AHP-based seismic vulnerability index for critical urban water and sanitation infrastructure

Fatma Zohra Halfaya[a], *Mahmoud* Bensaibi[b]

[a] University of Blida 1, Civil Department, People's Democratic Republic of Algeria,
e-mail: fz_halfaya@yahoo.fr, **corresponding author**,
ORCID iD: https://orcid.org/0009-0009-6030-3664

[b] Infrastructure Studies Control and Assistance Group, GEICA, People's Democratic Republic of Algeria,
e-mail:bensaibim@gmail.com,
ORCID iD: https://orcid.org/0000-0003-1409-4610

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Abstract:

Introduction/purpose: This research develops a systematic methodology for assessing the seismic vulnerability of buried water supply and wastewater pipeline networks. The objective is to integrate geological, geotechnical, and structural parameters within a unified decision-support framework, thus enabling infrastructure managers to identify and prioritize vulnerable segments in earthquake-prone regions.

Methods: The methodology combines the Vulnerability Index (VI) approach with the Analytic Hierarchy Process (AHP) to assign relative weights to factors such as pipe material, diameter, age, burial depth, soil type, liquefaction potential, seismic intensity, and fault crossings. Expert judgment and pairwise comparisons are used to determine these weights. Geographic Information System (GIS) tools and field surveys support the spatial analysis. The approach is applied to the city of Blida, Algeria, characterized by high seismic hazard and diverse soil conditions.

Results: The AHP-based VI approach produced detailed vulnerability maps for both water and sewer networks, classifying pipeline segments into low, medium, and high vulnerability levels. The method demonstrated higher precision and contextual relevance compared to empirical assessments, revealing material brittleness, diameter, and geotechnical conditions as key determinants.

Conclusion: The AHP–VI framework provides a robust, adaptable, and transparent tool for seismic risk assessment of lifeline infrastructure. Its applicability extends to both civilian and military contexts, supporting *strategic planning, targeted mitigation, and resilience enhancement of critical buried pipelines in seismically active regions.*

Key words: Analytic Hierarchy Process (AHP), vulnerability index, water supply network, wastewater network, seismic risk, GIS.

Introduction

Assessing the seismic vulnerability of buried pipelines in water supply and wastewater systems is a key concern in the broader context of disaster risk reduction and infrastructure resilience. Earthquakes can cause significant damage to these essential systems, jeopardizing the delivery of potable water and the functioning of sanitation services in affected areas. Accordingly, establishing a systematic and robust methodology for vulnerability assessment is crucial for strengthening the seismic resilience of these networks (Farahmandfar et al, 2016; Bata et al, 2022; Hou et al, 2023; Boskabadi et al, 2020).

This study presents a methodological framework based on the Vulnerability Index (VI) for evaluating the seismic susceptibility of buried pipelines (Adafer & Bensaibi, 2017). To improve the precision of this assessment, the Analytic Hierarchy Process (AHP) is integrated to assign relative weights to the different parameters that influence pipeline behavior under seismic loading conditions (Saaty, 1987; Bernasconi et al, 2010; Omkarprasad & Sushil, 2006; Bhushan & Rai, 2004; Roy et al, 2023; Sharveen et al, 2022). By combining the structured decision-making capabilities of AHP with the implementation of the VI, this approach offers an effective tool for assessing and ranking pipeline vulnerability.

Previous research has increasingly emphasized the importance of assessing the seismic vulnerability of lifeline infrastructure, particularly in seismically active regions. Numerous studies highlight the necessity of incorporating the specific characteristics of water distribution systems into such evaluations (Halfaya, 2013; Halfaya et al, 2017; Germoso et al, 2021; Ballantyne, 2010; Tucker, 2010; O'Rourke & Deyoe, 2004; O'Rourke, 2009; Maruyama et al 2011; Christodoulou & Fragiadakis, 2015; Braun et al, 2020; Roy et al, 2021; Roy et al, 2022). Additionally, several investigations have examined the seismic performance of wastewater pipeline networks (Matsuhashi et al, 2014; Baris et al, 2021; Giovinazzi et al, 2015; Kerpelis et al, 2021; Rahimi & Rezaii, 2021).

