Research Paper

Scenario-Based Evaluation of Earthquake Impacts on Gas Infrastructure in Tehran

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ABSTRACT

Tehran, the capital of Iran, lies in a highly active seismic zone and is exposed to significant earthquake risk due to multiple nearby faults. Among critical urban infrastructure, the gas distribution network is especially vulnerable to earthquakes, but it has not been thoroughly studied in most current risk assessments. This study proposes a probabilistic framework to evaluate the seismic vulnerability of Tehran's gas distribution network under four major earthquake scenarios (Mosha, North Tehran Fault, Eyvanakey, and Rey faults). The methodology incorporates both aleatory and epistemic uncertainties from hazard and damage assessments of buried pipelines and pressure reduction stations. The intra-event variability of ground motion values is considered in the analysis through random sampling from spatial-cross correlation model. Similarly, the aleatory uncertainty of damage types (leak and break) in pipelines is captured in the analysis through random sampling from a probabilistic distribution. Results from 1,000 Monte Carlo simulations reveal that the Eyvanakey scenario poses the highest risk, particularly in south-eastern Tehran, while the Rey scenario results in minimum damage. The spatial distribution of risk underscores the importance of localized mitigation strategies. The proposed framework provides an appropriate tool for urban seismic risk assessment and resilience planning of gas utility systems in seismically active cities.

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1. Introduction

Tehran, the capital of Iran, plays an important role in the country's political, economic, and administrative systems. As the most populous city in Iran, with over 8 million residents in the urban area and more than 15 million in the metropolitan region, Tehran serves as the primary hub for governance, commerce, education, and industry (SCI, 2016). This centrality makes the city a critical lifeline not only for its inhabitants but also for the functioning of the country as a whole. Thus, a major earthquake in this area would not only pose a severe threat to human life and urban infrastructure, but would also disrupt essential national operations, potentially resulting in cascading consequences at regional and national levels.

Tehran, located in a highly active seismic region, faces substantial earthquake hazards due to the presence of numerous nearby active faults. Historical records and scientific assessments consistently highlight the city's vulnerability to large-magnitude earthquakes, which pose serious threats to urban safety and resilience (Berberian & Yeats, 1999; 2017). As illustrated in Figure (1), four major seismogenic sources surround Tehran: (1) the Mosha Fault, with its eastern, central, and western segments-the central segment being the closest to the city center; (2) the eastern segment of the North Tehran Fault, intersecting the city's northern boundary; (3) the Eyvanakey Fault, situated southeast of Tehran; and (4) the northern and southern segments of the Rey Fault, located in the south. These fault systems define the primary seismic scenarios threatening the Tehran metropolitan area (Ashtari et al., 2005).

Numerous studies have evaluated the seismic hazard associated with the aforementioned fault scenarios, focusing on potential ground motion values. For example, Alikhanzade and Zafarani (2023), and Zafarani et al. (2009, 2012) applied physics-based simulations to estimate ground shaking. These studies highlight the significant threat posed by the potential rupture of these seismically active sources in Tehran.

Despite numerous studies aimed at estimating potential casualties and damages resulting from earthquakes in Tehran (Firuzi et al., 2019; Kheirkhah et al., 2021; Kalantari et al., 2023; Firuzi et al., 2024), relatively limited attention has been paid to the seismic vulnerability of infrastructures such as the gas distribution network. Damage to this critical infrastructure can disrupt gas supply for both residential and industrial sectors, leading to widespread socioeconomic consequences. Therefore, enhancing the resilience of the gas network against earthquakes is vital for minimizing disruptions and ensuring community recovery. A comprehensive seismic risk assessment that incorporates all relevant uncertainties is a necessary first step toward this goal.

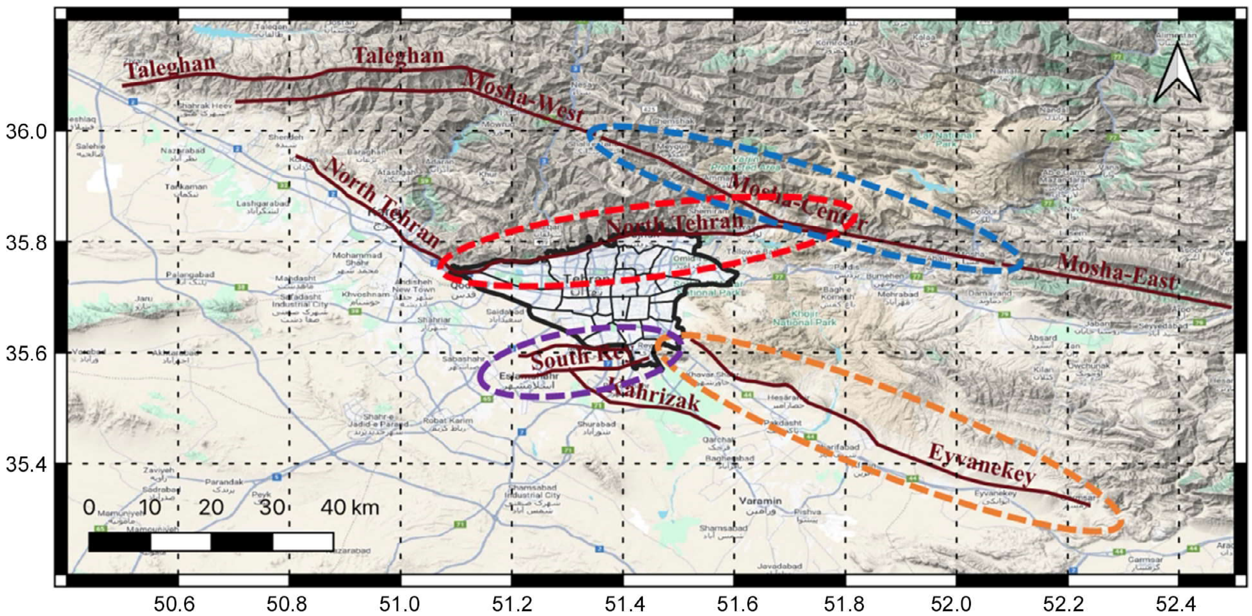


Figure 1. Major active faults around Tehran, Iran.

One of the earliest efforts in this regard was made by JICA (2000), which aimed to develop a seismic risk map for Tehran. This study assesses the vulnerability of the gas distribution network for three seismic scenarios: Rey, North Tehran, and Mosha faults. The results indicated that the Rey seismic scenario posed the highest risk, particularly to southern Tehran, while the Mosha fault was not expected to cause significant damage to gas distribution network. More recently, Baratian and Kashani (2022) proposed a probabilistic method to estimate the recovery time of gas networks by incorporating system uncertainties through random sampling. More recently, Ghafoori et al. (2020) assessed the seismic vulnerability of Qom's water distribution network, providing insights that could be applied to other infrastructure. Other relevant studies-such as those by Farahani et al. (2020) and Mousavi et al. (2014)-also addressed the seismic vulnerability of gas network, though they focused on other regions of Iran rather than Tehran. Also, certain types of uncertainties, such as intra-event variability, have been overlooked in previous studies. Therefore, the aim of this study is to develop a practical approach that incorporates such uncertainties into the seismic risk assessment of Tehran's gas distribution network.

The urban gas distribution network consists of two main components: buried pipelines and pressure reduction stations. Buried pipelines are susceptible to both strong ground shaking (SGS) and permanent ground Failure (GF), such as those induced by fault rupture, liquefaction, or landslides. These hazards can lead to failures such as leakage or rupture along the pipeline. Pressure reduction stations, as above-ground facilities, are also vulnerable to seismic excitations and may experience different levels of damage depending on the intensity and characteristics of ground motion (Gehl et al., 2014).

