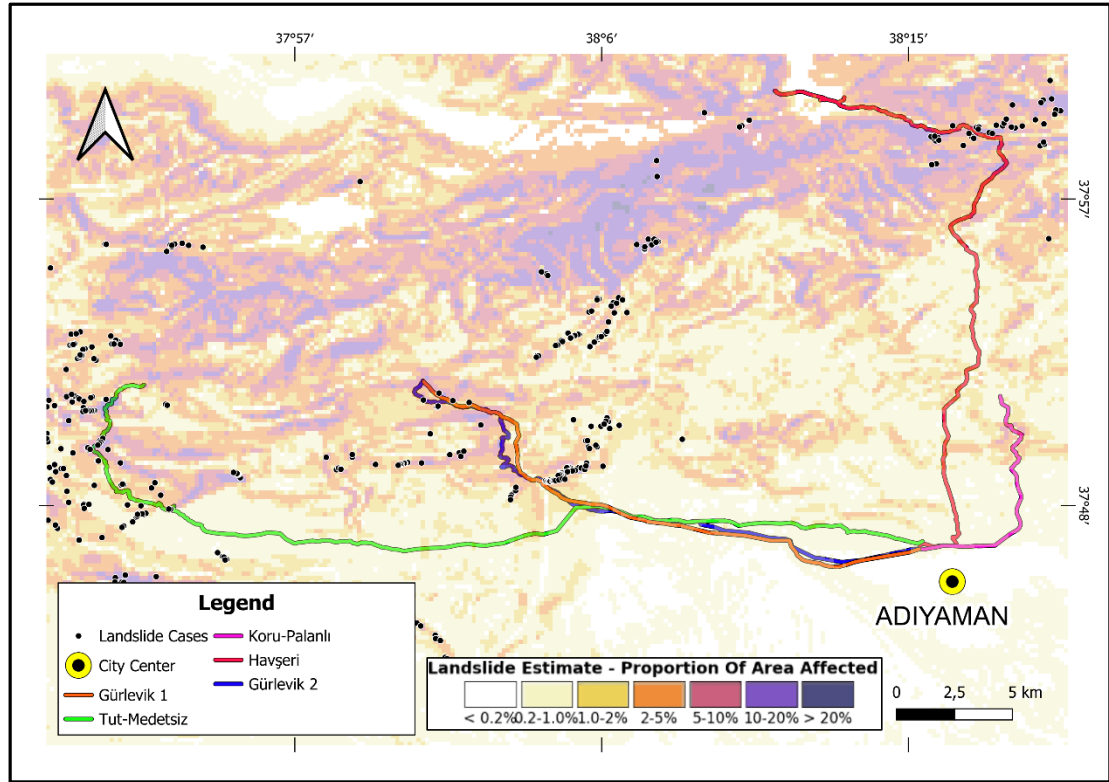


Figure 6.5: Distribution of landslide cases along with transmission line for Adıyaman city center superimpose with landslide probability model.

Specifically, 25 instances of damage have been recorded along the Gürlevik 2 transmission line. This line is 29 km in length and is entirely constructed of steel. **Figure 6.6** gives some examples from 25 damage points from Gürlevik 2 steel pipeline. The diameters are Φ 400 and 500 mm respectively.

The distance between the damaged sections and the nearest surface fault rupture varies between approximately 8 and 16 km. The Gürlevik 2 transmission line transports water from the source, located at an elevation of approximately 1300 meters, to the Adıyaman city center at an elevation of approximately 700 meters. This is achieved through gravity-driven flow across regions with varying slopes and through terrains with differing geological structures. **Table 6.2** provides information regarding the damages on the specified line, including their locations, distances to the nearest surface rupture and distance from water source.



Figure 6.6: Damages in Gürlevik 2 transmission line.

Table 6.2: Information about damage point locations along Gürlevik 2 line.

Damage Point	Distance from the Spring (km)	Distance to the Surface Rupture (km)	Latitude	longitude
1	2.41	8.50	37.85074	38.02390
2	2.55	8.57	37.85039	38.02555
3	2.72	8.70	37.84993	38.02719
4	3.00	8.86	37.84851	38.02980
5	3.76	9.23	37.84807	38.03795
6	4.27	9.58	37.84691	38.04333
7	5.38	9.97	37.84187	38.05061
8	5.58	10.75	37.84054	38.05100
9	5.81	10.93	37.83861	38.05180
10	6.01	11.13	37.83679	38.05222
11	6.26	11.35	37.83527	38.05409
12	6.40	11.59	37.83401	38.05446
13	6.98	11.63	37.83194	38.05180
14	8.05	11.74	37.82313	38.05170
15	8.51	12.58	37.82107	38.05376
16	9.68	12.93	37.81723	38.05710
17	9.95	13.43	37.81575	38.05938
18	10.08	13.68	37.81485	38.06035
19	11.41	13.78	37.81066	38.07134
20	11.79	14.58	37.80827	38.07419
21	12.05	15.08	37.80710	38.07671
22	12.35	15.33	37.80554	38.07927
23	12.48	15.43	37.80460	38.08014
24	12.66	15.58	37.80371	38.08178
25	12.83	15.70	37.80282	38.08327

The slope range of pipeline damage area is between 10° and 50° with the majority of damages concentrated in subzones where the slope is approximately 30° . The first and last damage points were located approximately 2.4 km and 12.8 km from the pipeline's origin at the source, respectively [Table 6.2]. Significantly, all 25 damage sites were concentrated within a 10.4 km segment of the line that traverses relatively steep terrain.

However, when examining the non-damaged area, it is obviously seen that both the PGV values are lower compared to the damaged region and the terrain slope is significantly flatter. Therefore, **Toprak et al. [2024a]** highlighted that the importance of strategic planning in these vulnerable regions about a direct or indirect impact of landslide-prone areas on pipeline damage.

The Gürlevik 1 line is the oldest transmission line supplying water to Adıyaman. At the time of the earthquake, this line had been in use for approximately 50 years and experienced damage rendering it inoperable after the earthquake. The line has a total

length of 27 km, with the first 15 km constructed of steel. In the steel section extending to the Durukaynak region, a total of 82 damages were recorded. These damages start from the initial kilometers of the line and continue to the end of the 15 km steel segment. The remaining 12 km of the line consists of AC-type pipes, where an uncountable number of damages occurred. Due to the extent of these damages, the ASKİM personnel were insufficient in number to carry out the repairs, necessitating support from other institutions. **Figure 6.7** presents some damage views from different two damage points in 82 damages of steel section of Gürlevik 1 line. The diameter of the damaged pipes is Φ 300 mm.



Figure 6.7: Damages in steel section of Gürlevik 1 transmission line.

A significant damage incident occurred at a location where the Gürlevik DI and Gürlevik 2 pipelines run parallel. In this event, both the Gürlevik DI and Gürlevik 2 pipelines sustained damage [**Figure 6.8**]. Rock fall was the main factor contributing to the pipeline damage at this site. The case reveals that critical considerations must be taken into account during the construction and protection of pipelines in regions susceptible to geological hazards [**Toprak et al., 2024a**]. Although the DI pipeline was not in use during the earthquake, the Gürlevik 2 steel pipeline continued to supply water to the city center. During the earthquake, both pipes were not buried, they were

uncovered due to the ongoing construction of the pipeline. The damages occurring in DI pipes, leading to deformation and displacement, are typically observed at the joints under repetitive loading conditions [Liu and Cui, 2025]. However, in this specific case, the body of the exposed DI pipe was damaged by the rock fall. This emphasizes the importance of burying pipelines in areas at risk of landslides to mitigate potential damage.



Figure 6.8: Damages in Gürlevik DI and 2 transmission lines due to rock falls.

During the Kahramanmaraş earthquakes, field observations demonstrated that various damage mechanisms, such as tensile failures, buckling issues, bending fractures and joint failures, occurred during the seismic events [Toprak et al., 2024a].

Figure 6.9 and **Figure 6.10** illustrate various damage mechanisms observed in the Gürlevik water transmission lines in Adıyaman. In **Figure 6.9a**, it is evident that a Φ 500 mm diameter steel pipe in the Gürlevik 2 transmission line sustained damage due to local buckling as a result of axial compression loading. On the other hand, **Figure 6.9b** depicts a joint failure case in a Φ 300 mm diameter steel pipe in the Gürlevik 1 transmission line. The additional seismic loads caused separation at the joint, a region with relatively lower structural strength.

Figure 6.10a illustrates a case in Gürlevik 1 pipeline. The $\varnothing$ 300 mm diameter steel pipe experienced complete separation as a result of torsional and tensile forces induced by seismic activity. On the other hand, **Figure 6.10b** showcases a damage scenario in which predominant transverse deformation (i.e., bending) led to fractures from Gürlevik 1 pipeline. The 52-year old pipe has $\varnothing$ 300 mm diameter.

It should also be noted that the damage examples presented here represent only a few instances among dozens of observed failures. Although this study primarily focuses on the damages in the Gürlevik and Havşeri water transmission lines, failures were also recorded in the Tut-Medetsiz and Koru-Palanlı transmission lines. These damages were particularly more concentrated in the Gürlevik 1 and 2 transmission lines. Considering all field observations, it can be said that some factors had significant role on these pipeline damages. Those factors are summarized as long-term corrosion in steel pipes, thinning of the pipe walls and the deterioration of joint connections. Additionally, all of these experiences emphasizes the importance of developing more robust infrastructure systems capable of withstanding potential seismic hazards [Toprak et al., 2024a].



a)



b)

Figure 6.9: Different types of damages in Adıyaman: a) Local buckling failure
b) Joint failure.

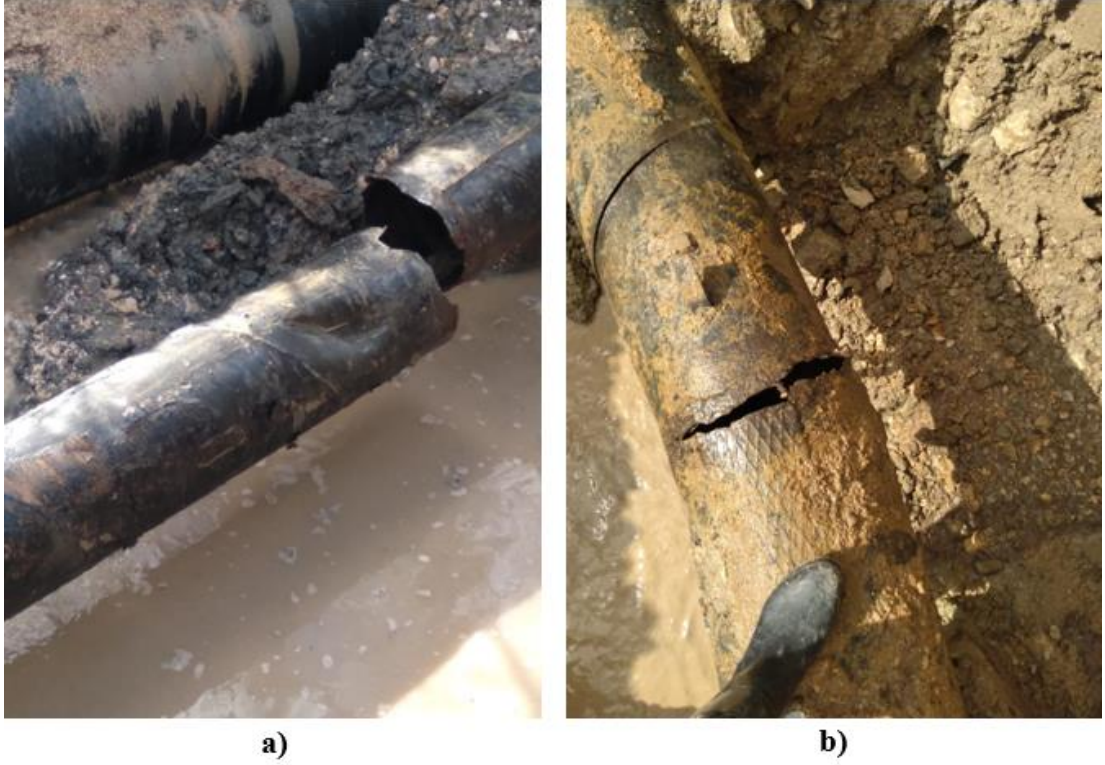


Figure 6.10: Different types of damages in Adıyaman: a) Tension failure b) Bending failure.

6.2. Damages in Distribution Lines

In the post-disaster period, approximately 100 network malfunctions occurred daily and the majority of these malfunctions were related to subscriber disconnection operations. While pipe damage was relatively minimal in the city center of Adıyaman, a significant number of network line damages were observed in the Alitaşı neighborhood due to the use of asbestos cement (AC) pipes in its system. Consequently, Alitaşı emerged as one of the few locations with a high incidence of water network damages. **Figure 6.11** represents some repair applications right after the Kahramanmaraş earthquakes.

6.3. Damages in Reservoirs

Seismic activities not only damage pipelines but can also affect critical infrastructure within water supply systems such as reservoirs, valve chambers and other essential structures. Thus, the operation of the water supply system becomes disrupted. **Figure 6.12** illustrates the damages at the Gürlevik source caused by rock falls. The distance

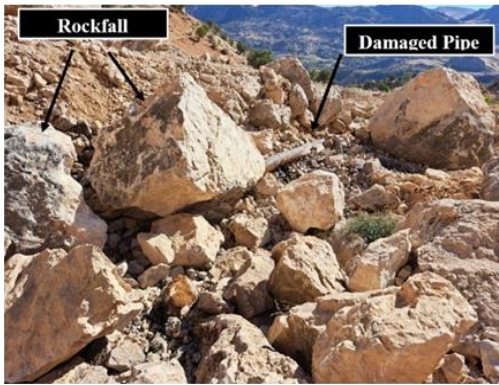
between the source point in question and the nearest fault is approximately 7 kilometers. The water source is located in a steep and rugged terrain, which serves as the primary cause of the earthquake-induced rock falls mentioned. Rock falls triggered by the earthquake caused damage to the reservoir structure, the water outlet of the source, and public facilities located at the spring point of the Gürlevik 2 transmission line. At the Gürlevik spring point, the rock falls included blocks with a maximum size of 2.5 meters, with the majority of rock sizes ranging between 1.5 and 2.5 meters.



Figure 6.11: Some examples from distribution line problems in Adıyaman city center (ASKİM personal communication).



(a)



(b)



(c)



(d)

Figure 6.12: Damages in Gürlevik source due to rock falls.

As previously stated, there are 25 identified damages concentrated along approximately 10 km of the 29 km-long Gürlevik 2 pipeline. Similarly, the initial 15 km steel section of the 27 km Gürlevik 1 pipeline contained 82 damages distributed throughout the pipeline. Additionally, several structural facilities were damaged due to rock falls triggered by the earthquake that occurred at the Gürlevik source point. **Figure 6.13** illustrates the earthquake-induced landslides around the Gürlevik source area following the Kahramanmaraş earthquakes and depicts the relative positions of these landslide locations based on the study conducted by **Görüm et al. [2023]** in relation to the Gürlevik 1 and Gürlevik 2 pipelines. The figure reveals some intersections between actual landslide incidents and the pipeline routes. Additionally, it is anticipated that, in addition to the landslides shown in the figure, other unreported landslides may have also occurred along the Gürlevik 1 and Gürlevik 2 pipelines.