Globally, numerous comprehensive studies have addressed the seismic resilience of urban infrastructure, with particular emphasis on water and wastewater systems (ATC25, 1991; ATC25-1, 1991; FEMA, 1997; FEMA, 2000; OYO Corporation, 1999; RISK-UE, 2003). The present research builds on the recommendations from these studies and adapts the methodology to real-world contexts, particularly potable water pipelines in seismically active areas (Ansal, 2008) with the aim of improving preparedness and enhancing the reliability of water and sanitation services during seismic events. Furthermore, the validation of the methodology for wastewater networks broadens its applicability to other underground utilities, enhancing its relevance for diverse urban environments.

This research proposes a novel and practical framework for seismic vulnerability assessment of buried pipelines, combining the analytical strength of AHP with the operational value of the Vulnerability Index. The application of the methodology to the water and wastewater infrastructure of Blida, Algeria, provides actionable insights to support the resilience of vital public services in earthquake-sensitive regions.

Vulnerability Index (VI) methodology

The Vulnerability Index (VI) method offers a structured and quantitative approach for evaluating seismic risk in buried water and wastewater pipeline systems. The methodology is composed of four key stages:

Identification of relevant factors

The initial step involves identifying the critical factors that influence pipeline performance under seismic loading. These typically include structural and geotechnical attributes such as pipe material, diameter, burial depth, soil type, liquefaction potential, and the age of the infrastructure. Each factor contributes uniquely to the pipeline's response to seismic activity, necessitating careful and context-specific consideration.

Assignment of weighting factors

In the second stage, the Analytic Hierarchy Process (AHP) — a well-established multi-criteria decision-making (MCDM) method, is employed to assign weights to the identified factors. AHP facilitates a structured comparison of the relative importance of each parameter through expert judgment and pairwise comparisons. This ensures that the final weighting reflects the actual influence of each factor on seismic vulnerability, while accounting for potential interdependencies among variables.

Formulation of the vulnerability index

The third step involves integrating the weighted factors into a single analytical expression to compute the Vulnerability Index. This index serves as a quantitative indicator of the relative seismic risk of different pipeline segments. The shift from qualitative assessments to a numerical index enables objective comparisons between network components and supports data-driven decision-making.

Classification of pipeline segments

The final stage consists of classifying pipeline segments according to their calculated Vulnerability Index values. They are typically grouped into discrete vulnerability levels such as low, moderate, high, and very high, providing infrastructure managers with a transparent and actionable framework for prioritizing interventions. This classification facilitates effective resource allocation, risk mitigation planning, and long-term infrastructure resilience strategies.

Overview of the analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s, is a widely adopted multi-criteria decision-making methodology. It is particularly effective in addressing complex decision problems that involve multiple, and sometimes conflicting, criteria. AHP decomposes such problems into a hierarchical structure, enabling systematic analysis and prioritization based on expert judgments.

Hierarchical structure

The AHP manages the decision-making problem as a multi-level hierarchy with three key components:

- Goal/Objective: This represents the overall target of the analysis in this case, assessing the seismic vulnerability of buried pipelines.
- Criteria: These are the factors that influence the achievement of the goal. Relevant criteria include pipe material, diameter, burial depth, age, soil type, and liquefaction potential.
- Alternatives: These refer to the different pipeline segments or configurations under evaluation.

This hierarchical organization provides a transparent structure for breaking down and analyzing complex problems in a logical and systematic manner.

Pairwise comparisons

A fundamental component of AHP is the use of pairwise comparisons to assess the relative importance of criteria and alternatives. Decision-makers evaluate each pair of elements at a given level of the hierarchy using expert judgment. This technique captures both qualitative preferences and quantitative significance, offering a nuanced view of relative priority.

Saaty's fundamental scale

To support pairwise comparisons, AHP employs Saaty's fundamental scale, which ranges from 1 to 9. A value of 1 denotes equal importance between two elements, while a value of 9 indicates an extreme preference for one element over the other. Intermediate values (2, 4, 6, 8) allow for graded distinctions between judgments. Reciprocals are automatically applied for inverse comparisons.

Table 1 – Saaty's fundamental scale for pairwise comparison

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience or judgment slightly favors one element
5	Strong importance	Clear and consistent preference for one element
7	Very strong importance	One element is strongly favored, with demonstrated dominance
9	Extreme importance	Evidence overwhelmingly favors one element
2,4,6,8	Intermediate values	Used when compromise or uncertainty exists between two adjacent levels
Reciprocals	Inverse values (1/x)	Applied to the opposite comparison

Consistency check

To ensure logical coherence in the judgment matrix, AHP incorporates a consistency check by computing the Consistency Ratio (CR). A CR value below 0.10 is generally considered acceptable. If the ratio exceeds this threshold, the decision-maker should revise the judgments to improve consistency and reliability.