A comprehensive seismic risk assessment must account for key sources of variabilities: (1) epistemic and (2) aleatory uncertainties. Epistemic uncertainty, stemming from limited knowledge or data, is typically represented using a logic tree framework. In contrast, aleatory variability, arising from the inherent randomness of natural processes, is incorporated through random sampling from probability distributions of uncertain parameters. For example, the intra-event variability of Ground Motion Prediction Equations (GMPEs) in hazard evaluations is captured using random sampling based on a spatial correlation model (Crowley & Bommer, 2006; Silva, 2017). Similarly, factors such as failure type (e.g., leakage or complete rupture) and the inherent variability of fragility curves are addressed through random sampling from suitable probability distributions (Eskandari et al., 2017).

The primary objective of this study is to evaluate the seismic vulnerability of Tehran's gas distribution network in four defined seismic scenarios, incorporating the key sources of epistemic and aleatory uncertainty. To this end, the paper is organized as follows: first, the theoretical foundations of the proposed methodology for uncertainty modeling are outlined; subsequently, this methodology is applied to the predefined seismic scenarios to estimate potential damage; and finally, the comprehensive discussion about the results are provided.

2. Conceptual Framework and Methodology

The process of seismic risk assessment consists of three fundamental components: 1) hazard assessment, 2) development of an exposure model (element at risk), and 3) applying appropriate fragility. By integrating these components, the expected level of damage within a region can be derived in term of parameters such as economic losses, structural damage, and casualties.

Furthermore, the overall performance of an infrastructure network such as a gas utility system can be evaluated using connectivity analysis (Esposito & Iervolino, 2014). Figure (2) illustrates the general framework for integrating these components to assess the seismic risk of a gas distribution network.

In the first module, ground motion values for a specific seismic scenario are estimated using GMPEs. A key feature of this module is the explicit consideration of uncertainties. Epistemic uncertainty in GMPEs is addressed through a logic tree, while aleatory uncertainty is incorporated by random sampling of intra-event variability from spatial correlation. This is particularly important for

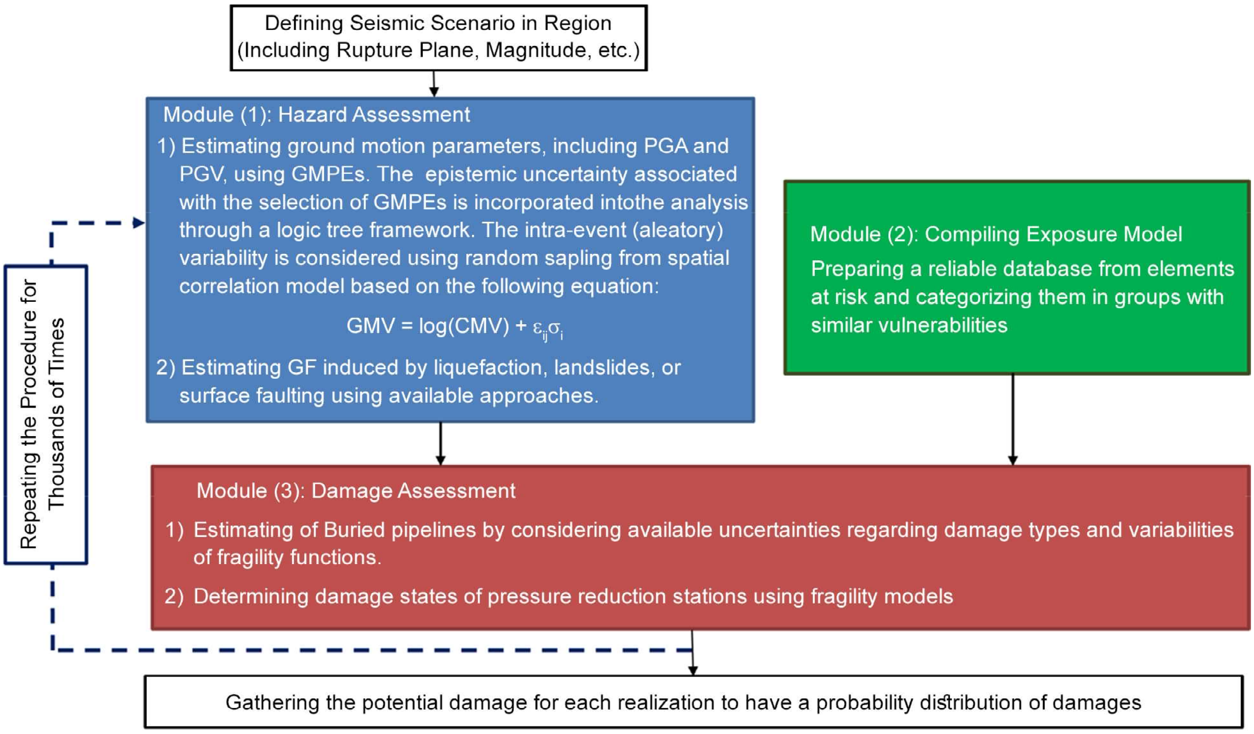


Figure 2. General framework of assessing the vulnerability of gas distribution network.

geographically distributed systems, such as gas distribution networks, where intensity measure values across different parts of the network are not independent. Ignoring this spatial correlation can result in unrealistic damage distributions and may lead to an underestimation of overall vulnerability, especially in seismic scenarios with long return periods or large-magnitude events.

De Risi et al. (2018) assessed the impact of a spatial cross-correlation model on the seismic risk assessment of gas distribution networks. Their findings demonstrated that neglecting spatial correlation leads to an underestimation of potential losses.

The second module focuses on developing a reliable exposure model, comprising the elements at risk. In the context of a gas distribution system, the network consists of two primary types of components based on geometry: point-like elements, such as pressure reduction stations, and edge-like elements, including underground pipelines. This study evaluates the seismic vulnerability of medium-pressure pipelines (260 psi) and reduction stations.

The third module focuses on damage assessment, where the physical response of gas network components, such as buried pipelines and pressure reduction stations, is evaluated under the estimated ground motions. Typically, damage states of buried pipelines are expressed in terms of leakage and breakage. These damage types may occur by both SGS and GF. Generally, pipelines subjected to SGS are assumed to experience 80% leakage and 20% breaks, while those impacted by GF are assumed to sustain 20% leakage and 80% breaks. However, more recent empirical data presented by Eidinger (2020) suggest alternative distributions: for SGS, 90% leakage and 10% breakage; for GF, a distribution of 50% leakage and 50% breakage. In the present study, the value provided by Eidinger (2020) is used.

To account for this uncertainty, random sampling from a uniform distribution is applied. If the random number is less than 0.1, the pipeline is assumed to experience a break under SGS. Similarly, if the random number is less than 0.5, the pipeline is assumed to break under GF. Additionally, the inherent variability in fragility curves is incorporated by adding a random number from a lognormal distribution. This approach enables the inclusion of aleatory uncertainty in fragility analysis, as demonstrated by the following expressions:

$$RR_{repair_{PGV}} = \exp(\log\left(\overline{RR_{repair_{PGV}}} + N\left(0,1.15\right)\right)) \quad (1)$$

$$RR_{repair_{PGD}} = \exp(\log\left(\overline{RR_{repair_{PGD}}} + N\left(0, 0.74\right)\right)) \qquad (2)$$

where $\overline{RR_{repair_{PGV}}}$ and $\overline{RR_{repair_{PGD}}}$ are the median values of the repair rate given by the fragility curve due to transient ground motion and ground failure, respectively. *N* denotes a normal distribution with a mean and standard deviation.

It should be noted that, for assessing the vulnerability of pressure reduction stations, a fragility function with four damage states-slight, moderate, extensive, and complete-is employed. Similar to the pipeline damage assessment, a random sampling from a uniform distribution is used to determine the damage state. In this procedure, the probability thresholds associated with different damage levels are utilized to assign a specific damage state based on the sampled value.

The integration of these modules, combined with the repetition of the analysis over thousands of times, enables a probabilistic estimation of the expected damage to the gas distribution network under various seismic scenarios. This stochastic approach accounts for key sources of epistemic and aleatory uncertainty, leading to a more realistic and comprehensive understanding of potential seismic impacts.

