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ИЗВЕСТИЯ
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ԲԱՐՁՐ ՏԵԽՆՈԼՈԳԻԱՆԵՐԻ ՏԵՂԵԿԱԳԻՐ
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Տեղեկագիրը հրատարակվում է Ակադեմիկոս Ի.Վ.Եղիազարովի ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտի, Հիդրավլիկական հետազոտությունների հայկական ազգային ասոցիացիայի, Երևանի կապի միջոցների գիտահետազոտական ինստիտուտի և Շուշիի տեխնոլոգիական համալսարանի կողմից: Հիմնադրվել է 2016թ.: Լույս է տեսնում տարեկան 4 անգամ:

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MODIFIED DIATOMACEOUS EARTH FOR EFFICIENT REMOVAL OF COPPER IONS FROM AQUEOUS SOLUTION

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Abstract

Heavy metal contamination in aquatic environments remains a considerable ecological threat, necessitating the development of cost-effective remediation technologies. Natural mineral sorbents, such as diatomaceous earth (DE), are valued for environmental remediation due to their affordability and inherent selectivity. This study investigates the synthesis and effectiveness of a sodium silicate-modified DE, specifically designed for the targeted adsorption of copper ions (Cu^{2+}) from wastewater. The modification process utilized a cost-effective sodium silicate solution to enhance the structural and surface properties of raw diatomaceous earth. To modify the substrate, raw DE was added to a diluted 0.5 M sodium silicate solution at a ratio of 5% sodium silicate by weight relative to the DE. The sodium-silicate-modified diatomaceous earth reduced the residual UV–Vis absorbance of the copper solution by approximately 50% compared with the unmodified material, indicating a substantially improved removal of dissolved copper species. The results demonstrate that sodium silicate modification significantly improves the material's structural stability and affinity for heavy metals, offering an efficient solution for industrial wastewater treatment.

***Keywords*:** adsorption; diatomaceous earth; copper; sodium silicate, heat treatment.

Introduction

Heavy metal contamination in aquatic environments continues to pose a significant environmental challenge. Conventional treatment methods, such as precipitation, ion exchange, membrane filtration, and activated carbon adsorption, are commonly utilized. However, these methods frequently incur high operational costs and exhibit limited selectivity for specific pollutants [1, 2].

Consequently, there is significant interest in developing affordable, highly efficient, and selective alternatives that facilitate the effective transfer of pollutants from liquid to solid phases [3, 4, 5]. Bio-sorbents, including bacteria, algae, and fungi, provide a variety of functional groups [7, 8]. In contrast, mineral sorbents such as zeolites, perlite, and clay rocks are particularly esteemed for their abundance and mechanical stability. These properties are especially advantageous when these sorbents are in granular forms, making them suitable for use in demanding aquatic environments [6,7,8].

Among these mineral matrices, diatomaceous earth (DE) stands out as an environmentally friendly, siliceous sedimentary rock [9].

Characterized by a highly porous structure, large specific surface area, lightweight nature, and high thermal reactivity, DE consists primarily of amorphous silica (SiO_2) alongside minor metal oxides (Al_2O_3, Fe_2O_3, and MgO) [10, 11, 12].

Although raw diatomaceous earth (DE) serves as an effective sorbent for a range of organic and inorganic compounds [13, 14], attaining high selectivity for particular heavy metal cations, without interference from co-existing ions, continues to represent a significant research challenge [15]. Surface modification presents an effective approach to addressing selectivity limitations. The integration of sodium silicate into the diatomite matrix confers both structural and chemical advantages: it serves as a binder to enhance structural stability and provides a plentiful source of active silanol (Si-OH) groups upon activation [16,17,18]. This modification transforms the morphology and textural properties of the diatomite, thereby substantially enhancing its surface reactivity and compatibility for the adsorption of target heavy metals.

The impurities present in natural diatomite can unfavorably impact the uptake of heavy metal ions from aqueous solutions [19].

Therefore, modification of the diatomite surface was necessary to optimize heavy-metal removal. A variety of methodologies can be used to modify the diatomite surface. Ediz et al. showed that the characteristics of diatomite are improved for use in filtration [20] when calcinated at 1000 ◦C. It was demonstrated that, through this process, the density and permeability of the diatomite were enhanced from 2.29 to 2.34 g/cm3 and from 2.15×10−14 to 4.74×10-13 m2, respectively. In this way, calcinated diatomite could be used successfully for filtration purposes. Most of the modifications cited here concern the inorganic functionalization of diatomite. In the past, this has been in the past the most common way to improve the selectivity and extraction performance of the material. However, the fact that diatomite may be considered as amorphous silica opens the way for functionalization purposes [21,22].

The study aimed to synthesize a sodium-silicate-modified diatomite, thoroughly characterize its modified physicochemical properties, and systematically assess its efficacy in selectively removing heavy metal ions from aqueous solutions. The use of sodium silicate offers several advantages, including low cost, non-toxic processing, a straightforward one-step modification route, thermal stabilization at a relatively low calcination temperature (400 °C), and the production of mechanically robust adsorbents suitable for continuous filtration systems.

Materials and Methods

The diatomaceous earth (DE) used in this study consisted of granulates with a grain size of 0.5–1 mm and was purchased from the "DIATOMITE" Research and Production Closed Joint-Stock Company (CJSC). Copper sulfate pentahydrate $CuSO4 \cdot 5H2O$ was utilized to prepare the experimental solutions at a fixed concentration of 0.5 g/L. Sodium silicate solution (liquid glass), characterized by the generalized formula $Na2O(SiO2)x \cdot xH2O$ was used as an inorganic binder and surface modifier.

Modification and Calcination of Diatomaceous Earth

To modify the substrate, raw DE was added to a diluted 0.5 M sodium silicate solution at a ratio of 5% sodium silicate by weight relative to the DE. The resulting slurry was thoroughly mixed for 60 minutes to ensure complete penetration of the sodium silicate into the microscopic pores of the DE. To synthesize a rigid, water-insoluble structure suitable for long-term filtration, the modified DE was calcined in a muffle furnace at 400°C for 2 hours.

Results and discussion

By using sodium silicate, the DE becomes a highly active silica surface that has superior mechanical stability in water filtration columns and an enhanced capacity to adsorb dissolved heavy metal contaminants compared to raw DE.

It increases the density of silanol groups (-Si-OH) on the surface. These groups act as chemical anchors that can either directly bind to certain heavy metal cations (Cu^{+2}) or serve as a bridge to attach other organic molecules. Sodium silicate acts as an excellent, chemically compatible inorganic binder. This enables the fabrication of stable pellets, beads, or granules that won't disintegrate when submerged in water.

Water glass deposits additional silica species on the diatomite surface:

$$Si{-}O^{-} + Cu^{2+} \rightarrow Si{-}O{-}Cu^{+} \quad (1)$$

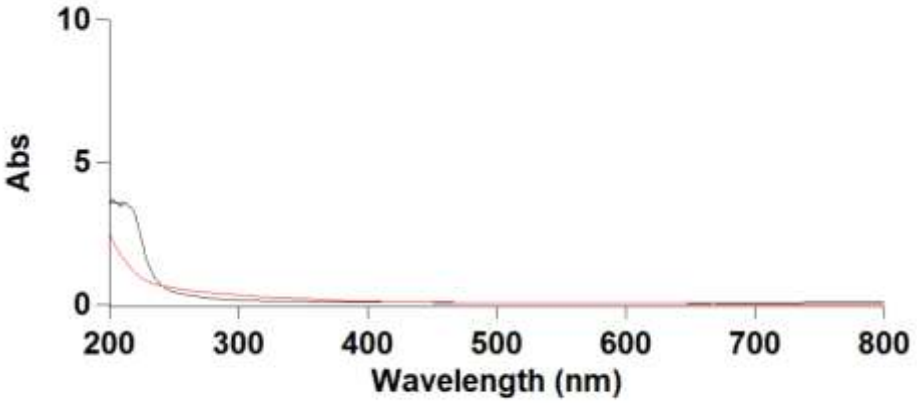

Fig.1 UV-Vis analysis of unmodified and modified DE

This increases the number of active silanol groups (Si–OH), which become negatively charged at neutral pH and attract Cu^{2+} ions. The calcination at 400 °C removes physically adsorbed water, improves pore accessibility, and strengthens the silica network. At 400 °C, the silica surface still retains hydroxyl groups necessary for metal binding.

The UV–Vis spectra revealed a pronounced absorption in the ultraviolet region below 230 nm, while negligible absorbance was observed at wavelengths above 300 nm. After

treatment with the adsorbent, the absorbance intensity decreased markedly, indicating a reduction in the concentration of dissolved copper-containing species. The absence of significant absorption bands in the visible region suggests either a low residual Cu^{2+} concentration or efficient removal of copper ions from the aqueous phase.

UV–Vis spectra of the $CuSO_4$ solutions before and after adsorption revealed a pronounced decrease in absorbance intensity in the 200–250 nm region after treatment. Before modification, the residual absorbance was approximately 3.6. After modification, the residual absorbance changed to 1.8. The sodium-silicate-modified diatomaceous earth reduced the residual copper concentration by approximately 50% compared with the unmodified diatomaceous earth, demonstrating a significant enhancement in adsorption performance.

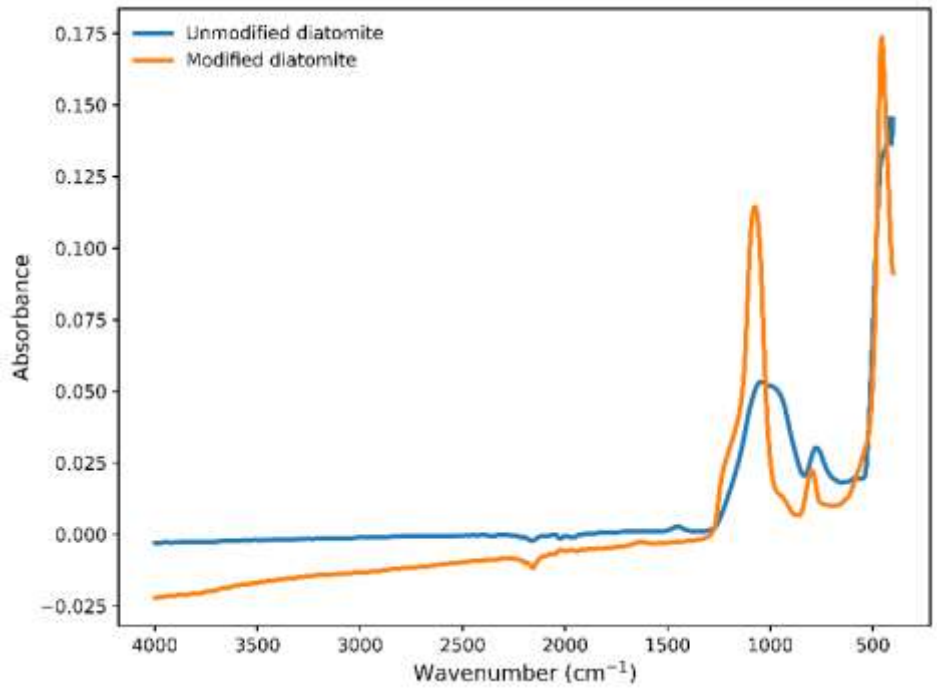

Fig. 2 FTIR analysis of unmodified and modified DE

The FTIR (Shimadzu IRTracer-100), spectra of both unmodified and modified diatomite display the characteristic absorption bands associated with silica-rich diatomite.

The predominant absorption band in the 1000–1100 cm^{-1} range is linked to the asymmetric stretching vibration of Si–O–Si bonds. Additionally, the bands near 790–800 cm^{-1} and approximately 460 cm^{-1} are attributed to the symmetric stretching and bending vibrations of the siloxane network, respectively. Post-modification, these characteristic silica bands persist, indicating that the treatment does not compromise the fundamental structure of diatomite. Nonetheless, slight variations in band intensity and broadening of the Si–O–Si absorption, along with a modest increase in the hydroxyl absorption region, imply alterations in the surface silanol groups and an increase in surface-bound hydroxyl species. These spectral modifications confirm successful surface modification while maintaining the original porous silica framework of the diatomite.

Conclusions

In this study, a high-performance functional material was successfully developed through the chemical modification of natural diatomite using sodium silicate. The systematic

characterization and subsequent performance evaluations yielded the following key conclusions:

- The sodium silicate modification successfully altered the surface characteristics of the raw diatomite. Analytical results from FTIR confirmed that the sodium silicate was uniformly distributed across the diatom frustules, introducing a high density of reactive silanol (Si-OH) groups and establishing strong Si-O-Si chemical bonds without destroying the underlying porous framework of the diatomite.
- The sodium-silicate modified diatomite exhibited outstanding efficiency when applied to adsorb heavy metals from wastewater. Specifically, before modification, the residual absorbance was approximately 3.6. After modification, the residual absorbance changed to 1.8. The modified material left 50% less copper in the solution compared to the unmodified material (a 50% reduction in residual copper).
- The research demonstrates a facile, cost-effective, and environmentally friendly strategy to upgrade low-cost natural diatomite into a high-value functional material. The excellent performance and straightforward synthesis route suggest that sodium-silicate modified diatomite holds immense potential for large-scale industrial applications in wastewater treatment.

References

1. Elsayed, E. 2011. Natural diatomite as an effective adsorbent for heavy metals in water and wastewater treatment (a batch study). Water Science 32(1), pp. 32-42, DOI: 10.1016/j.wsj.2018.02.001.
2. Ziying Bu, Ying Fang, Hanjie Chen, Mei Zhang, Fulong Wang. Study on the adsorption properties of organically modified diatomite for methylene blue. Scientific Reports volume 15, Article number: 27561 (2025)
3. