



EVALUATION OF THE MANAGEMENT EFFICIENCY OF THE SEISMIC MONITORING SYSTEM OF THE REPUBLIC OF ARMENIA USING ARTIFICIAL INTELLIGENCE METHODS (1991–2024)

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Received 20.11.2024.
Revised 23.04.2025.
Accepted 09.05.2025.

Keywords:

*Database, Monitoring system,
Earthquake, Artificial
Intelligence, Management*

A B S T R A C T

Efficient management of seismic monitoring systems in seismically active zones is vital for building accurate databases, forecasting earthquakes, and ensuring earthquake-resistant infrastructure. The 1988 Spitak earthquake, which devastated Shirak and Lori, highlighted the need for strong seismic oversight. However, in 1991, Armenia's government transferred the seismic monitoring system from the National Academy of Sciences to other state bodies, initially the Ministry of Emergency Situations and, more recently, the Ministry of Internal Affairs. These institutions, often headed by non-specialists, lacked the scientific expertise required to manage such a highly specialized field. As a result, seismic R&D has stagnated; access to crucial earthquake data remains limited for professionals. This research aims to evaluate the current management efficiency of Armenia's seismic monitoring system using the ChatGPT model and address long-standing issues that persist despite the existence of numerous scientific publications on the subject. The findings could help inform future improvements in system oversight and access.



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1. INTRODUCTION

Armenia is situated in one of the most tectonically active and seismically hazardous regions of the world – the Caucasus. Throughout history, devastating earthquakes have caused significant human and economic losses across the territory of Armenia. The 1988 Spitak earthquake remains a tragic reminder of the importance of seismic preparedness, having resulted in over 25000 deaths and the destruction of critical infrastructure. This catastrophe exposed the country's vulnerability and underscored the crucial role of a well-

managed seismic monitoring system in mitigating future risks (Arefyev, 2008).

In response to this challenge, Armenia historically maintained a robust seismological research infrastructure. Until 1991, the seismic monitoring system was administered by the National Academy of Sciences of Armenia, specifically through the Nazarov Geophysics and Engineering Seismology Institute. This institution, staffed by leading scientists and specialists, played a central role in gathering, processing, and analyzing seismic data for both scientific and public

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safety purposes. However, in 1991, Armenia's government transferred the seismic monitoring system from the National Academy of Sciences to other state bodies, initially the Ministry of Emergency Situations and, more recently, the Ministry of Internal Affairs. These entities, often led by non-experts in seismology, lacked the scientific expertise required for efficient and informed management.

The consequences of this decision have been far-reaching. Despite the increase in the number of seismic stations and the development of advanced technologies, the overall efficiency and reliability of Armenia's seismic monitoring have diminished. Seismic data collection has become inconsistent, with many significant datasets now being no longer publicly accessible. Furthermore, important scientific developments and technical innovations in the field have not been effectively implemented within the system. This situation has hindered national security efforts and the advancement of earthquake forecasting and hazard mitigation.

Given the rising global emphasis on artificial intelligence (AI) in scientific research and decision-making, this research proposes a novel approach to evaluate the management efficiency of Armenia's seismic monitoring system by incorporating AI-based analysis. Specifically, the authors utilize the ChatGPT language model to simulate expert evaluations, examining structural weaknesses and policy deficiencies within the system. This approach enables an objective assessment of how managerial decisions have impacted scientific outcomes, data accessibility, and public safety.

The research aims to assess whether the current management framework aligns with the strategic needs of seismic risk mitigation in Armenia. Through historical comparison, technical data analysis, and AI-supported interpretation, the research seeks to identify critical gaps and recommend reforms. The research findings aim to support the development of a more transparent, scientifically grounded, and efficient monitoring system that can address current social needs and safeguard future generations.

2. METHODOLOGY

This research employs a mixed-methods approach combining historical analysis, comparative data assessment, and AI-based expert evaluation to assess the management efficiency of Armenia's seismic monitoring system from 1991 to 2024.

This research began with a historical overview of the seismic monitoring system in Armenia, focusing on two key periods:

- 1971–1991: Under the administration of the National Academy of Sciences of Armenia;

- 1991–2010 and beyond: Under the Ministry of Emergency Situations and the Ministry of Internal Affairs.

A set of earthquakes with magnitudes greater than 5 ($M > 5$) that occurred in Armenia from 736 AD to 2022 was compiled and analyzed. Parameters such as epicenter coordinates, intensity, magnitude, and casualty count were recorded and visualized using maps and tables. The authors analyzed the distribution of seismic stations and the travel times of P- and S-waves in 1971–1991 and 1991–2010. Graphical analyses were employed to assess the accuracy of seismic wave propagation results, providing insight into the reliability of baseline data processing.