3. Application of the Method for Tehran

This section outlines the application of the proposed framework to assess the seismic vulnerability of Tehran's gas distribution network under four distinct seismic scenarios. Table (1) provides a summary of the main characteristics of predefined seismic scenarios, including parameters such as earthquake magnitude, rupture length, dip, rake, strike and upper and lower seismic depth. It should be noted that a range of possible magnitudes is considered for each scenario. A random magnitude is chosen from the defined range in Table (1), and this analysis is repeated 1,000 times to account for the uncertainty in the scenario magnitude in the calculations. The analysis is conducted using the scenario-based module of OpenQuake, an appropriate tool to incorporate various uncertainties and variabilities in seismic hazard analysis. OpenQuake allows for detailed modeling of potential seismic events and their impact on infrastructure, making it an ideal choice for evaluating the vulnerability of complex systems like gas distribution networks (Pagani et al., 2014).

To estimate ground motion parameters, including PGA and PGV, which are important seismic intensity of fragility curves, GMPEs were employed. In the present study, four GMPEs of Zhao et al. (2006), Boore et al. (2014), Kale et al. (2015), and Kotha et al. (2016) were adopted. These relations show good performance in statistical tests conducted by Firuzi et al. (2022). To capture the aleatory uncertainty inherent in the GMPEs, random sampling was conducted from the intra-event variability. Specifically, this variability was addressed through the application of spatial correlation models, such as those developed by Zafarani et al. (2020, 2022, 2025), which are developed to the specific seismic characteristics of Iran. However, despite the strength of these localized models, the present study utilizes the model developed by Weatherill et al. (2014), which is embedded in the OpenQuake software.

Local site conditions were incorporated using the VS30 map proposed by Abbasnejadfard et al. (2023). The corresponding amplification factor was taken into account through the site effect terms in the GMPEs. Figures (3) and (4) present a sample ground motion realization for selected seismic scenarios from 1,000 simulations. The results indicate that, in the seismic scenarios of NTF and Mosha Fault, the northern areas of Tehran are

Table 1. Main characteristics of predefined seismic scenarios

Parameters	Mosha (Central Segment)	NTF (East Segment)	Eyvanakey Fault	Rey Fault
Magnitude (Mw)	7.1~7.3	7.0~7.2	7.1~7.3	6.4~6.6
Rupture Length (km)	80	64	75	18
Dip	75	75	40	80
Depth	10	10	10	10
Strike	283	263	265	265
Upper and Lower Seismic Depth (Km)	3-20	3-20	3-20	3-20

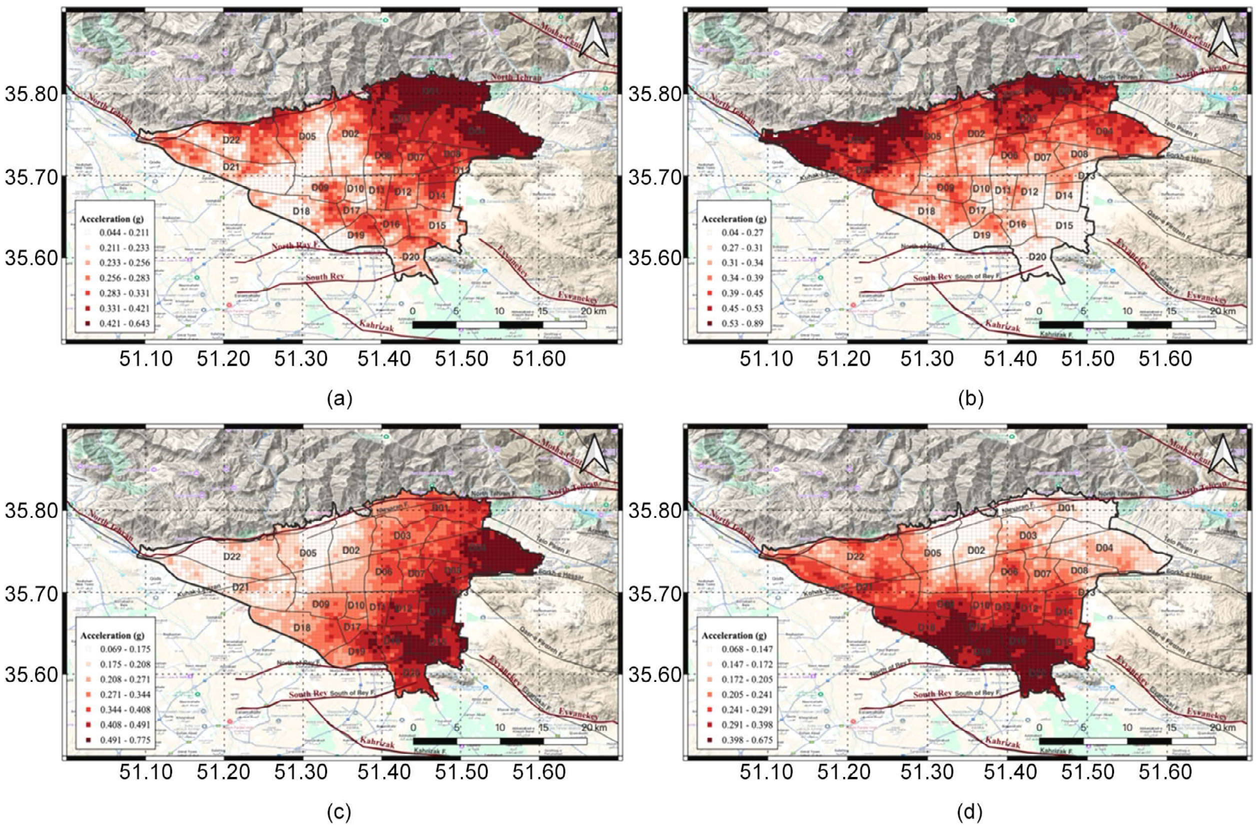


Figure 3. Distribution of PGA values for distinct seismic scenarios: (a) the rupture central segment of Mosha fault, (b) the rupture of eastern segment of NTF, (c) the rupture of Eyvanakey fault, and (d) the rupture of Rey fault.

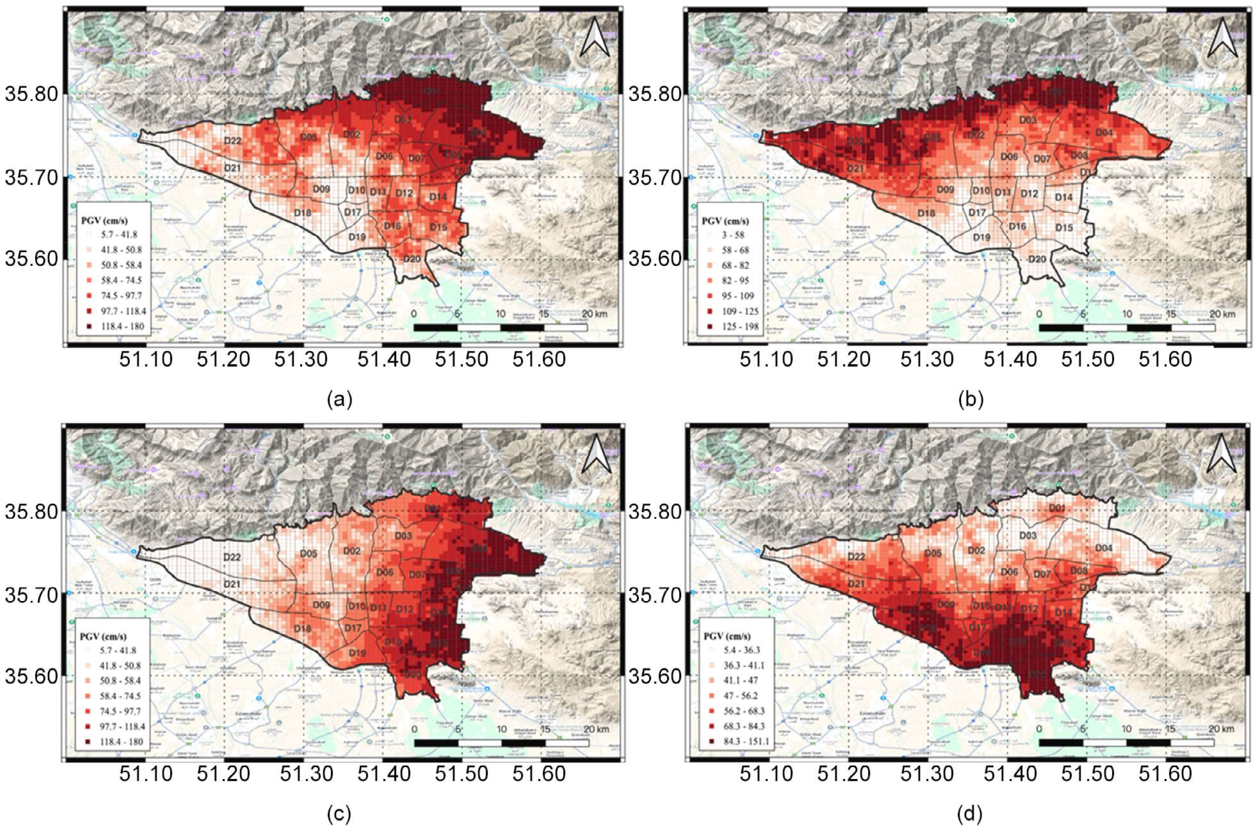


Figure 4. Distribution of PGV values for distinct seismic scenarios: (a) the rupture central segment of Mosha fault, (b) the rupture of eastern segment of NTF, (c) the rupture of Eyvanakey fault, and (d) the rupture of Rey fault.

subjected to higher ground accelerations. The maximum PGA values for these scenarios were estimated at 0.88 g and 0.64 g, respectively, reflecting a high potential for damage in these areas. Conversely, in seismic scenarios of the Rey and Eyvanakey faults, the southern parts of Tehran experience higher accelerations, with maximum PGA values of approximately 0.67 g and 0.77 g, respectively. These findings align with studies done by Zafarani et al. (2009), who assessed the potential ground motion values from the ruptures of the Mosha, Rey, and NTF faults. The ground motion values in the present study are slightly higher than those reported in Zafarani et al. (2009), which can be attributed to the inclusion of site-effects.

Landslide hazard was quantified using the widely recognized HAZUS methodology, which is known for its ability to assess landslide risk with limited input data while effectively incorporating key susceptibility factors such as geological conditions and slope gradient. This methodology is particularly advantageous in scenarios where comprehensive datasets may be unavailable, as it requires only basic geospatial information to generate meaningful results. The approach follows a systematic three-step process: 1) evaluating landslide susceptibility, 2) performing a probabilistic assessment of triggering mechanisms, and 3) estimating ground displacement resulting from landslides. Each of these steps plays a crucial role in accurately assessing the potential impact of landslides on infrastructure and human settlements.

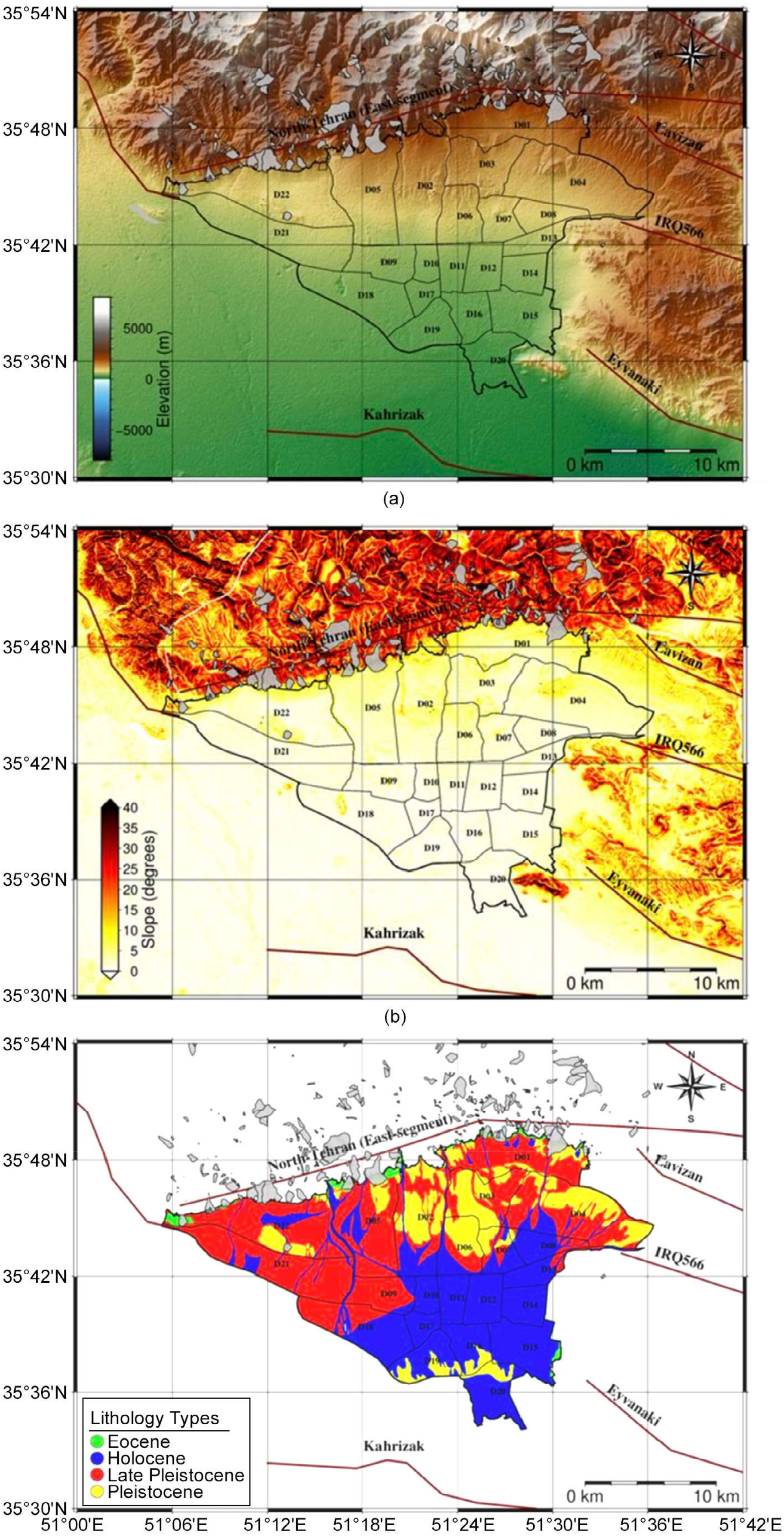
In this study, to quantify susceptibility, we utilized a 50-meter resolution Digital Elevation Model (DEM) derived from the Shuttle Radar Topography Mission (SRTM), which provided high-resolution topographic data essential for accurate slope analysis. The grdgradient function within the Generic Mapping Tools (GMT) software was employed to compute slope gradients, which is a critical factor in landslide susceptibility, as steeper slopes generally exhibit higher susceptibility to landslides. These factors (i.e., geological conditions, slope angle, and groundwater depth) were then integrated to determine critical acceleration required to trigger landslides. This acceleration value was then compared with ground motion values derived from various seismic scenarios to assess the likelihood of landslide triggering during seismic events.

Finally, permanent ground displacements resulting from landslides were estimated using the empirical model proposed by Saygili and Rathje (2008), which provides a framework for estimating displacements based on the characteristics of the triggered landslides. The distribution of geological conditions and slope angles, which serve as the key parameters influencing landslide susceptibility, are presented in Figure (5). This figure provides a clear visual representation of how these factors vary across the study area, further supporting the analysis and conclusions drawn from the landslide hazard assessment.

Based on the findings of JICA (2004) and Askari and Kasaei (2003), the potential for liquefaction in Tehran is generally very low. Only a small area in the southeastern part of the city, where the groundwater table is relatively shallow, shows a low level of susceptibility. Considering the limited extent and low likelihood of this hazard, liquefaction has not been included in the risk calculations of this study.

As mentioned, this study assesses the seismic vulnerability of Tehran's medium-pressure pipelines (260 psi) and reduction stations. As described by Nourzadeh et al. (2019), these pipelines are primarily made of steel (API 5L-Gr. B and API 5L-X42), with diameters ranging from 5.08 to 121.92 cm and wall thicknesses between 0.173 and 0.953 cm, typically buried at depths of 100 to 120 cm. Tehran's network includes 268 reduction stations and approximately 720 km of medium-pressure pipelines, distributed across 22 municipal districts (JICA, 2004), as shown in Figure (6). It is worth mentioning that the data for Tehran's gas network is taken from the JICA study (2000). While it is likely that the network has been expanded since then, the study uses the same data from the JICA (2000) report due to the difficulty in accessing updated information.

The final step in seismic risk assessment involves the selection and application of appropriate fragility curves, which quantitatively describe the probability of various damage states occurring as a function of ground motion intensity. For pressure reduction stations, the fragility model proposed by



(c)

Figure 5. (a) Elevation map of Tehran with 50-meter resolution, (b) topographic slope of the Tehran region, and (c) Lithology map of Tehran, which is based on data from JICA (2004) (gray shaded polygons are past landslides).

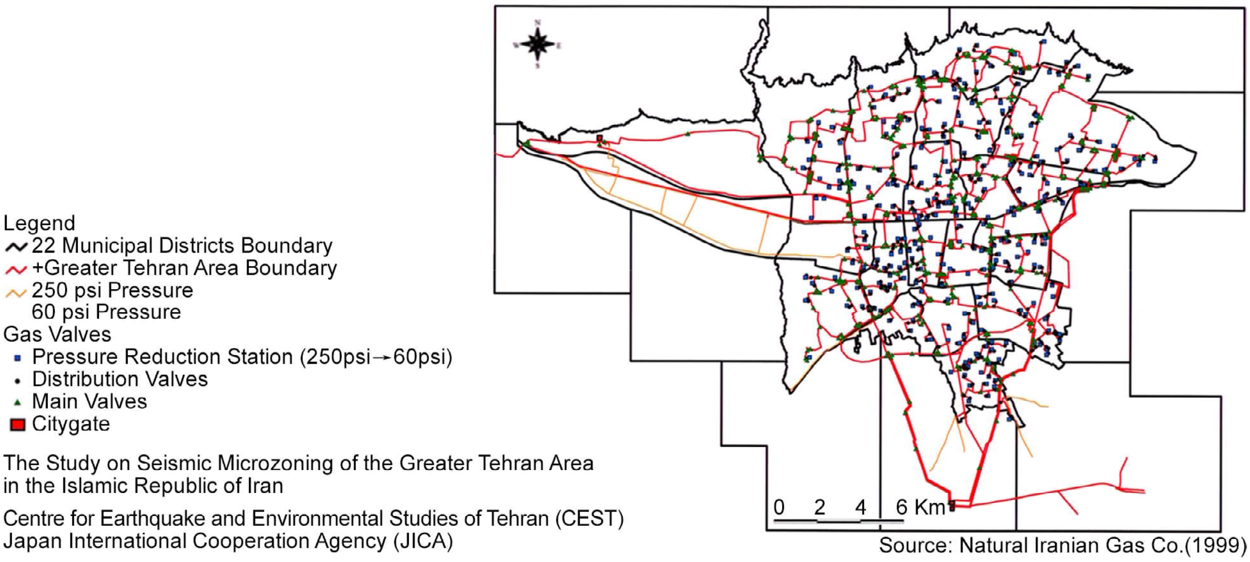


Figure 6. Distribution of pressure reduction stations and medium-pressure pipelines (250 psi) within 22 municipal districts of Tehran (the figure is taken from JICA (2004) report)

FEMA (2004) is utilized in this study. This model classifies potential damage into four discrete states including slight, moderate, extensive, and complete. These damage states, depicted in Figure (7a), provide a basis for estimating the damage level of pressure reduction stations. The main parameters of the fragility curves also provided in Table (2).

For buried pipelines, the assessment relies on the fragility relationships proposed in ALA (2001), which are widely adopted for evaluating the seismic performance of underground lifelines (Figure 7b, 7c). These curves present the potential damage in terms of leaks and breaks. To address the inherent uncertainty in the nature of pipeline failures, particularly the distinction between leaks and breaks, a random sampling from probabilistic distribution of Eidinger (2020) is employed.

Table 2. The main and standard deviation of lognormal distribution for fragility curves of pressure reduction stations.

Damage State	Mean	Standard Deviation
Slight	0.15	0.75
Moderate	0.35	0.65
Extensive	0.75	0.65
Collapse	1.15	0.80

This section provides the results of four predefined seismic scenarios. Figure (8) illustrates the spatial distribution of the probability of extensive damage across Tehran, corresponding to the median values obtained from 1,000 Monte Carlo simulations based

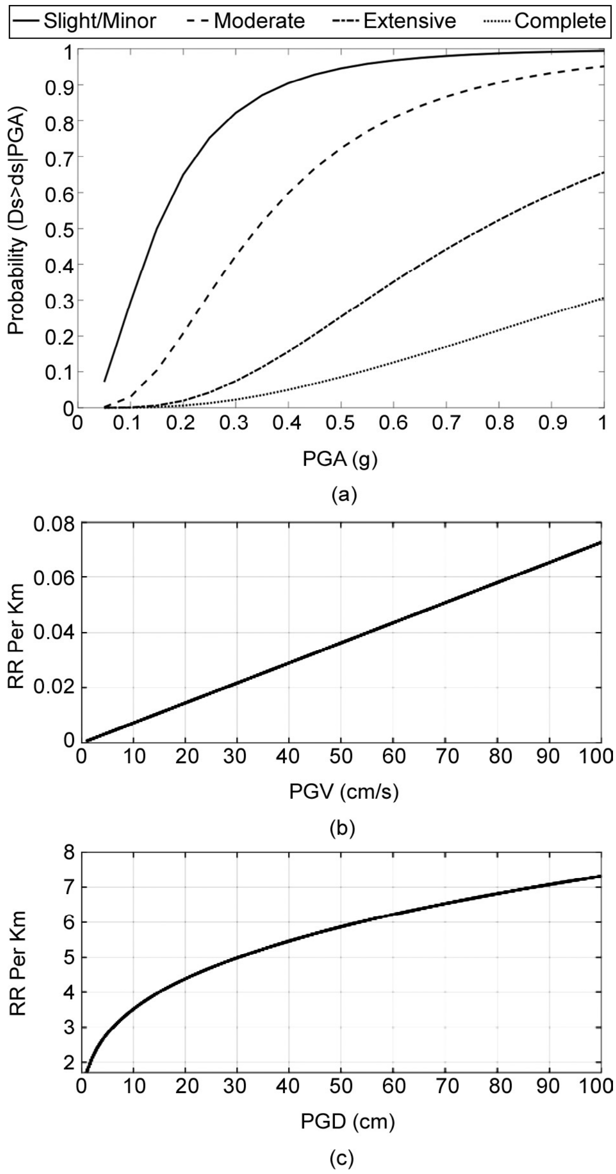


Figure 7. (a) Four damage states of reduction stations according to ALA (2000), (b) Fragility curves of buried pipeline from SGS, and (c) Fragility curves of buried pipeline from GF.