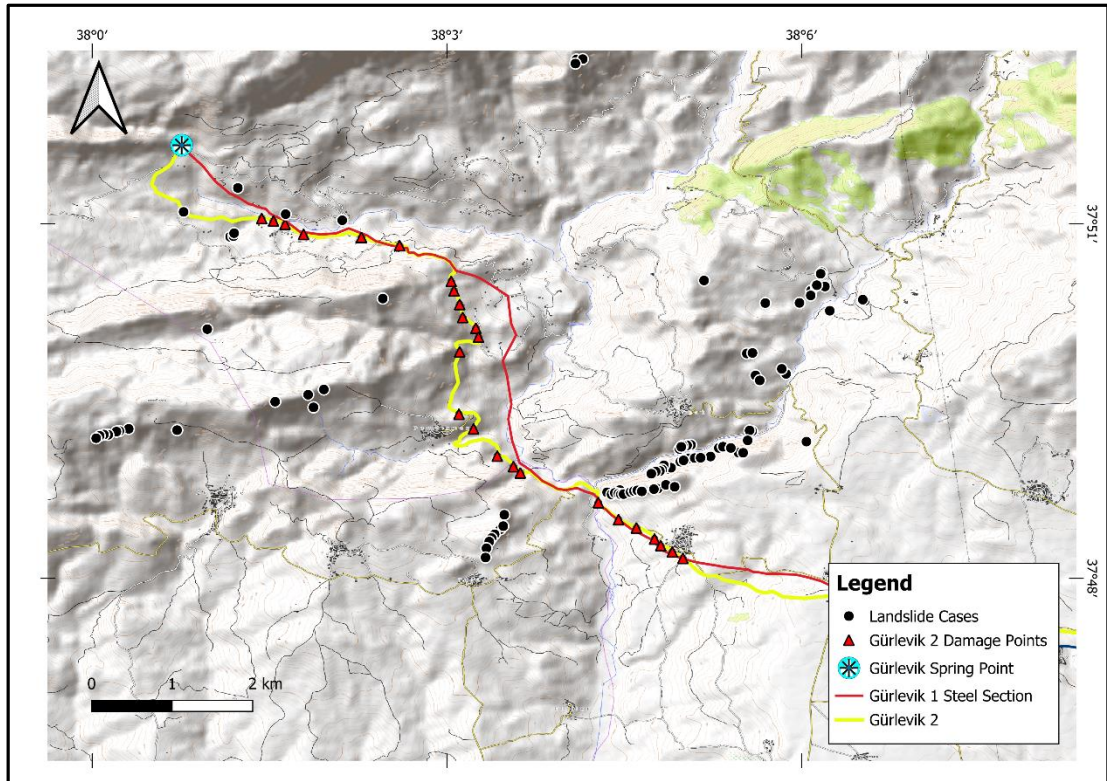


Figure 6.13: The spatial distributions of landslides, Gürlevik water supply networks relevant damages.

7. METHODOLOGY AND ANALYSIS

As part of the study, a series of field visits were conducted to the study area to collect the damage data required as a priority, and on-site inspections were carried out. Subsequently, data acquisition was achieved in coordination with administrative units. The collected data were utilized in analyses with the aid of GIS. For the analyses and calculations, QGIS software version 3.34.1 was employed, while Google Earth™ was utilized as the source for the current land use and condition map.

QGIS, previously referred to as Quantum GIS, is a free, open-source GIS software that is cross-platform, highly scalable, and supports plugin development using Python and C++ programming languages. Since the release of its first major version in 2009, QGIS has become an increasingly popular software and is now utilized across various disciplines worldwide for GIS processing tasks **[Moyroud and Portet, 2018]**.

The raw data obtained within the scope of the study were integrated into the QGIS ecosystem. The acquired pipeline routes and damage locations were defined in the system as vector data. Additionally, certain data sourced from the literature, such as the probabilistic landslide map, were integrated into the system as raster data and utilized in the analyses.

Within the scope of the study, site-specific PGV data obtained from the literature were interpolated across the study area at 1 cm/s intervals using the interpolation method. Subsequently, the existing data were converted into contours using the 'Contour' plugin. The interpolated PGV contours and grids were then overlaid with pipeline routes and damage locations. Following this, the damage data were classified based on specific PGV intervals. Afterwards, the number of damages and pipeline lengths corresponding to these intervals were calculated to derive RR values. After calculating the RR values, their validity was confirmed by applying screening criteria. Finally, an attempt was made to establish a relationship between RR and PGV values.

Additionally, an effort was made to establish a relationship between terrain slope and RR. In this regard, the terrain slopes perpendicular to the Gürlevik 2 pipeline were calculated at specific intervals. The slope values were determined within the range of 80-85 meters and slope calculations were conducted for a total of 349 points along a 29-kilometer stretch of the pipeline. As a result, a damage correlation was identified.

Repair rate (RR) for pipelines is a measure used to determine the frequency of repairs needed per unit length of the pipeline. RR can be described as the equation (7.1) given below.

$$RR = \frac{\text{Total Number of Damages}}{\text{Total Pipe Length (km)}} \quad (7.1)$$

Damage relationships are developed using regression analysis results of points corresponding to RR values for specific PGV intervals. When determining these PGV intervals, a screening criteria parameter is employed with the aim of producing meaningful correlations and ensuring sufficient pipeline length. The screening criteria was established by **O'Rourke et al. [2014]** and is calculated using equation (7.2) provided below.

$$x \geq [\phi^{-1}(\beta_c)]^2 / [\alpha^2(RR)] \quad (7.2)$$

In the equation (7.1); x represents the sampling length, β_c is the confidence interval, $\phi^{-1}(\beta_c)$ is corresponding standard normal deviate, RR is the repair rate and α corresponds acceptable margin of error. The probability (confidence level) that the sampled repair count lies within α of the true value can be assessed by acknowledging that, according to the central limit theorem, the sampled repairs adhere to a normal distribution.

The study focused on landslide potential, evaluating the impacts of mass movements on transmission pipelines. While attempting to establish damage relationships on transmission pipelines, detailed analysis of network damages could not be conducted due to insufficient damage data for the distribution lines along with Adıyaman city center.

As a result of the analyses, PGV distribution map is presented in **Figure 7.1**. The PGV range for the Gürlevik 2 pipeline was determined to be 27-50 cm/s, with the damaged region falling within the range of 31-46 cm/s. The PGV range for the Gürlevik 1 transmission pipeline was found to be 28-48 cm/s, while the PGV range for the Koru-Palanlı transmission pipeline was determined to be 30-32 cm/s. For the Havşeri transmission pipeline, the PGV range was calculated as 32-54 cm/s, with the PGV value at the damage point coinciding with the fault measured as 43 cm/s. In the Tut-Medetsiz transmission pipeline, the PGV range was obtained as 27-86 cm/s. In the city center of Adıyaman, the PGV range was determined to be 30-35 cm/s, with the

maximum value recorded in the Alitaşı neighborhood, where the highest number of network damages occurred. Results are presented in **Table 7.1**. Besides, PGV distribution along the length of the lines are given in **Table 7.2**.

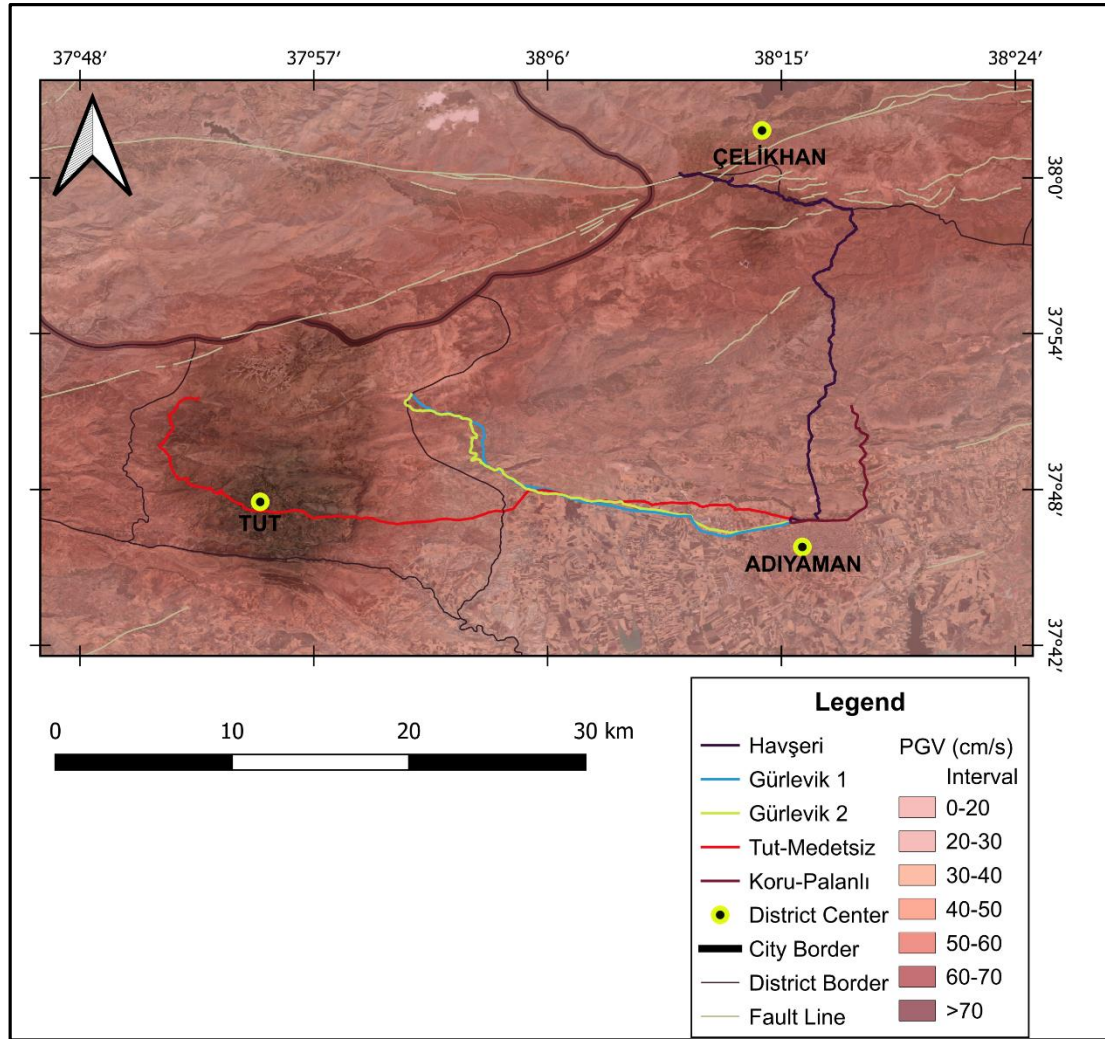


Figure 7.1: PGV distribution map of Adıyaman city center and nearby districts.

Table 7.1: Corresponding PGV values for water supply networks.

Line Name	PGV Interval (cm/s)
Gürlevik 1 (AC)	27-32
Gürlevik 1 (Steel)	28-48
Gürlevik 2	27-50
Havşeri	32-54
Tut-Medetsiz	27-86
Koru-Palanlı	30-32
Distribution Network (City Center)	30-35

Table 7.2: Distribution of PGV intervals for each transmission line.

PGV Interval (cm/s)	Line	Gürlevik 1	Gürlevik 2	Havşeri	Tut-Medetsiz	Koru-Palanlı
[20-30]	Length (km)	12.4	12.3	-	12.5	0.1
	%	46.4	42.4	-	26.3	1.1
(30-40]	Length (km)	10.1	11.4	20.2	10.1	12.9
	%	37.8	39.3	51.0	21.1	98.9
(40-50]	Length (km)	4.2	5.3	16.9	11.5	-
	%	15.9	18.3	42.6	24.2	-
(50-60]	Length (km)	-	-	2.6	7.3	-
	%	-	-	6.5	15.3	-
(60-70]	Length (km)	-	-	-	3.3	-
	%	-	-	-	6.9	-
(70-80]	Length (km)	-	-	-	1.9	-
	%	-	-	-	4.0	-
(80-90]	Length (km)	-	-	-	1.0	-
	%	-	-	-	2.1	-
Total Length of the Line (km)		26.7	29.0	39.7	47.6	13.0

Table 7.3 gives the RR calculation for Gürlevik 1 and 2 lines. The confidence interval was determined as 90% for the Gürlevik 1 pipeline, while it was obtained as 85% for the Gürlevik 2 pipeline.

Table 7.3: RR values for Gürlevik 1 and 2 lines with respect to PGV intervals.

PGV Interval (cm/s)	Number Of Damage	Covered Distance (km)	Repair Rate (RR)
Gürlevik 2 Transmission Line			
(30, 40]	16	14.73	1.09
(40, 50]	9	6.04	1.49
Gürlevik 1 Transmission Line Steel Section			
[28, 48]	82	15.03	5.46

Additionally, the RR data obtained from the Gürlevik 2 pipeline are presented in **Figure 7.2** alongside the corresponding PGV values. In the figure, the correlations provided by **O'Rourke et al. [2014]** for AC and CI pipe types are compared with the data specific to Gürlevik 2 in a comparative manner.

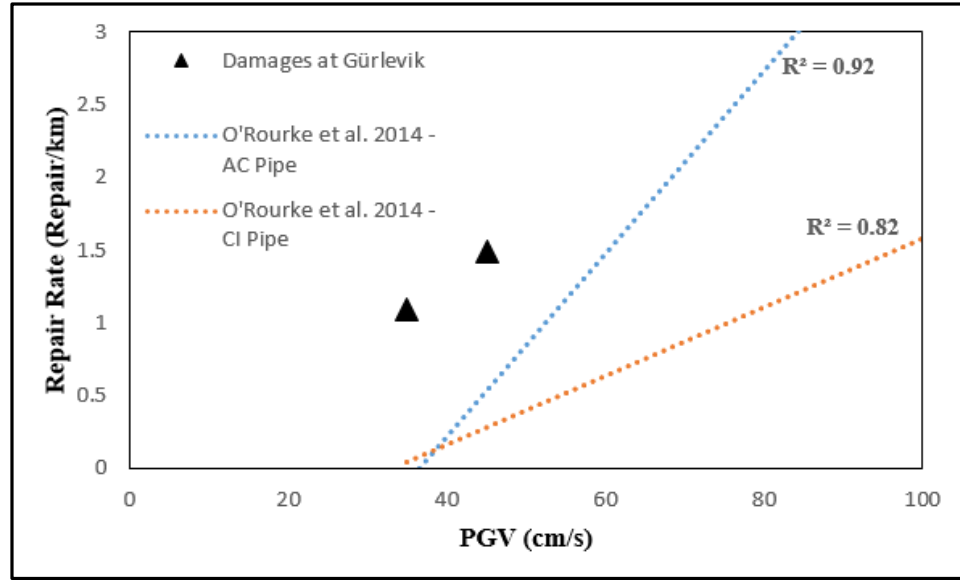


Figure 7.2: Comparison of damage data from Gürlevik 2 with the literature.

Figure 7.3a introduces the USGS landslide hazard prediction map which has been superimposed on the Gürlevik 2 steel pipeline route. The model has been developed using an empirical model by **Nowicki Jessee et al. [2018]** as mentioned before.

Figure 7.3b illustrates the elevation profile of the Gürlevik 2 pipeline, highlighting 25 damage points along its route and their respective distances. It also incorporates the lithological structures traversed by the pipeline as previously detailed in **Table 6.1**. The figure is generated using Google Earth™ and displays the elevation profile along the pipeline route with parallel to the pipeline. The x-axis denotes the actual ground distance and the y-axis represents the elevation above sea level. It is worth noting that the elevation data obtained from Google Earth may pose certain limitations.