Computing of relative ponderations

The ponderations of criteria and alternatives are derived mathematically, typically using eigenvector calculations based on the pairwise comparison matrices. These weights reflect the relative importance of each element in contributing to the overall objective and form the basis for aggregating judgments across the hierarchy.

Synthesis and decision-making

In the final step, the results from all hierarchical levels are aggregated to obtain a ranked list of alternatives. The synthesis of calculated weights enables a comprehensive evaluation of options, facilitating well-informed and justifiable decision-making based on a structured analytical foundation.

Seismic vulnerability of the water supply network

The developed methodology is applied to assess the seismic vulnerability of the water supply network through a hierarchical structure based on the Analytic Hierarchy Process (AHP). This structure consists of three levels, each designed to capture different aspects of vulnerability.

Hierarchical structure of parameters

The AHP-based evaluation of seismic vulnerability in the service drinking water network is structured across three hierarchical levels.

Level 1 – Parameters: Three key parameters are selected for the vulnerability assessment: structural, ground-related, and seismic hazard parameters;

Level 2 – Factors: Each parameter is subdivided into specific factors that characterize different physical or environmental conditions influencing pipeline vulnerability;

Level 3 – Categories: Each factor is further broken down into distinct categories. Expert judgment is used to assign scores to each category based on its relative importance or contribution to seismic vulnerability.

This multi-level structure (Figure 1) allows for a detailed and granular assessment of pipeline components and their susceptibility to seismic hazards.

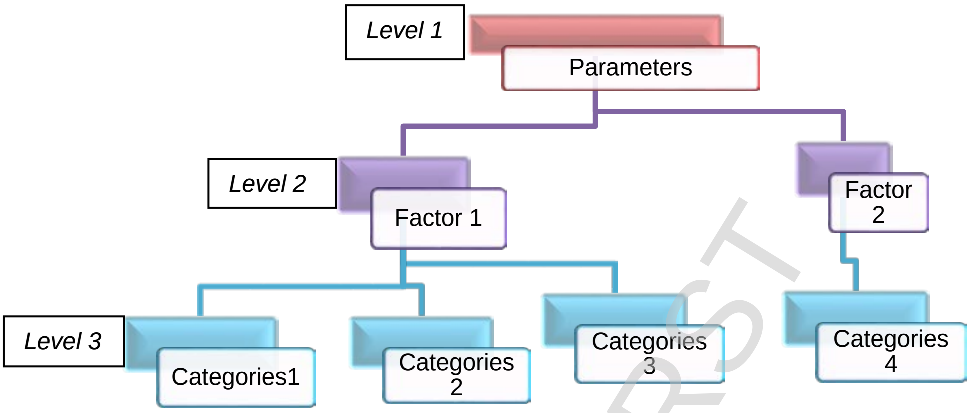

Figure 1 – The used multi-level structure

Weight determination using AHP

The AHP method is applied to assign weights to each parameter and factor, based on pairwise comparisons using Saaty's scale. These weights indicate the relative importance of each element within the decision-making process in contributing to the overall vulnerability. While the categories themselves are not directly included in the pairwise comparison matrices, they are scored using expert judgement to quantify their impact within each factor.

Summary of weights and scores

Table 2 presents the full hierarchical structure, including parameters, factors, categories, and their respective weights and scores. These values form the foundation for the Vulnerability Index calculation for water pipelines.

Table 2 – Hierarchical structure and weights for water pipeline vulnerability assessment

Parameters	Weight	Factor	Weight	Category	Score
Structural	0.571	Materials	0.75	Asbestos Cement	60
				Cast Iron	50
				Ductile Iron	40
				Steel	30
				Galvanized Steel	20
				Polyvinyl chloride (PVC)	10
				Polyethylene HDPE	0
		Diameters	0.25	φ < 75 mm	50
				75 mm <φ<150 mm	40
				150 mm <φ<250 mm	30
				250 mm <φ<450 mm	20
				450 mm < φ <1000 mm	10
				φ > 1000 mm	0
Ground	0.143	Soil Type	0.75	Alluvium: very soft soil S1	40
				Dilluvium: soft soil S2	30
				Medium Soil S3	20
				Medium Rocky Soil S4	10
				Hard Rock Soil S5	0
		Slide	0.25	No slippage	0
				Medium Slippage	10
				Significant Slippage	30
Seismic Hazard	0.286	Intensity	0.539	MMI<8	10
				8≤MMI<9	20
				9≤MMI<10	30
				10≤MMI<11	40
				11≤MMI	50
		Liquefaction	0.163	0≤LP*<5	0
				5≤LP<15	10
				15≤LP	30
		Fault Cross	0.294	No intersection	0
				One intersection	10
				Multiple intersections	30

**LP stands for liquefaction potential (according to the Iwasaki method)*

Analytical expression of the vulnerability index

The overall Vulnerability Index (VI) for each pipeline segment is calculated using the following expression:

$$VI = \sum_{i=1}^{3} W_i \left(\sum_{j=1}^{2\ or\ 3} W_{ij} \left(\sum_{k=1}^{3\ or\ 5\ or\ 6\ or\ 7} C_{ijk} W_{ij} \right) \right) \qquad (1)$$

Where:

Wi is the weight of the ith parameter,
Wij is the weight of the jth factor under parameter i,
Cijk is the score assigned to the kth category under factor j.

Classification of vulnerability levels

Based on expert feedback and seismic risk considerations, the following classification system is proposed for interpreting the computed VI values.

Table 3 – Seismic vulnerability classification for water pipelines

VI	Vulnerability Level	Interpretation	Color Code
0 < VI< 25	Low	Low risk of damage	Green 🟢
25 ≤ VI < 35	Medium	Moderate risk; replacement recommended	Orange 🟠
35 ≤ VI < 50	High	High risk; urgent replacement required	Red 🔴

Interpretation:

Green - Low-risk segments; no immediate action is necessary;

Orange - Moderate-risk segments; replacement is advised in the medium term;

Red - High-risk segments; urgent replacement or reinforcement is recommended.

Seismic vulnerability of the sewer network

The methodology originally designed to evaluate the seismic vulnerability of the drinking water distribution network has been extended to the sewer (wastewater) system. Given the structural and operational differences between these two systems, specific factors relevant to sewer pipelines have been incorporated within the same AHP-based framework.

Identification of relevant factors and AHP structure

Similar to the water supply analysis, the AHP methodology is structured into three levels for the wastewater network:

Level 1 – Parameters: The three primary parameters are structural, geotechnical (ground-related), and seismic hazard conditions;

Level 2 – Factors: Each parameter comprises specific factors tailored to sewer infrastructure, such as wastewater chemical composition and slope;

Level 3 – Categories: For each factor, categories are defined and scored using expert judgment to reflect their contribution to seismic vulnerability.

Identified Factors:

A. Structural Parameter:
   1. Pipe material,
   2. Pipe diameter,
   3. Chemical nature of the wastewater.

B. Ground Parameter:
   1. Soil type,
   2. Landslide risk,
   3. Slope.

C. Seismic Hazard Parameter:
   1. Seismic intensity,
   2. Fault crossings,
   3. Liquefaction potential.

These factors are evaluated within the AHP framework to quantify their relative influence on seismic vulnerability.

Weight assignment using AHP

The AHP method is employed to determine the weights of each parameter and factor. Expert-based pairwise comparisons are conducted to ensure the prioritization reflects real-world significance and local context. Table 4 summarizes the derived weights for the parameters, factors, and categories.

Table 4 – AHP *weights for seismic vulnerability assessment of sewer pipelines*

Parameters	Weight	Factor	Weight	Category	Score
Structural	0.685	Materials	0.633	Asbestos	50
				Sand stone	40
				Cast Iron	30
				Reinforced concrete	20
				Polyvinyl chloride (PVC)	10
				Polyethylene HDPE	0
				PRV	0
		Diameters	0.261	D < 300 mm	20
				300 ≤ D ≤ 600 mm	10
				D > 600 mm	0
		Chemical nature of the water	0.106	PH<7 (acid)	20
				PH>7 (basic)	10
Ground	0.093	Soil type	0.707	Alluvium: very soft soil S1	40
				Dilluvium: soft soil S2	30
				Medium Soil S3	20
				Medium Rocky Soil S4	10
				Hard Rock Soil S5	0
		Slide	0.201	No slippage	0
				Moderate Slippage	10
				Significant Slippage	30
		Slope	0.092	1%< p ≤ 3%	20
				3% < p ≤ 5%	10
				p >5%	0
Seismic Hazard	0.221	Intensity	0.724	MMI<8	10
				8≤MMI<9	20
				9≤MMI<10	30
				10≤MMI<11	40
				11≤MMI	50
		Cross with fault	0.083	No intersection	0
				One intersection	10
				Multiple intersections	30
		Liquefaction	0.193	0≤LP*<5	0
				5≤LP<15	10
				15≤LP	30

**LP stands for liquefaction potential (according to the Iwasaki method)*

Analytical expression of the Vulnerability Index (VI)

The Vulnerability Index for sewer pipelines is calculated using the same formula as for water pipelines:

$$VI = \sum_{i=1}^{3} W_i \left(\sum_{j=1}^{3} W_{ij} \left(\sum_{k=1}^{2\ or\ 3\ or\ 5\ or\ 7} C_{ijk} W_{ij} \right) \right) \tag{2}$$

Where:

W_i is the weight of the parameter,
W_{ij} is the weight of the corresponding factor,
C_{ijk} is the score of the category.

Vulnerability classification for sewer pipelines

A classification system is established to interpret the calculated VI values for sewer pipelines. This system enables decision-makers to identify priority areas for intervention

Table 5 – Seismic vulnerability classification for sewer pipelines

VI	Vulnerability Level	Interpretation	Color Code
0 < VI< 15	Low	Minor risk; no immediate action required	Green 🟢
15 ≤ VI < 25	Medium	Moderate risk; monitoring recommended	Orange 🟡
25 ≤ VI < 40	High	High risk; reinforcement or replacement needed	Red 🔴

This classification mirrors that used for water pipelines and supports consistent risk communication and management strategies across both network types.

Case studies and results

To demonstrate the applicability of the proposed methodology, two case studies on the water supply and wastewater networks of Blida, Algeria were conducted. These case studies illustrate how the AHP-based Vulnerability Index (VI) approach can be used to assess seismic risk and guide infrastructure management decisions.

Case study: water supply network of Blida

The water distribution system of Blida extends over approximately 94 km and includes pipelines made of various materials such as cast iron, asbestos cement, steel, PVC, and HDPE. The pipe diameters range from 50 mm to 800 mm.

This network is situated in a seismically active area, directly influenced by the Soumaa–Bouinan fault, a 30 km-long fault capable of generating earthquakes with a maximum magnitude of 6.8 ± 0.28 (according to CRAAG studies). This corresponds to an intensity of IX < MMI < X on the Modified Mercalli Intensity (MMI) scale (CRAAG, 2005). Liquefaction potential across the study area was assessed based on criteria from reference (Bahi & Bensaibi, 2012).

A previous study of the same network was conducted using an empirical approach (Halfaya, 2013). The results of that empirical evaluation were compared to those obtained using the AHP-based analytical method described in this paper.

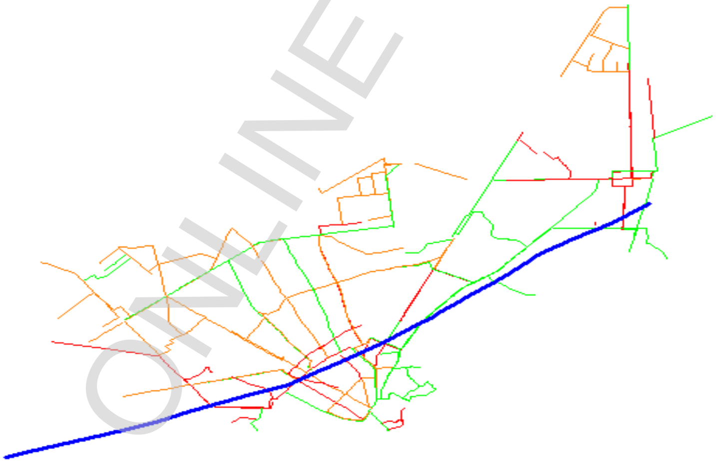

Figure 2 – GIS-based seismic vulnerability map of the water network

The comparison reveals discrepancies between the two approaches, with the AHP-based method providing more nuanced, data-driven classification based on localized geological and infrastructural factors.

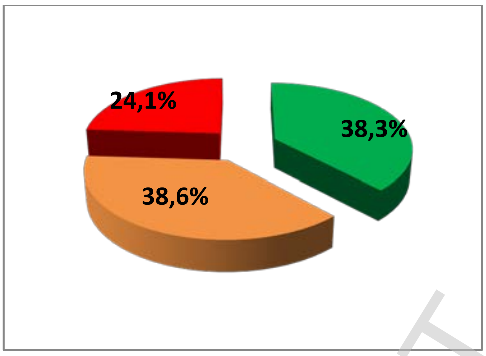

Figure 3 – Distribution of pipeline vulnerability classes (empirical method)

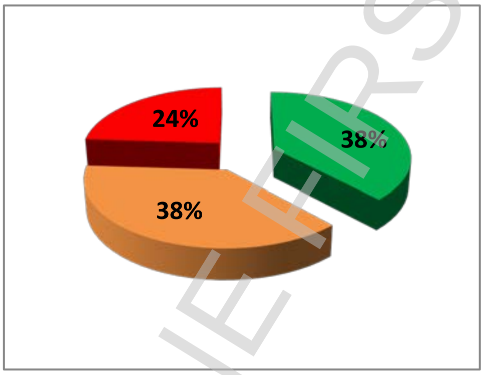

Figure 4 – Distribution of pipeline vulnerability classes (analytical method)

Case studies: sewer network of Blida

Two sets of case studies were carried out to evaluate seismic risk within the wastewater pipeline network using the developed methodology.

Reinforced concrete pipes

This analysis focused on two reinforced concrete (RC) sewer pipes of different diameters: 300 mm and 1000 mm. The conditions for each pipe segment were evaluated based on the factors and categories defined in the AHP hierarchy.

Table 6 – Seismic vulnerability results for reinforced concrete sewer pipes

Materials	RC	
Diameters Φ (mm)	300	1000

Chemical nature of the wastewater	Basic	
Type de sol	S1	
Liquefaction	0≤ PL≤5	
Side	No slippage	
Slope	3% < p ≤ 5%	
Intensity	MMI ≤ 8	
Cross with Fault	1 intersection	
Vulnerability Index (VI)	15.6	13.82
Classification	🟡	🟢

These results suggest that both pipes fall within the low to moderate vulnerability range, with diameter playing a significant role in risk differentiation.

Newly installed pipelines (2022)

This study assessed several sewer pipelines recently installed across multiple localities in Blida. The following assumptions were applied:

Chemical Nature of Wastewater: Basic
Ground Type: Soil S1
No Landslide Risk
Seismic Intensity: IX < MMI < X (USGS)
No Liquefaction Risk

Table 7 - Seismic vulnerability assessment of sewer pipelines in Blida (2022 installations)

Localities	Materials	Diameters	Slope (for 1000)	Number of intersections with fault	VI	Classification
Bougara	RC	1000	4	1	17.2	🟡
Larbaa	PVC	300	5	0	14.5	🟢
Bougara	PVC	500	6	1	14.6	🟢
O.Yaich	PEHD	400	6	1	10.3	🟢
Chréa	PEHD	300	6	0	10.1	🟢
Larbaa	PEHD	300	6	0	10.1	🟢
Bouarfa	PEHD	500	6	0	10.1	🟢
O.E.Alleug	RC	1200	5	0	17	🟡
Bouarfa	RC	800	6	0	17	🟡

Analysis

The results confirm that reinforced concrete (RC) pipes consistently present higher vulnerability indices compared to PVC and HDPE alternatives. This aligns with established knowledge regarding material brittleness and seismic performance. Nevertheless, RC pipes continue to be used in certain locations—likely due to cost, local availability, or legacy infrastructure constraints.

Conclusion

This study proposes a systematic methodology for evaluating seismic risk in underground water supply and wastewater networks, by integrating the Analytic Hierarchy Process (AHP) with a structured Vulnerability Index (VI) framework. The method incorporates a wide range of parameters—spanning geological, geotechnical, and structural characteristics—including soil type, liquefaction potential, pipeline material, diameter, burial depth, and age. These parameters are assigned relative weights based on expert evaluations through the AHP method.

The methodology was applied to the city of Blida, Algeria—an urban area characterized by high seismic activity and diverse subsurface conditions. By leveraging GIS tools and field data, a seismic vulnerability map was generated to identify critical segments of the water and sewer networks. The findings facilitate strategic planning, allowing decision-makers to prioritize maintenance, reinforcement, or replacement of vulnerable pipelines.

The results demonstrate the practical value of the AHP-based approach in bridging the gap between engineering data and operational decision-making. The methodology offers several advantages: adaptability to various urban contexts, transparency in weighting and scoring, and the ability to incorporate both expert knowledge and field-based observations. It is particularly well-suited for use in developing countries, where infrastructure vulnerabilities are significant and technical data may be scarce.

Beyond civilian infrastructure, the proposed methodology holds significant potential for military applications. Military bases, forward operating posts, and command facilities frequently depend on buried pipeline systems to maintain essential services such as potable water, sanitation, and cooling systems. In seismically active regions or post-conflict reconstruction zones, ensuring the continuity and resilience of such lifeline infrastructure is a strategic priority. The AHP-based framework can assist military engineers and planners in identifying critical vulnerabilities, supporting logistics continuity, and enhancing the resilience of mission-critical installations.

Future work

Further enhancements could include integrating probabilistic seismic hazard models, incorporating real-time monitoring data (e.g., ground motion sensors), and refining the AHP weighting process using machine learning algorithms. Additionally, the inclusion of socioeconomic and strategic impact indicators—such as population exposure, service disruption costs, and recovery priorities—would broaden the scope and utility of the methodology, ultimately contributing to more resilient and sustainable infrastructure systems in both civilian and military contexts.

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Indeks seizmičke ranjivosti kritične urbane vodovodne i kanalizacione infrastrukture zasnovan na metodi AHP

Fatma Zohra Halfaya[a], **autor za prepisku**, *Mahmoud* Bensaibi[b]

[a] University of Blida 1, Civil Department, People's Democratic Republic of Algeria

[b] Infrastructure Studies Control and Assistance Group, GEICA, People's Democratic Republic of Algeria

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Sažetak:

Uvod/cilj: Ovo istraživanje razvija sistematsku metodologiju za procenu seizmičke ranjivosti podzemnih vodovodnih i kanalizacionih mreža. Cilj je integracija geoloških, geotehničkih i strukturnih parametara u jedinstveni okvir za odlučivanje koji omogućava upravnicima infrastrukture da identifikuju i prioritizuju ranjive segmente u regionima sklonim zemljotresima.

Metode: Metodologija kombinuje pristup Indeksa ranjivosti (eng. VI) sa metodom Analitičkog hijerarhijskog procesa (AHP) kako bi se dodelile relativne težine faktorima kao što su materijal cevi, prečnik, starost, dubina ukopa, tip tla, potencijal za likvefakciju, seizmička jačina i ukrštanje sa rasedima. Težine su određene na osnovu stručnog mišljenja i uporednih parova. Alati geografskog informacionog sistema (GIS) i terenska ispitivanja podržavaju prostornu analizu. Pristup je primenjen na grad Blida, Alžir, koji odlikuje visoki seizmički rizik i raznoliki tipovi tla.

Rezultati: Pristup Indeksa ranjivosti koji se zasniva na AHP metodi proizveo je detaljne mape ranjivosti vodovodnih i kanalizacionih mreža, klasifikujući segmente cevi na niske, srednje i visoke nivoe ranjivosti. Ovaj metod je pokazao veću preciznost i kontekstualnu relevantnost u poređenju sa empirijskim procenama, otkrivajući lomljivost materijala, prečnik i geotehničke uslove kao ključne determinante.

Zaključak: Okvir Indeksa ranjivosti i AHP metode pruža robustan, prilagodljiv i transparentan instrument za procenu seizmičkog rizika po vitalnu infrastrukturu. Njegova primena se proteže na civilni i vojni sektor, podržavajući strateško planiranje, ciljane mere ublažavanja rizika i unapređenje otpornosti kritičnih podzemnih cevovoda u seizmički aktivnim regionima.

Ključne reči: analitički hijerarhijski proces (AHP), indeks ranjivosti, mreža vodosnabdevanja, kanalizaciona mreža, seizmički rizik, GIS.

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