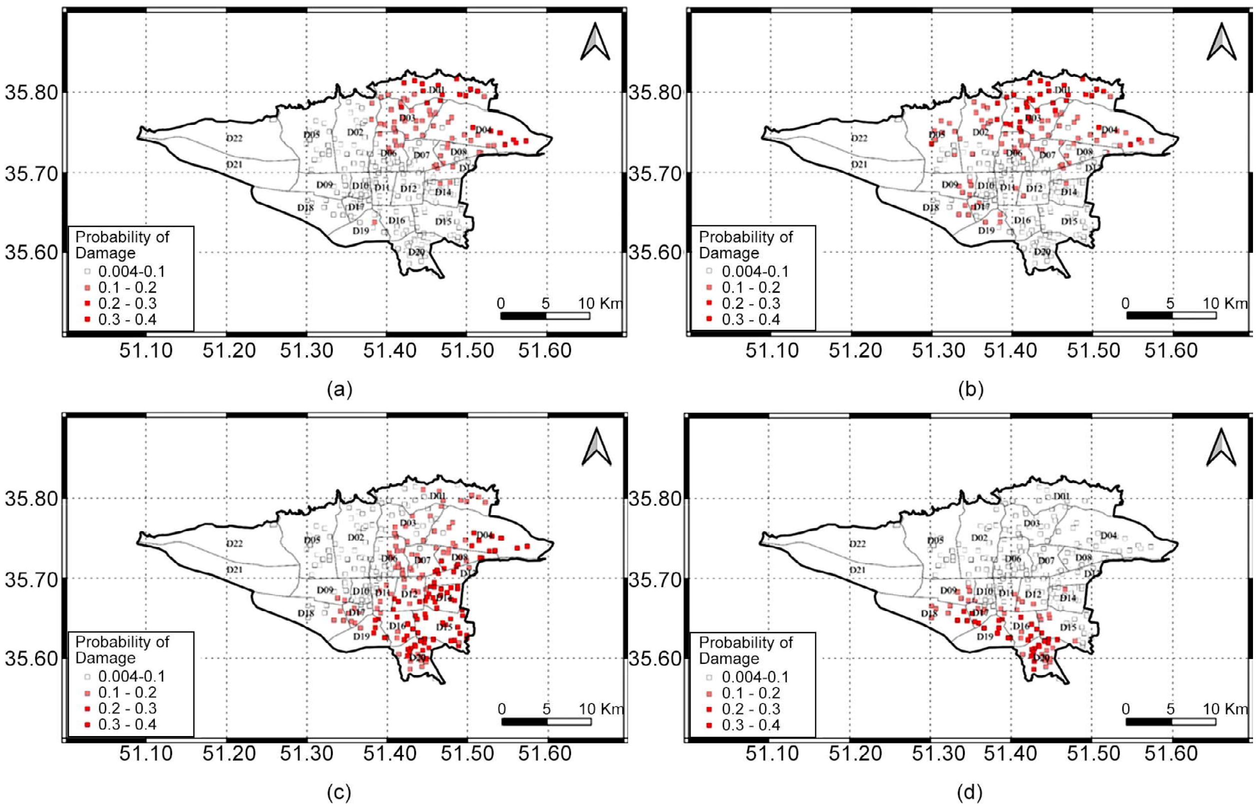


Figure 8. Distribution of extensive damage state in pressure reduction stations across Tehran under different seismic scenarios: (a) Mosha, (b) NTF, (c) Eyvanakey, and (d) Rey.

on the adopted fragility curves. In this analysis, it is assumed that most pressure reduction stations are equipped with anchored subcomponents and are therefore modeled as anchored facilities.

The results show substantial spatial variability in expected damage across the city, largely influenced by the proximity of infrastructure to fault rupture zones and the spatial concentration of facilities. Among the four scenarios, the Eyvanakey fault scenario (Figure 8c) shows the highest probability of extensive damage, especially in the southeastern districts of Tehran (notably D15, D20, and D16). This is attributed to the high density of pressure reduction stations in these areas, combined with the high ground motion values expected from a rupture along the nearby Eyvanakey fault. In contrast, the Mosha fault scenario (Figure 8a) indicates moderate damage probabilities, primarily concentrated in the northeastern parts of the city. The NTF scenario (Figure 8b) shows a similar spatial pattern to the Mosha fault, with slightly higher damage probabilities in the central and northeastern districts. However, the overall probabilities remain below 0.3, suggesting a moderate level of vulnerability under this scenario. The Rey fault scenario (Figure 8d) shows localized high-risk areas, particularly in the southern districts.

These findings highlight the importance of scenario-based seismic risk assessment. They emphasize that infrastructure vulnerability is not only a function of ground motion intensity but also of the spatial distribution of assets. Targeted mitigation efforts should focus on southeastern Tehran, where the convergence of hazard intensity and asset exposure poses the greatest risk, particularly in the case of rupture along the Eyvanakey fault.

Figures (9) and (10) show the spatial distribution of damage to buried pipelines in terms of leaks and breaks per kilometer, respectively, under four distinct seismic scenarios. As depicted in Figure (8), the severity and extent of pipeline leakage vary considerably with the seismic source. The Eyvanakey scenario (Figure 9c) induces the most widespread and intense leakage across the network, particularly in the central and southeastern districts, where leak rates exceed 0.25 per km in several segments. The Mosha and NTF scenarios (Figures 9a and 9b) also show significant leakage, particularly in the northern and northeastern parts of the region, with moderate leak densities ranging between 0.05-0.25 per km.

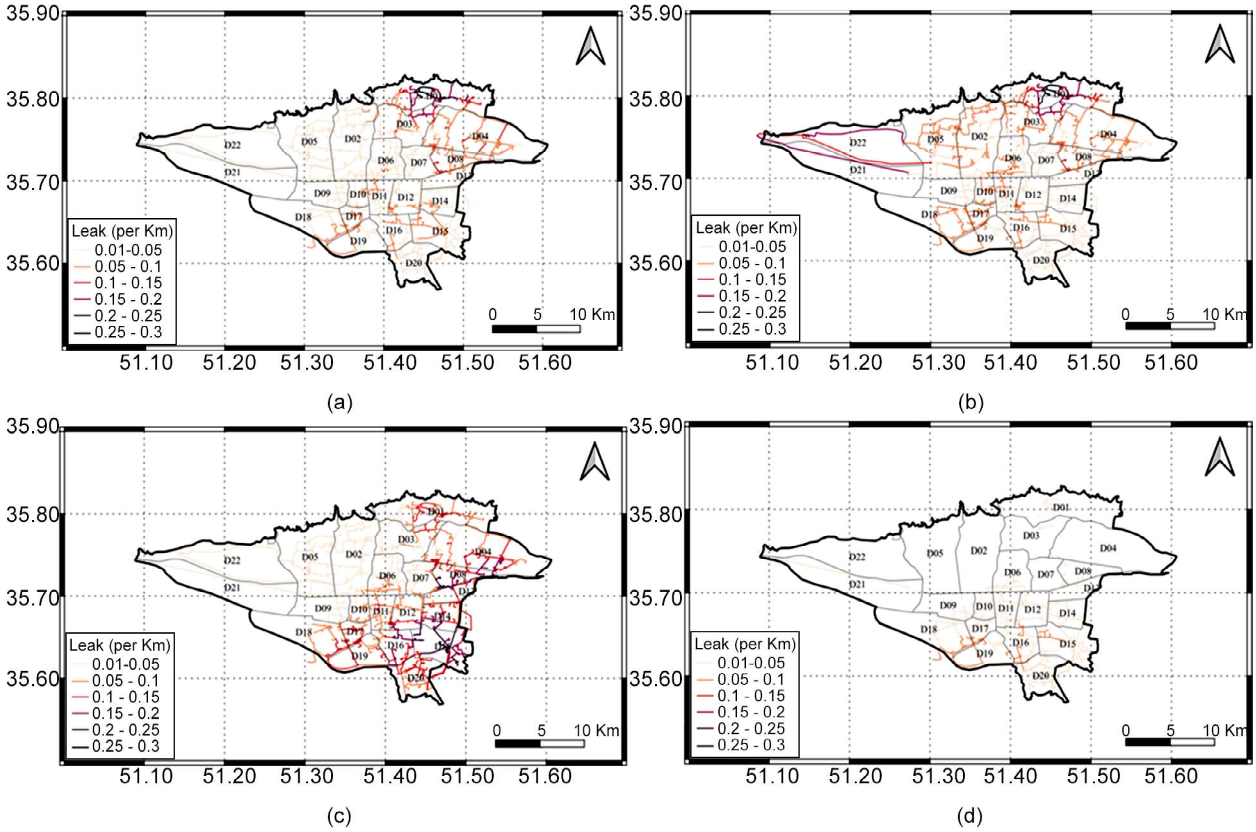


Figure 9. Distribution of damage to buried pipeline in terms of leaks per km under different seismic scenarios: (a) Mosha, (b) NTF, (c) Eyvanakey, and (d) Rey.

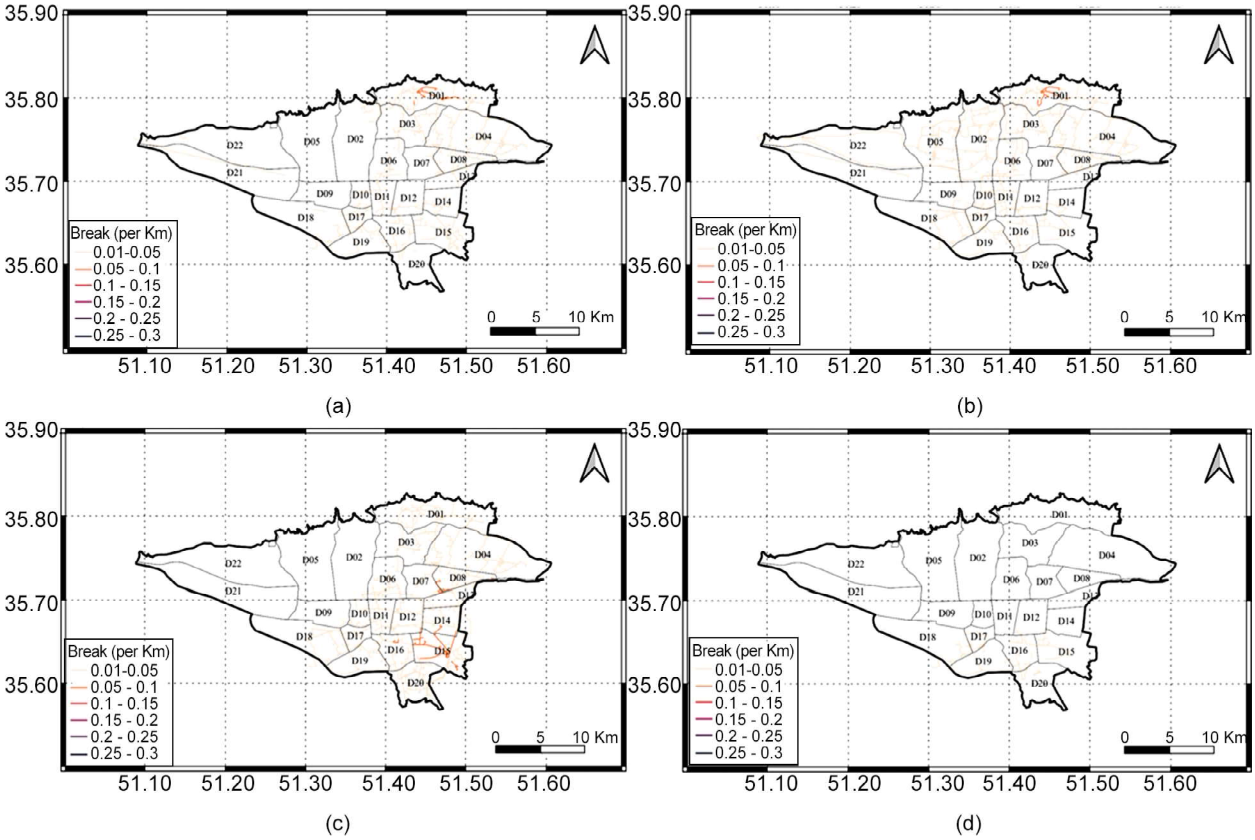


Figure 10. Distribution of damage to buried pipeline in terms of breaks per km under different seismic scenarios: (a) Mosha, (b) NTF, (c) Eyvanakey, and (d) Rey.

In contrast, the Rey scenario (Figure 9d) results in minimal pipeline leakage, with most districts remaining below 0.05 leaks per km.

Similarly, the distribution of pipeline breaks shown in Figure (10) follows a comparable spatial trend but with lower intensity levels. The Eyvanakey fault again causes the highest breakage rates (Figure 10c), though these remain less than 0.25 breaks per km even in the most affected zones. The Mosha and NTF scenarios (Figures 10a and 10b) show localized damage, with break rates mostly below 0.15 per km. The Rey scenario (Figure 10d) continues to represent the least damaging event, with negligible break incidents across all districts.

The results indicate that the buried pipeline network is most vulnerable to seismic events originating from the Eyvanakey fault, followed by the Mosha and NTF sources. The Rey fault scenario presents minimal risk in terms of both leakage and breakage, suggesting a lower hazard potential for underground infrastructure in the event of seismic activity from that source.

It should be noted that the analysis for prioritizing gas distribution components does not currently incorporate the frequency or probability of seismic scenario occurrences in the risk calculations. To address this, seismicity rates and slip rates associated with each seismic source could be used and combined in a weighted manner with the damage levels of each seismic scenario. This approach would enable a more accurate prioritization of gas infrastructure resilience, considering the likelihood of each scenario's occurrence.

4. Conclusion

This study developed and applied a comprehensive probabilistic framework to assess the seismic vulnerability of Tehran's urban gas distribution network under four seismic scenarios associated with the Mosha, NTF, Eyvanakey, and Rey faults. By integrating key sources of epistemic and aleatory uncertainty related to the intra-event variability and damage types, the analysis provides an appropriate estimation of seismic impacts on gas utility components.

The findings reveal that the Eyvanakey scenario poses the greatest threat to both pressure reduction stations and buried pipelines, particularly in southeastern districts of Tehran, where high ground motion intensities coincide with dense infrastructure concentration. In contrast, the Rey fault scenario shows the lowest levels of expected damage across all components, indicating a relatively lower risk for the southern parts of the city under that scenario.

The results also underscore the spatial variability in damage patterns, driven not only by seismic intensity, but also by the geographical distribution and structural vulnerability of infrastructure assets. This variability is influenced by factors such as soil amplification effects, and the proximity of key components to fault ruptures. The results can be used for defining super and middle block gas zones to reduce the cascading consequences of damage from the gas network.

From a practical perspective, the study highlights the need for scenario-specific mitigation planning, with particular attention to districts D15, D16, and D20, where the convergence of high hazard and exposure levels yields high risk. The proposed methodological framework serves as a valuable decision-support tool for prioritizing seismic risk reduction efforts, strengthening infrastructure resilience, and guiding emergency response strategies in Tehran and other seismically active urban regions.

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References

Abbasnejadfard, M., Bastami, M., Jafari, M. K., & Azadi, A. (2023). Spatial correlation models of V_{S30} values: A case study of the Tehran region. *Engineering Geology*, *325*, 107300.

ALA. (2001). *Seismic Fragility Formulations for Water Systems, Part 1: Guidelines*. American Lifeline Alliance, ASCE.

Alikhanzadeh, R., & Zafarani, H. (2023). Physics-based probabilistic seismic hazard analysis: The case of Tehran Basin in Iran. *Bulletin of Earthquake Engineering*, *21*(14), 6171-6214.

Ashtari, M., Hatzfeld, D., & Kamalian, N. (2005). Microseismicity in the region of Tehran. *Tectonophysics*, *395*(3-4), 193-208.

Askari, F., & Kasaei, M. (2003). Analysis of liquefaction potential in some parts of southeast Tehran. *Electronic Journal of Geotechnical Engineering*.

Baratian, A., & Kashani, H. (2022). Probabilistic framework to quantify the seismic resilience of natural gas distribution networks. *International Journal of Disaster Risk Reduction*, 81, 103282.

Berberian, M., & Yeats, R. S. (1999). Patterns of historical earthquake rupture in the Iranian Plateau. *Bulletin of the Seismological Society of America*, *89*(1), 120-139.

Berberian, M., & Yeats, R. S. (2017). *Tehran: An Earthquake Time Bomb*.

Boore, D. M., Stewart, J. P., Seyhan, E., & Atkinson, G. M. (2014). NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes. *Earthquake Spectra*, *30*(3), 1057-1085.

Crowley, H., & Bommer, J. J. (2006). Modelling seismic hazard in earthquake loss models with spatially distributed exposure. *Bulletin of Earthquake Engineering*, 4(3), 249-273.

De Risi, R., De Luca, F., Kwon, O. S., & Sextos, A. (2018). Scenario-based seismic risk assessment for buried transmission gas pipelines at regional scale. *Journal of Pipeline Systems Engineering and Practice*, *9*(4), 04018018.

Eidinger, J. M. (2020). *Seismic Fragility of Natural Gas Transmission Pipelines and Wells (Technical Report)*. G&E Engineering Systems Inc.

Eskandari, M., Omidvar, B., Modiri, M., Nekooie, M. A., & Alesheikh, A. A. (2017). Geospatial analysis of earthquake damage probability of water pipelines due to multi-hazard failure. *ISPRS International Journal of Geo-Information*, *6*(6), 169.

Esposito, S., & Iervolino, I. (2014). Application to L'Aquila gas network. *In SYNER-G: Systemic Seismic Vulnerability and Risk Assessment of Complex Urban, Utility, Lifeline Systems and Critical Facilities: Methodology and Applications*, 283-299. Springer.

Farahani, S., Tahershamsi, A., & Behnam, B. (2020). Earthquake and post-earthquake vulnerability assessment of urban gas pipelines network. *Natural Hazards*, *101*, 327-347.

Federal Emergency Management Agency. (2004). *Using HAZUS-MH for Risk Assessment*.

Firuzi, E., Ansari, A., Amini Hosseini, K., & Karkooti, E. (2022). Developing a customized system for generating near real time ground motion ShakeMap of Iran's earthquakes. *Journal of Earthquake Engineerin*g, *26*(7), 3680-3702.

Firuzi, E., Ansari, A., Amini Hosseini, K., & Kheirkhah, N. (2024). Developing an earthquake damaged-based multiseverity casualty method by using Monte Carlo simulation and fuzzy logic; case study: Mosha fault seismic scenario, Tehran, Iran. *Stochastic Environmental Research and Risk Assessment*, 1-21.

Firuzi, E., Ansari, A., Amini Hosseini, K., & Rashidabadi, M. (2019). Probabilistic earthquake loss model for residential buildings in Tehran, Iran to quantify annualized earthquake loss. *Bulletin of Earthquake Engineering*, *17*, 2383-2406.

Gehl, P., Desramaut, N., Réveillère, A., & Modaressi, H. (2014). Fragility functions of gas and oil networks. *In SYNER-G: Typology Definition and Fragility Functions for Physical Elements at Seismic Risk: Buildings, Lifelines, Transportation Networks and Critical Facilities*, 187-220, Springer.

Ghafoori, S. M. M., Zafarani, H., & Adlparvar, M. R. (2020). Identification of optimization-based probabilistic scenarios for seismic loss analysis of Qom lifelines. *Bulletin of Earthquake Science and Engineering*, *7*(1), 1-14.

Japan International Cooperation Agency. (2000). *The Study on Seismic Microzoning of the Greater Tehran Area in the Islamic Republic of Iran (Final Report, Main Report, SSF JR 00186)*.

Japan International Cooperation Agency & Tehran Disaster Mitigation and Management Organization. (2004). *The Comprehensive Master Plan Study on* *urban Seismic Disaster Prevention and Management for the Greater Tehran Area in the Islamic Republic of Iran (Final Main Report, JR 04-039)*.

Kalantari, M., Firuzi, E., Ahmadipour, M., & Sorooshian, S. (2023). Estimating annualized earthquake loss for residential buildings in Tehran, Iran. *Bulletin of Earthquake Engineering*, *21*(4), 2259-2280.

Kale, O., Akkar, S., Ansari, A., & Hamzehloo, H. (2015). A ground motion predictive model for Iran and Turkey for horizontal PGA, PGV, and 5% damped response spectrum: Investigation of possible regional effects. *Bulletin of the Seismological Society of America*, *105*(2A), 963-980.

Kheirkhah, N., Kalantari, M., Firuzi, E., & Amini Hosseini, K. (2021). Assessing the sensitivity of seismic loss estimation to the geographic resolution of building exposure model. *Journal of Seismology and Earthquake Engineering*, *23*(3), 67-78.

Kotha, S. R., Bindi, D., & Cotton, F. (2016). Partially non-ergodic region specific GMPE for Europe and Middle-East. *Bulletin of Earthquake Engineering*, *14*(4), 1245-1263.

Mousavi, M., Hesari, M., & Azarbakht, A. (2014). Seismic risk assessment of the 3rd Azerbaijan gas pipeline in Iran. *Natural Hazards*, *74*, 1327-1348.

Nourzadeh, D. D., Mortazavi, P., Ghalandarzadeh, A., Takada, S., & Ahmadi, M. (2019). Performance assessment of the Greater Tehran Area buried gas distribution pipeline network under liquefaction. *Soil Dynamics and Earthquake Engineering*, *124*, 16-34.

Pagani, M., Monelli, D., Weatherill, G., Danciu, L., Crowley, H., Silva, V., ... & Vigano, D. (2014). OpenQuake engine: An open hazard (and risk) software for the global earthquake model. *Seismological Research Letters*, *85*(3), 692-702.

Saygili, G., & Rathje, E. M. (2008). Empirical predictive models for earthquake-induced sliding displacements of slopes. *Journal of Geotechnical and Geoenvironmental Engineering*, *134*(6), 790-803.

Statistical Centre of Iran. (2016). National census of population and housing technical reports (Years: 2016, 2011, 2006, 1996, 1986, 1976). https://www.amar. org.ir

Silva, V. (2017). Critical issues on probabilistic earthquake loss assessment. *Journal of Earthquake Engineering*, *22*(9), 1683-1709.

Weatherill, G., Esposito, S., Iervolino, I., Franchin, P., & Cavalieri, F. (2014). Framework for seismic hazard analysis of spatially distributed systems. *In SYNER-G: Systemic Seismic Vulnerability and Risk Assessment of Complex Urban, Utility, Lifeline Systems and Critical Facilities: Methodology and Applications*, 57-88, Springer.

Zafarani, H., Noorzad, A., Ansari, A., & Bargi, K. (2009). Stochastic modeling of Iranian earthquakes and estimation of ground motion for future earthquakes in Greater Tehran. *Soil Dynamics and Earthquake Engineering*, *29*(4), 722-741.

Zafarani, H., Vahidifard, H., & Ansari, A. (2012). Sensitivity of ground-motion scenarios to earthquake source parameters in the Tehran metropolitan area, Iran. *Soil Dynamics and Earthquake Engineering*, *43*, 342-354.

Zafarani, H., Ghafoori, S. M. M., Soghrat, M., & Shafiee, M. (2020). Spatial correlation of peak ground motions and pseudo-spectral acceleration based on the Sarpol-e-Zahab Mw 7.3, 2017 earthquake data. *Annals of Geophysics*, *63*(4), SE439.

Zafarani, H., Ghafoori, S. M. M., & Adlaparvar, M. R. (2022). Spatial correlation of peak ground motions and pseudo spectral acceleration based on the Iranian multievent datasets. *Journal of Earthquake Engineering*, *26*(12), 6042-6062.

Zafarani, H., Khalaj, A., Ghafoori, S. M. M., & Soghrat, M. R. (2025). Spatial correlation of peak ground motions (PGA and PGV) and spectral accelerations based on the Iranian earthquake data. *Pure and Applied Geophysics*, 1-16.

Zhao, J. X., Zhang, J., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., ... & Fukushima, Y. (2006). Attenuation relations of strong ground motion in Japan using site classification based on predominant period. *Bulletin of the Seismological Society of America*, *96*(3), 898-913.