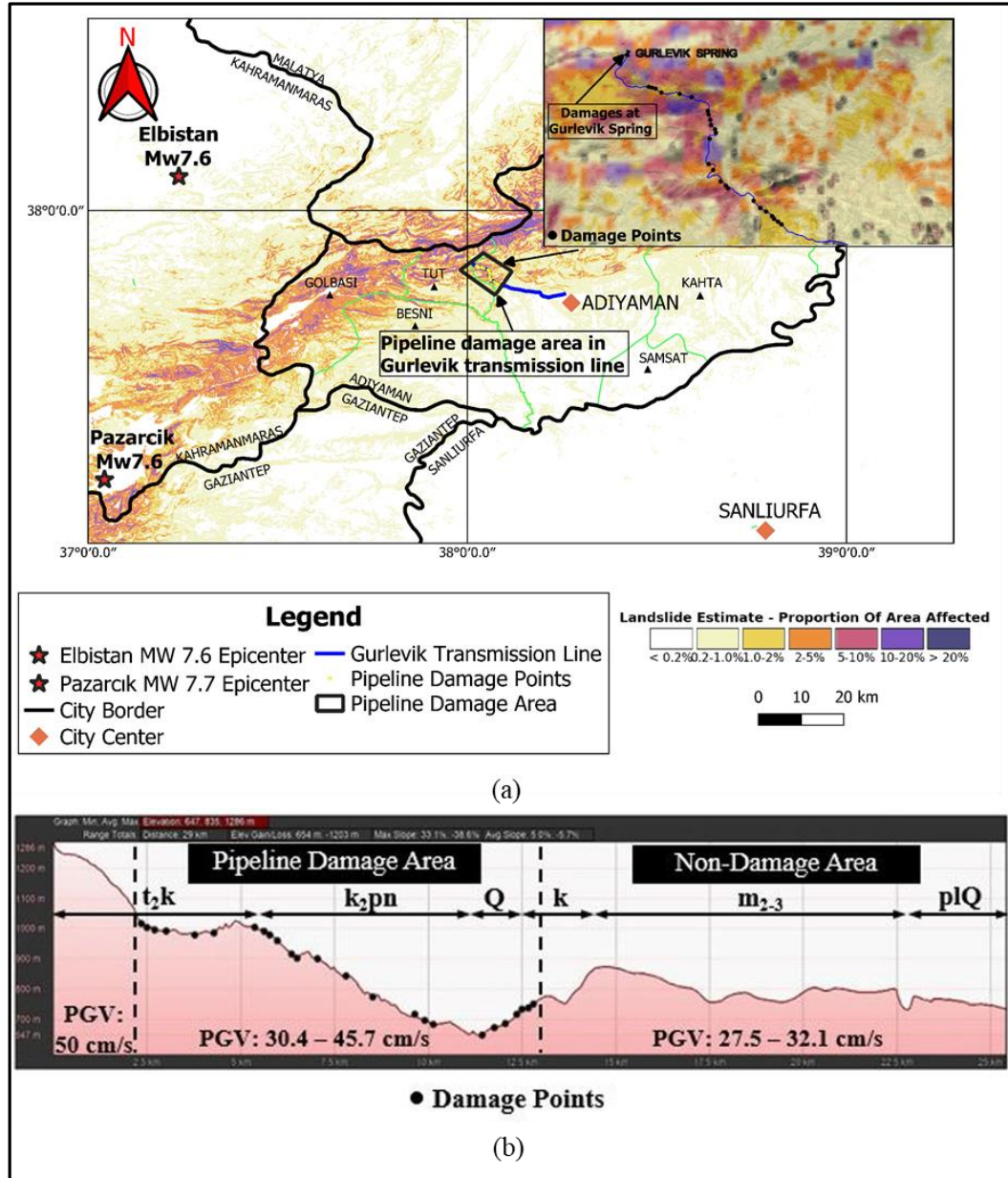


Figure 7.3: Details of the terrain where Gürlevik 2 transmission line passes.

The precision of this data may fluctuate, with typical errors ranging between 10 to 30 m, depending on factors like data resolution and its sources, such as the Shuttle Radar Topography Mission (SRTM) [Toprak et al., 2024a]. The figure also illustrates the variation in peak ground velocity (PGV) values along the pipeline route. In the heavily damaged sections of the pipeline, PGV values range from 30.4 to 45.7 cm/s, whereas in undamaged sections, the values are between 27.5 and 32.1 cm/s. Additionally, at the source point of the pipeline, the PGV value is approximately 50 cm/s. These PGV values were derived from the study by Toprak et al. [2024d].

Table 7.4 shows elevations and the slopes of the field surface which are perpendicular and longitudinal inclinations with respect to the pipe axis. Slope degree values were calculated via Google Earth™. The slope in the direction parallel to the axis of the pipe is expressed by determining the slope at the exact point of damage, whereas the slopes perpendicular to the pipe direction are defined as the average of the slopes measured at the pipe's exact location, as well as 100 meters to the right and 100 meters to the left of the pipe's location.

Table 7.4: Topographic information of damage points along the Gürlevik 2 line.

Damage Point	Altitude (m)	Average Slope (//) ¹	Average Slope (⊥) ²	Slope Range (⊥) ²
1	1016	4.1	1.8	0-3
2	1009	1.0	2.3	2-6
3	1000	8.9	3.4	2-6
4	995	1.8	8.8	7-10
5	986	2.1	8.4	8-9
6	992	6.4	13.8	12-15
7	1005	6.4	12.8	10-14
8	1004	7.6	12.5	10-15
9	983	3.9	13.7	13-17
10	966	5.9	15.2	13-18
11	934	4.1	13.0	11-15
12	922	8.6	15.5	13-17
13	904	6.7	18.7	16-20
14	837	4.2	11.5	10-13
15	782	5.5	18.0	16-19
16	724	9.0	12.5	11-15
17	700	2.3	18.7	16-19
18	693	5.2	15.7	15-18
19	648	4.2	9.4	7-11
20	673	2.3	9.6	8-11
21	684	4.3	8.9	5-12
22	706	7.7	5.9	4-6
23	727	4.8	6.5	3-9
24	737	0.9	8.9	8-10
25	746	6.8	4.5	3-5

1: In parallel direction to the line 2: In perpendicular direction to the line

Table 7.5 gives the RR calculation for Gürlevik 2 lines along slope intervals with 0-20 degree. The intervals represent the slope degrees to perpendicular direction to the line. The confidence interval was determined as 65%.

Table 7.5: RR calculations for damage points along the Gürlevik 2 line with respect to slope intervals.

Slope Interval (°)	Average Slope (°)	Length (km)	Repair #	RR	Confidence Interval (%)
0-5	2.5	14.5	4	0.28	65
5-10	7.5	6.08	7	1.15	
10-15	12.5	4.92	8	1.63	
15-20	17.5	3.58	6	1.68	

In **Figure 7.4**, the distribution of RR data along the Gürlevik 2 pipeline is presented based on slope degree intervals. In the figure, slope intervals are divided into 5-degree increments within the range of 0 to 20 degrees.

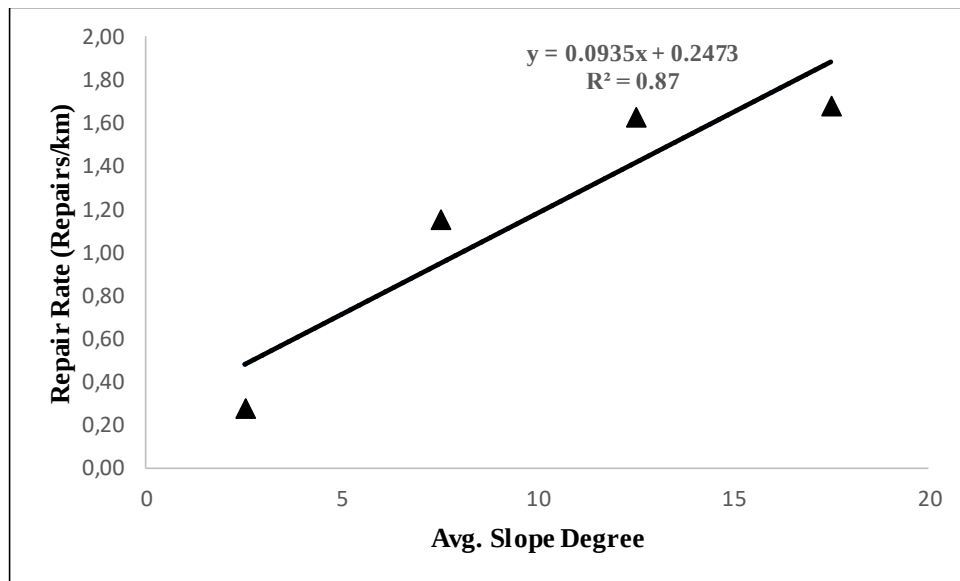


Figure 7.4: The correlation of RR and slope degree for Gürlevik 2 line.

8. CONCLUSIONS

Major earthquakes not only damage superstructure systems but also disrupt infrastructure systems, making the lifelines of a city nonfunctional and creating the groundwork for long-term problems that may persist for years. Evaluating the current resilience of infrastructure systems that are likely to be exposed to earthquake impacts and analyzing their behavior under both existing and potential future earthquakes are crucial for estimating potential problems that may arise in the future.

The city center of Adıyaman is among the most severely affected areas in terms of both superstructure and infrastructure following the Kahramanmaraş earthquakes on February 6. While thousands of buildings were destroyed, infrastructure systems such as potable water, sewage, natural gas and telecommunications experienced significant disruptions in the aftermath of the earthquake.

Significant damage occurred in the Gürlevik 1 and 2 transmission lines, which supply water to the city center. Rock falls resulted in damages to some points of the water supply system in Adıyaman. The fact that these transmission pipelines traverse steep mountains in a region with a high landslide risk has made them affected from permanent ground deformations caused by earthquake-induced landslides.

In contrast to the Gürlevik transmission lines, the primary cause of damage to the Havşeri transmission line was faulting effects. Fault-induced permanent ground deformations in the region, coupled with the impact of soil amplification, resulted in buckling and ruptures along the first kilometers of the pipeline. While some of these damages were identified immediately after the earthquake, others were discovered during systematic damage assessment efforts conducted over time.

The other transmission lines supplying water to the city, namely the Tut-Medetsiz and Koru-Palanlı pipelines, also sustained varying degrees of damage. However, due to the unavailability of detailed data for these two pipelines within the scope of the study, an assessment of the extent of damage could not be conducted. It would seem that, the impact of these damages on the water supply system was relatively limited compared to the Gürlevik and Havşeri pipelines, due to the lower water demand they serve and the smaller number of damages.

Within the scope of the study, damage relationships were sought to be established for 25 instances of damage occurring along the Gürlevik 2 pipeline. Although the obtained RR data were analyzed in relation to PGV values, it was determined that the resulting relationship did not fully align with the literature. Furthermore, a detailed examination of RR values across different PGV intervals revealed that the damage in this region clustered within specific PGV ranges. This finding suggests that in areas where permanent ground deformations are significant, such deformations play a more dominant role in damage formation compared to the impact of PGV.

Another relationship explored within the scope of the study involved correlating RR values with slope values. The analysis revealed a logical association between terrain slope values and pipeline damage. Along the Gürlevik 2 pipeline, it was observed that pipeline damage, clustered at various locations, occurred more frequently in regions with steep slopes. The established relationship ($R^2 = 0.87$) indicates that pipelines traversing steeply sloped areas and diverse geological units are likely to be significantly affected by permanent ground deformations induced by seismic activity.

To synthesize the findings of the study, it is undeniable that the resilience of infrastructure systems in the aftermath of disasters holds critical importance for effective disaster management. Water supply systems are vital for urban areas and the sustainability of their operation necessitates comprehensive seismic risk analyses. As demonstrated in the case of Adıyaman city center, having access to multiple water sources and delivering water to the urban center through diversified options provides a significant advantage for cities.

The damages observed in Adıyaman were found to arise from various mechanisms. Permanent ground deformations, such as landslides and faulting, were identified as major contributors to the damage. Furthermore, the use of outdated and degraded materials, such as AC pipes and steel pipes that have been in service for over 50 years, as seen in the Gürlevik 1 pipeline, is believed to have exacerbated the extent of damage.

In light of all this information, it can be stated that water supply systems, which fulfill some of humanity's most essential needs, must be thoroughly analyzed starting from the time of the construction of the pipelines. The risks inherent within these systems should be carefully considered, and strategies necessary for the establishment of

earthquake-resilient cities must undoubtedly be applied to these systems as well. Informed by scientific knowledge, the appropriate measures must be taken.

REFERENCES

- Adıyaman Municipality (2023) “Adıyaman (Merkez) Belediyesi Yaklaşık 6000 Ha Alanın İmar Planına Esas Mikrobölgeleme Etüt Raporu”, Adıyaman, Türkiye.
- Adıyaman Municipality (2024), <https://www.adiyaman.bel.tr/Baskanmz-Tutdere-Havseri-Icme-Suyu-Hattn> (Accessed: 18.12.2024).
- AFAD, (2023a), “06 Şubat 2023 Pazarcık-Elbistan Kahramanmaraş (Mw: 7.7 – Mw: 7.6) Depremleri Raporu”, Technical Report No: ARCRL-66-234, Deprem ve Risk Azaltma Genel Müdürlüğü Deprem Dairesi Başkanlığı, Türkiye.
- AFAD, (2023b). Disaster and Emergency Management Presidency (AFAD). <https://www.afad.gov.tr/genel-hayata-etkili-afet-bolgesi-hk> (Accessed: 24.11.2024).
- AFAD, (2024). Instrumental Earthquakes Catalog. <https://deprem.afad.gov.tr/event-instrumental>, (Accessed: 31.12.2024).
- Akcan, S.O., Tekin, S., Yeşilyurt, A., Zülfişkar, A.C. (2024). Evaluation of the february 6, 2023 earthquakes (Mw 7.7 and Mw 7.6) in Adıyaman by deterministic seismic hazard analysis. Proceedings of the 7th International Conference on Earthquake Engineering and Seismology. ICEES 2023. Lecture Notes in Civil Engineering, vol 488. Springer, Cham. https://doi.org/10.1007/978-3-031-57659-1_11.
- Ansal, Atilla; Kurtuluş, Aslı; and Tönük, Gökçe, Damage to water and sewage pipelines in Adapazari during 1999 Kocaeli, Turkey earthquake (2008). International Conference on Case Histories in Geotechnical Engineering. 5.
- Ayala, A.G., O’Rourke, M.J., (1989), “Effects of the 1985 Michoacan Earthquake on Water Systems and Other Buried Pipelines in Mexico”, Technical Report no. In: NCEER-89-0009. State University of New York, USA.
- Bolgi, T., (1961). “V. Petrol Bölgesi Sektisyon Ölçmeleri, Reşan-Dodan Arası Batısındaki Sahanın Srüktürel Etüdüleri”, Report no. 162, 52 s, TPAO Arama Grubu, Türkiye.
- Bolgi, T., (1964). “AR/TPI/645, 662, 663, 665 Ruhsat Nolu Adıyaman Sahalarının Jeolojik Etüdü”, Report no. 325, 19 s, TPAO Arama Grubu, Türkiye.
- Bouziou, D. (2015). “Earthquake-Induced Ground Deformation Effects on Buried Pipelines”, Phd Thesis, Cornell University.
- Chen, W. W., Shih, B. J., Chen, Y. C., Hung, J. H., & Hwang, H. H. (2002). Seismic response of natural gas and water pipelines in the Ji-Ji earthquake. *Soil Dynamics and Earthquake Engineering*, 22(9-12), 1209-1214.
- Ceylan M., (2020), “İçme Suyu Boru Hasarlarının Detaylı İncelenmesi: Christchurch Depremi Örneği”, Master Thesis, Pamukkale University.

Chung, R. (1996), “The January 17, 1995 Hyogoken-Nanbu (Kobe) Earthquake: Performance of Structures, Lifelines, and Fire Protection Systems” (Vol. 18). US Department of Commerce, Technology Administration, National Institute of Standards and Technology.

Darvishi, R., Lashgari, A., & Jafarian, Y. (2024). Predictive models for assessment of buried pipeline response under seismic landslides in Iran. *Transportation Geotechnics*, 45, 101208.

Davis, C. A. (2014). Water system service categories, post-earthquake interaction, and restoration strategies. *Earthquake Spectra*, 30(4), 1487-1509.

Duman, T. Y., & Emre, Ö. (2013). The East Anatolian Fault: geometry, segmentation and jog characteristics. *Geological Society, London, Special Publications*, 372(1), 495-529.

Duran, O., Şemşir, D., Sezgin, İ., & Perinçek, D. (1988). Güneydoğu Anadolu’da Midyat ve Silvan gruplarının stratigrafisi, sedimantolojisi ve petrol potansiyeli. *TPJD Bülteni*, 1(2), 99-126.

Emre, Ö., Duman, T. Y., Özalp, S., Elmacı, H., Olgun, Ş., & Şaroğlu, F. (2013). Active fault map of Turkey with explanatory text. General directorate of mineral research and exploration special publication series, 30.

Emre, Ö., Duman, T. Y., Özalp, S., Şaroğlu, F., Olgun, Ş., Elmacı, H., & Çan, T. (2018). Active fault database of Turkey. *Bulletin of Earthquake Engineering*, 16(8), 3229-3275.

Erdik, M. 2001. “Structural Control for Civil and Infrastructure Engineering.” In Proc., 3rd Int. Workshop on Structural Control, edited by F. Casciati, and G. Magonette, 149–186. Singapore: World Scientific.

European Union (2024), EU Commission, The EU Facility for Refugees in Turkey. https://neighbourhood-enlargement.ec.europa.eu/enlargement-policy/turkiye/eu-support-refugees-turkiye_en (Accessed: 29.12.2024).

Gorum, T., Tanyas, H., Karabacak, F., Yilmaz, A., Girgin, S., Allstadt, K.E., Suzen, M.L., Burgi, P., 2023. Preliminary documentation of coseismic ground failure triggered by the February 6, 2023 Türkiye earthquake sequence. *Eng. Geol.* 327, 107315.

Hamada, M., Isoyama, R., & Wakamatsu, K. (1996). Liquefaction-induced ground displacement and its related damage to lifeline facilities. *Soils and foundations*, 36(Special), 81-97.

Herece, E., (2008). Atlas of the East Anatolian Fault, General Directorate of Mineral Research and Exploration (MTA), Special Publication Series, 13.

Isenberg, J., Richardson, E., Kameda, H., & Sugito, M. (1991). Pipeline response to Loma Prieta earthquake. *Journal of Structural Engineering*, 117(7), 2135-2148.

- Işık, E., Avcil, F., Arkan, E., Büyüksaraç, A., İzol, R., & Topalan, M. (2023). Structural damage evaluation of mosques and minarets in Adıyaman due to the 06 February 2023 Kahramanmaraş earthquakes. *Engineering Failure Analysis*, 151, 107345.
- İlker, S., (1972). “VI. Bölge Adıyaman Kuzey ve Kuzeydoğusundaki Sahalar Hakkında Jeolojik Rapor”, Report no. 981, 27 s, TPAO Arama Grubu, Türkiye.
- Kameda, H. (2000). Engineering management of lifeline systems under earthquake risk. *Bulletin of the New Zealand Society for Earthquake Engineering*, 33(3), 248-264.
- Katayama, T., Kubo, K., & Sato, N. (1975). Earthquake damage to water and gas distribution systems. *National Conference on Earthquake Engineering*, EERI, Oakland, CA.
- Kaya, E. S., Uckan, E., O'Rourke, M. J., Karamanos, S. A., Akbas, B., Cakir, F., & Cheng, Y. (2017). Failure analysis of a welded steel pipe at Kullar fault crossing. *Engineering Failure Analysis*, 71, 43-62.
- Khalifa, A., Bashir, B., Çakir, Z., Kaya, Ş., Alsalman, A., & Henaish, A. (2021). Paradigm of geological mapping of the adıyaman fault zone of eastern turkey using landsat 8 remotely sensed data coupled with pca, ica, and mnfa techniques. *ISPRS International Journal of Geo-Information*, 10(6), 368.
- Komac, M., (2006). A landslide susceptibility model using the analytical hierarchy process method and multivariate statistics in perialpine Slovenia. *Geomorphology* 74 (1–4), 17–28.
- Köylüoğlu, M., (1986). Güneydoğu Anadolu otokton birimlerin kronostratigrafi, mikrofasiyes ve mikrofosilleri. (Chronostratigraphy, microfacies and microfossils of the autochthonous units of the SE Anatolia). Turkish Petroleum Corporation, Research Center Educational Publication 9, pp. 1–53.
- Liu, W., & Cui, W. (2025). Fatigue performance and failure mechanism of ductile iron pipes with socket joints under traffic loads. *Engineering Failure Analysis*, 167, 109004.
- Lyberis, N., Yurur, T., Chorowicz, J., Kasapoglu, E., & Gundogdu, N. (1992). The East Anatolian Fault: an oblique collisional belt. *Tectonophysics*, 204(1-2), 1-15.
- Maxson, J. H. (1936). Geology and petroleum possibilitied of the Hermis Dome. *MTA Compilation*, 255, 25.
- Milashuk, S., & Crane, W. (2012). Pipeline damage caused by transient ground deformation: Case study of 2010 Darfield and 2011 Christchurch earthquakes. *Soil Dynamics and Earthquake Engineering*, 41, 84-88.
- Moyroud, N., & Portet, F. (2018). Introduction to QGIS. *QGIS and generic tools*, 1, 1-17.

MTA, (2002). 1:500.000 Scale Geological Maps of Turkey, No:16 Hatay Map Section. <https://www.mta.gov.tr/en/maps/list> (Accessed 10.01.2024).

Mülayim, O., Köroğlu, F., & Alkaç, O. (2024). Industrial geotourism and geoeducation potential of SE Türkiye: a case study of the petroleum industry in the Adıyaman region. *Geoheritage*, 16(1), 26.

Nacaroğlu, E. (2017). “Sismik Etkiler Altındaki Gömülü Boru Hatlarında Hasar Analizleri”, Phd Thesis, Pamukkale University.

Nair, G. S., Dash, S. R., & Mondal, G. (2018). Review of pipeline performance during earthquakes since 1906. *Journal of Performance of Constructed Facilities*, 32(6), 04018083.

Nowicki Jessee, M. A., Hamburger, M. W., Allstadt, K., Wald, D. J., Robeson, S. M., Tanyas, H., & Thompson, E. M. (2018). A global empirical model for near-real-time assessment of seismically induced landslides. *Journal of Geophysical Research: Earth Surface*, 123(8), 1835-1859.

O'Rourke, T. D. (1998). An overview of geotechnical and lifeline earthquake engineering. In *Geotechnical earthquake engineering and soil dynamics III* (pp. 1392-1426). ASCE.

O'Rourke, T. D., Jeon, S. S., Toprak, S., Cubrinovski, M., Hughes, M., van Ballegooy, S., & Bouziou, D. (2014). Earthquake response of underground pipeline networks in Christchurch, NZ. *Earthquake Spectra*, 30(1), 183-204.

O'Rourke T.D., Jeon S.S., Toprak S., Cubrinovski M., Jung J.K., 2012. Underground lifeline system performance during the Canterbury earthquake sequence, In *Proceedings of the 15th world conference on earthquake engineering*, Lisbon, Portugal Vol. 24.

O'Rourke, T. D., & Toprak, S. (1997). GIS assessment of water supply damage from the Northridge earthquake. In *post-earthquake reconstruction strategies: NCEER-INCEDE center-to-center project* (pp. 109-22).

O'Rourke, T. D., Toprak, S., & Sano, Y. (1998). Factors affecting water supply damage caused by the Northridge earthquake. In *US-Japan workshop on earthquake disaster prevention for lifeline systems* (p. 57).

Perinçek, D. (1978). “V-VI-IX Bölge Güneydoğu Anadolu Otokton-Allokton Birimler Jeoloji Sembolleri”, Report no. 6657, TPAO Arama Grubu, Türkiye.

Pineda-Porras, O., & Ordaz, M. (2007). A new seismic intensity parameter to estimate damage in buried pipelines due to seismic wave propagation. *Journal of Earthquake Engineering*, 11(5), 773-786.

Pitilakis, K., Alexoudi, M., Argyroudis, S., Monge, O., & Martin, C. (2006). Earthquake risk assessment of lifelines. *Bulletin of Earthquake Engineering*, 4, 365-390.

Presidency Strategy and Budget Office (SBO) (2023). “2023 Kahramanmaraş and Hatay Earthquakes Report”, Türkiye Cumhuriyeti Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, Türkiye.

Presidency Strategy and Budget Office (SBO) (2024). “Kahramanmaraş ve Hatay Depremleri Yeniden İmar ve Gelişme Raporu”, Türkiye Cumhuriyeti Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, Türkiye.

Reitman, N. G., R. W. Briggs, W. D. Barnhart, A. E. Hatem, J. A. Thompson Jobe, C. B. DuRoss, R. D. Gold, J. D. Mejstrik, C. Collett, R. D. Koehler, and S. Akçiz (2023). Rapid Surface Rupture Mapping from Satellite Data: The 2023 Kahramanmaraş, Turkey (Türkiye), Earthquake Sequence, The Seismic Record. 3(4), 289–298, doi: 10.1785/ 0320230029.

Shih, B. J., & Chang, C. H. (2006). Damage survey of water supply systems and fragility curve of PVC water pipelines in the Chi–Chi Taiwan earthquake. Natural Hazards, 37, 71-85.

Sungurlu, O., (1974). “VI. Bölge Kuzey Sahalarının Jeolojisi”, Report no. 871. 32 s, TPAO Arama Grubu, Türkiye.

Şentürk, S., Çakır, Z., Ergintav, S., & Karabulut, H. (2019). Reactivation of the Adıyaman Fault (Turkey) through the Mw 5.7 2007 Sivrice earthquake: An oblique listric normal faulting within the Arabian-Anatolian plate boundary observed by InSAR. Journal of Geodynamics, 131, 101654.

Taşgın, C. K., Orhan, H., Türkmen, İ., & Aksoy, E. (2011). Soft-sediment deformation structures in the late Miocene Şelmo Formation around Adıyaman area, Southeastern Turkey. Sedimentary Geology, 235(3-4), 277-291.

Tekin, S., & Akcan, S. O. (2023). 6 Şubat 2023 Tarihinde (Mw 7.7. ve Mw 7.6) Gerçekleşen Depremler ile İlgili Değerlendirmeler ve İlk Analiz Sonuçları. <https://uzalcbs.adiyaman.edu.tr/files/uzalcbs.adiyaman.edu.tr/tr/slaytlar/0001/01/6-subat-2023-depremlerine-ait-bilgi-notu/rapor.pdf> (Accessed: 13.12.2024).

Toprak, S., (1998), “*Earthquake Effects on Buried Lifeline Systems*”, Phd Thesis, Cornell University.

Toprak, S., Nacaroglu, E., Ceylan, M., Dundar, G., & Cirmiktili, O. Y. (2020, March). Pipe type and seismic performance in Christchurch, New Zealand. In IOP Conference Series: Materials Science and Engineering (Vol. 800, No. 1, p. 012042). IOP Publishing.

Toprak, S., Nacaroglu, E., & Koç, A. C. (2011). Seismic damage probabilities for segmented buried pipelines. *Applications of statistics and probability in civil engineering*, 2-4.

Toprak, S., Nacaroglu, E., & Koç, A. C. (2015). Seismic response of underground lifeline systems. *Perspectives on European Earthquake Engineering and Seismology: Volume 2*, 245-263.

Toprak, S., Nacaroglu, E., van Ballegooy, S., Koc, A. C., Jacka, M., Manav, Y., Torvelainen, E., O'Rourke, T.D. (2019). Segmented pipeline damage predictions using liquefaction vulnerability parameters. *Soil Dynamics and Earthquake Engineering*, 125, 105758.

Toprak, S., & Taşkın, F. (2007). Estimation of earthquake damage to buried pipelines caused by ground shaking. *Natural hazards*, 40, 1-24.

Toprak, S., Taskin, F., & Koc, A. C. (2009). Prediction of earthquake damage to urban water distribution systems: a case study for Denizli, Turkey. *Bulletin of engineering geology and the environment*, 68, 499-510.

Toprak, S., Wham, B. P., Nacaroglu, E., Ceylan, M., & Dal, O. (2024c). Performance of water systems during the February 6th Kahramanmaras earthquakes. *Earthquake Spectra*, 87552930241293571.

Toprak, S., Wham, B. P., Nacaroglu, E., Ceylan, M., Dal, O., & Senturk, A. E. (2024a). Impact of seismic geohazards on water supply systems and pipeline performance: Insights from the 2023 Kahramanmaras earthquakes. *Engineering Geology*, 340, 107681.

Toprak S., Wham, B., Nacaroglu, E., Ceylan, M., Dal, O., & Senturk, A.E. (2024b). The effects of February 6, 2023 Kahramanmaras earthquakes on pipelines. 18th World Conference on Earthquake Engineering. Milan, Italy.

Toprak, S., & Yoshizaki, K. (2003). Boru hatlarına deprem yüklerinin etkisi. *Ulusal Deprem Mühendisliği Kongresi*, 26-30.

Toprak, S., Zulfikar, C., Mutlu, A., Tugsal, U.M., Nacaroglu, E., Karabulut, S., Ceylan, M., Ozdemir, K., Parlak, S., Dal, O., Karimzadeh, S., (2024d). The aftermath of 2023 Kahramanmaras earthquakes: evaluation of strong motion data, geotechnical, building, and infrastructure issues. *Natural Hazards*, 1-38.

Tuna, D. (1973). “VI. Bölge Litostratigrafi Birimleri Adlarnasının Açıklayıcı Raporu”, Report no. 813, 131 s, TPAO Arama Grubu, Türkiye.

TÜİK, (2023). Data Portal for Statistics, Population and Demography. <https://data.tuik.gov.tr/Kategori/GetKategori?p=Nufus-ve-Demografi-109> (Accessed: 21.11.2024).

Türkmen, İ., Aksoy, E., Orhan, H., Nazik, A., Koç Taşkın, C., 2010. Şelmo Formasyonu'nun Adýyaman dolayındaki yüzeylemelerinin sedimantolojik özellikleri ve yöresel tektonikle ilişkisi. TUBITAK Project No: 107Y291. 125 s, Ankara.

U.S. Geological Survey, (2023). The 2023 Kahramanmaras,, Turkey, Earthquake Sequence. <https://earthquake.usgs.gov/storymap/index-turkey2023.html>, (Accessed: 24.11.2024).

Wham, B. P., Dashti, S., Franke, K., Kayen, R., & Oettle, N. K. (2017). Water supply damage caused by the 2016 Kumamoto Earthquake. *Lowland Technology International*, 19(3), 151-160.

BIOGRAPHY

Adem Eren ŞENTÜRK graduated from Beşiktaş Anatolian High School in 2012 and completed his undergraduate studies at Yıldız Technical University in 2018, which he began in 2013. In 2022, he commenced his master's education in the Department of Civil Engineering at Gebze Technical University. Since 2019, Adem Eren ŞENTÜRK has been working as a research assistant at Maltepe University.

PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

Toprak, S., Wham, B. P., Nacaroglu, E., Ceylan, M., Dal, O., & Senturk, A. E. (2024). Impact of seismic geohazards on water supply systems and pipeline performance: Insights from the 2023 Kahramanmaras earthquakes. *Engineering Geology*, 340, 107681.

Toprak S., Wham, B., Nacaroglu, E., Ceylan, M., Dal, O., & Senturk, A.E. (2024). The effects of February 6, 2023 Kahramanmaras earthquakes on pipelines. 18th World Conference on Earthquake Engineering. Milan, Italy.