To address policy and management-related questions, the authors used the ChatGPT language model to simulate expert analysis in the absence of transparent, published evaluations. The AI was prompted with key questions related to:

- The consequences of transferring management to non-scientific ministries;
- The impact of inaccessible or unpublished seismic data;
- The need for science-based governance of seismic systems.

ChatGPT's responses were analyzed for their alignment with international best practices and relevance to Armenia's context.

The authors evaluated the efficiency of the seismic monitoring system using the following comparative indicators:

- Quantity and quality of seismic data collected;
- Number and operational efficiency of monitoring stations;
- Accuracy of epicenter and magnitude determination;
- Accessibility and public availability of data;
- Involvement of qualified scientific personnel.

Performance during the NAS-administered period (1971–1991) was compared to that of the post-1991 period, considering quantitative outcomes and expert (AI-assisted) judgments.

3. RESULTS

The territory of the Republic of Armenia is located in a tectonically active and seismically hazardous zone of the Caucasus, where earthquakes with magnitudes of $M=6.8-7$ have occurred, classified as catastrophic (Table 1). Table 1 presents the dates, magnitudes, epicenter coordinates, intensities, and the number of casualties for earthquakes with a magnitude greater than 4.8 that have occurred within Armenia's territory.

Table 1. Earthquakes with magnitude greater than 5 ($M > 5$) in Armenia: epicenter coordinates, date, intensity, and the number of casualties

Date	Name of Earthquake	Location	Magnitude	Intensity	Epicenter Coordinates	Casualties
13.02.2022	Metsavan earthquake	Metsavan (RA)	5.3	6	41°09'36" N, 44°00'04" E	
07.12.1988	Spitak earthquake	Spitak, Leninakan	6.9	7	40°59'13" N, 44°11'06" E	>25,000
27.04.1931	Zangezur earthquake	Zangezur (USSR)	6.4	8–9	39°17'28" N, 45°57'00" E	
22.10.1926	Leninakan earthquake	Leninakan (USSR)			40°42' N, 43°42' E	300
1840	Yerevan earthquake	Yerevan	7.4	9	39°36'0" N, 44°6'0" E	10,000
1679	Garni earthquake	Garni/Yerevan	7.0	8	40°12'0" N, 44°42'0" E	>7,600
893	Dvin earthquake	Dvin (Kingdom of Armenia)	5.3–7	9–10	40°0'0" N, 44°24'0" E	>70,000
736	Daragalez earthquake					>10,000

Source: Developed by the authors.

According to Table 1, earthquakes in Armenia have caused thousands of deaths and inflicted significant economic damage on the country's development since 736 AD. The deadliest event was the 893 Dvin earthquake, which claimed over 70000 lives, followed by the 1988 Spitak earthquake, with more than 25000 casualties. Both earthquakes had estimated magnitudes of approximately $M \approx 7$.

Figure 1 presents the map of earthquakes with magnitudes greater than 4.5 ($M > 4.5$) in Armenia and surrounding regions.

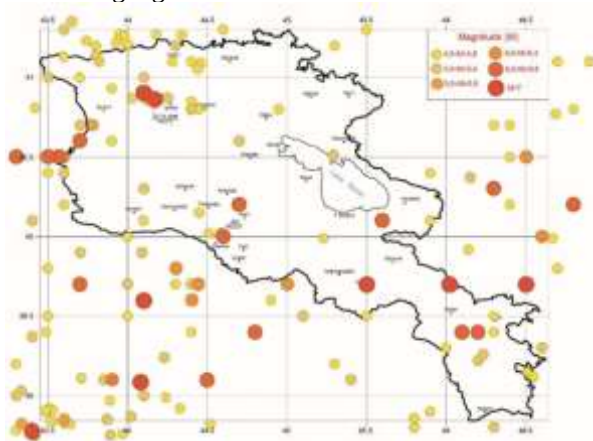


Figure 1. Map of earthquakes with magnitudes greater than 4.5 ($M > 4.5$) in Armenia and surrounding regions.

Source: Developed by the authors.

The data in Figure 1 underscore that Armenia lies in a seismically active zone and that every earthquake serves as a reminder to prepare for the next. Based on the available data, it is essential to evaluate the potential intensity of future seismic hazards, which requires the development and analysis of an accurate, comprehensive, and long-term database (Avetisyan et al., 2024).

Therefore, one of the most important tasks for ensuring the socio-economic stability and safety in the country is the effective management of seismic research.

Let us assess the socio-economic consequences of the Spitak earthquake and the resulting damage (Khachian, 2008). According to the calculations, the earthquake's coordinates were as follows:

$$\varphi = 40.867, \lambda = 44.199, h = 5 \text{ km.}$$

The earthquake affected 40% of the country's territory, home to about one million people. It claimed over 25000 lives, injured 19000 individuals, and left 500000 homeless. The total economic damage exceeded \$36 billion.

The number of casualties and the scale of destruction caused by the Spitak earthquake could have been significantly lower under the following conditions:

- 1) Availability of a comprehensive database, enabling accurate modeling of seismic activity patterns, reduction of seismic risks, and real-time assessment of the potential impact of impending earthquakes on human lives and infrastructure (Sargsyan et al., 2021);
- 2) Accurate evaluation of seismic zoning maps, correctly indicating an intensity of 10 points (or magnitude $M \approx 7$), rather than the underestimated 6–7 points ($M \approx 5$). According to the Gutenberg–Richter formula, which relates the energy released (E) during an earthquake to its magnitude (M): $\lg E = 1.5M + 11.8$ (Gutenberg–Richter, 1) or based on the empirical relationship we derived for the Caucasus region: $K = 5.23 + 1.35M$, where $K = \lg E$, calculations show that an earthquake of magnitude $M = 7$ releases approximately 32 times more energy than one of magnitude $M = 6$;

- 3) Buildings and structures were constructed to proper quality standards.

Given the existence of such facts, the Government of the Republic of Armenia should have prioritized the effective management and development of seismic scientific research because it is directly linked to national security, the loss of numerous human lives, and the decline of the country's economic capacities.

Seismological data are essential not only for the present but also for future generations for the following reasons:

- 1) Many problems remain unresolved, and nature may present new unexpected variations in earthquake strength, spatial distribution, and other aspects;
- 2) Each earthquake is a unique event. Any unrecorded occurrence may prove critical for assessing future seismic hazards;
- 3) Managing these complex processes effectively requires active involvement of the scientific community and highly qualified specialists in the field.

Since 1961, the Nazarov Institute of Geophysics and Engineering Seismology under the National Academy of Sciences of Armenia has served as the country's primary scientific authority in this field. It employed numerous Doctors and Candidates of Science, along with highly experienced specialists. However, in 1991, the Government of Armenia decided to transfer the seismic monitoring system from the National Academy of Sciences to institutions that were not governed on a scientific basis.

The aforementioned management approach led to the following consequences:

1. Since 1991, the fundamental data of earthquakes that have occurred in Armenia have not been published. Instead, it was transferred to various international organizations. In some cases, explosions have been misclassified and reported as earthquakes (Artemova & Mikhailova, 2014);
2. Qualitative analysis of earthquake bulletins indicates that the reliability of the collected data is insufficient for constructing Armenia's deep geological structure, developing 3D models, and solving several other scientific problems;
3. The monitoring system is not optimal, which is essential for reliably recording baseline data and improving the accuracy of processed results. Over time, the number of seismic stations fluctuated, initially increasing from 14 to 35, then declining back to 14. However, earthquake monitoring was often carried out using only 1 to 5 stations, meaning the system operated at just 3%–15% of its full capacity. This reflects significant managerial instability

within the seismic monitoring framework (Avetisyan et al., 2023; Burmin, et al., 2019);

4. The method currently used in Armenia to determine the main parameters of earthquakes cannot accurately resolve the issue of the spatial distribution of seismic events (Burmin et al., 2021).

Let us now assess the efficiency of the seismic monitoring system and the reliability of processing baseline data in 1971–1991 and 1991–2010. In the first period, the system was under the National Academy of Sciences of Armenia and consisted of 13 stations. During the second period, the system was first managed by the Government, later by the Ministry of Emergency Situations, and comprised 34 stations (Figure 2).

4. IMPLICATIONS

Among publicly listed organizations in the technology services sector, ServiceNow faces notable challenges in managing liquidity and is exploring effective solutions within its operational framework. This study proposes alternative approaches to assess the company's ability to service long-term, short-term, and total debt, considering its cash flow dynamics.

The findings of the evaluation are summarized as follows:

- Effective management of long-term debt is crucial for the financial health and strategic flexibility of technology service organizations. Sustainable debt management requires a multifaceted approach that includes prudent financial planning, regular performance evaluation, and alignment of debt structures with long-term business objectives;
- Strategic structuring of debt is a priority. Debt terms should align with the investment lifecycle to ensure repayment schedules coincide with revenue generation;
- Implementation of cash flow optimization measures is essential. Accurate forecasting and disciplined cash flow management help maintain sufficient liquidity to meet debt obligations without disrupting operations;
- Expense management and operational efficiency are key factors. Streamlining operations and reducing unnecessary expenditures can free up capital for debt servicing and reduce reliance on additional borrowing;
- Diversification of revenue streams through innovation and service expansion increases income sources, reduces financial risk, and supports more consistent debt repayment;
- Prioritization of technological investments allows concentration of capital on high-return projects, ensuring debt is used to create value rather than becoming an additional burden;

- Long-term debt management in technology service companies, particularly at ServiceNow, relates not only to financial engineering but also to organizational resilience, adaptability, and long-term value creation. Strategically managed, debt can serve as a powerful tool to foster innovation, scale operations, and strengthen competitive advantage.

Based on the research and analysis, the authors propose the following recommendations:

- Regularly review and update expense models, particularly for infrastructure, licenses, and labor costs;
- Utilize tools and historical data to forecast cash inflows and outflows accurately;
- Automate or improve invoice reconciliation, reduce payment cycles, and monitor overdue payments;
- Prioritize core expenditures, negotiate vendor terms, and manage payroll costs;

- Maintain a cash buffer to address unexpected deficits;
- Use credit lines, invoice factoring, or venture capital to cover shortfalls;
- Stabilize operational cash flows through improved billing systems, tracking of accounts receivable, and enhanced enterprise systems;
- Accelerate collection of receivables and negotiate payment terms, especially for recurring service contracts;
- Monitor liquidity using cash flow-to-debt ratios, free cash flow, and other cash-based indicators;
- Apply time-series analysis to forecast short-term cash flows and mitigate liquidity traps;
- Regularly monitor collections, payments, operating cash ratios, and cash-to-debt ratios;

Compare the company's collections, payments, and cash measurement indicators with peers to determine optimal positioning.

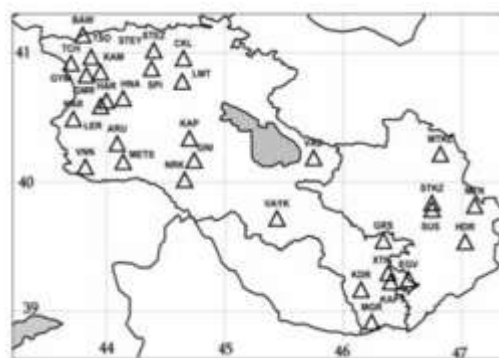
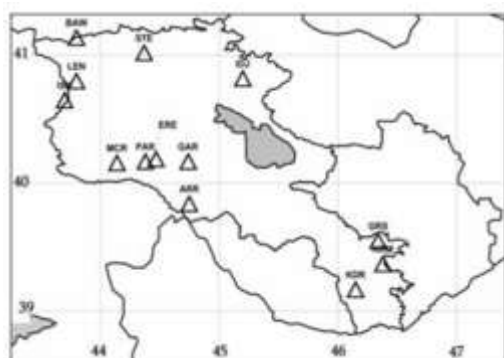


Figure 2. Distribution of seismic stations in Armenia during 1971–1990 and 1991–2010. Source: Developed by the authors.

Data analysis shows that the number of seismic stations in 1991–2010 was 2.6 times higher than in 1971–1990. Therefore, the modernization of the monitoring system should have contributed to improving the reliability of the results obtained from the processing of baseline data, especially considering that such modernization and maintenance required certain financial expenditures.

To clarify the issue of improving reliability, let us examine the time-dependence graphs of longitudinal (P) and transverse (S) seismic wave propagation for the specified time periods (Figure 3) (Avetisyan et al., 2023).

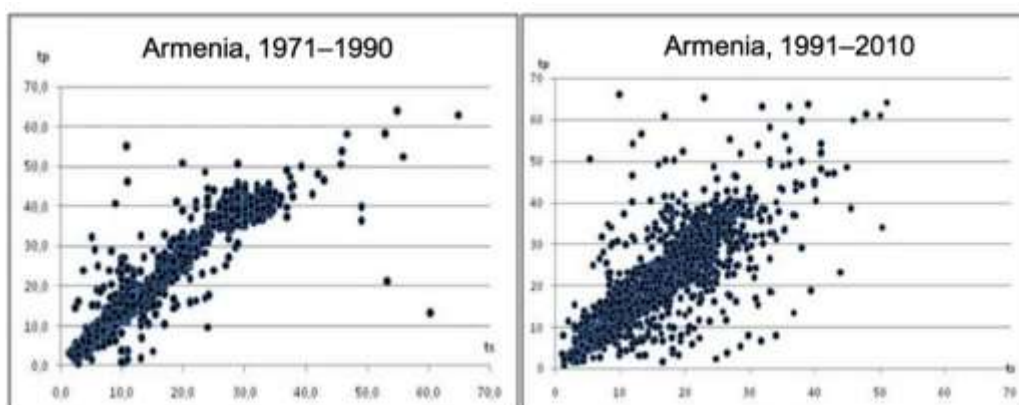


Figure 3. Graph of S-wave (transverse wave) travel time dependence on P-wave (longitudinal wave) travel time for earthquakes in Armenia in 1971–1991 and 1991–2010. Source: Developed by the authors.

According to Figure 3, although the number of seismic stations increased, the degree of scatter in the results obtained during the second period also increased. This indicates that the baseline and processed results have low accuracy.

Figure 4 evaluates the accuracy of epicenter determination based on the relative positions of seismic stations in Armenia (1991–1998).

Figure 4 shows the minimum energy-class earthquakes that can be recorded by the NSSP (National Seismic Survey Program) monitoring system. As evident from the data, in northwestern Armenia, where seismic stations are densely concentrated, the system can detect earthquakes of energy class 10 or magnitude 3.5, assuming each station operates with a magnification factor of 20000. In contrast, in the southwestern region, the system's sensitivity is significantly lower, allowing for the detection of only earthquakes with an energy class of 11.



Figure 4. Evaluation of epicenter determination accuracy based on the relative positions of seismic stations in Armenia (1991–1998). Source: Developed by the authors.

It should be noted that during the mentioned years, significant progress was made in terms of recording equipment, optimization of the monitoring system, and methods for processing baseline data. However, the results of research conducted in these areas were not implemented within the NSSP. As shown in Figures 3 and 4, this led to negative consequences.

Let us now clarify the answers to the raised questions with the help of AI.

Responding to the question of how the absence of subject-matter expertise in the leadership of the monitoring system can affect the development of scientific research, AI provides the following assessment: such a situation poses a serious challenge because it can impede the effective management of scientific research and the monitoring system. This scenario unfolded in Armenia after 1991.

Responding to the question of whether transferring the seismic monitoring system from the National Academy of Sciences of Armenia (NAS RA) to ministries such as the Ministry of Emergency Situations or the Ministry of Internal Affairs is advisable, AI offers the following assessment: for effective management, it is essential to uphold the principle of science-based governance. This can be achieved either by maintaining the system within an independent research center or within NAS RA, which possesses the necessary infrastructure and expertise to conduct advanced research in seismology and related fields.

Ultimately, regardless of the organizational structure, close cooperation with the research institutes of the Academy of Sciences and other relevant institutions is crucial. These institutes often possess the analytical, research, and technological capacities required for developing advanced seismic monitoring systems.

In response to the question of what consequences the unavailability or non-publication of baseline earthquake data since 1991 could have for scientific development and national security, AI states that this could lead to serious consequences. Without such data, the development of science may slow down, because specialists will be unable to study and analyze the information. This can hinder efforts in earthquake forecasting and early warning. Moreover, it may endanger national security because appropriate preventive measures cannot be effectively implemented. The current challenges in managing Armenia's seismic monitoring system indicate a pressing need for serious reforms in this field. These include the absence of science-based governance and a unified monitoring system, issues related to accurate data processing and accessibility, funding risks, and ineffective coordination between state agencies.

5. CONCLUSIONS

The aforementioned facts indicate that the seismic monitoring sector in Armenia urgently needs reforms. To achieve this, it is necessary to take the following steps:

- 1) For effective management of the seismic monitoring system, governance must be knowledge-based rather than administered by the Ministry of Internal Affairs or the Ministry of Emergency Situations. A professional council should be established, consisting of scientists and experienced specialists in the field;
- 2) A consolidated and optimized monitoring system, along with a centralized data repository, is essential for reliable seismic data analysis, accurate risk assessment, and improved disaster preparedness;
- 3) Global experience demonstrates that systems built on unified databases not only enhance the

efficiency of seismic data management but also attract qualified scientific personnel and enable more strategic allocation of financial resources.

If these reforms are implemented, Armenia will have a reliable and efficient seismic monitoring system that will contribute to the development of science and the enhancement of public safety.

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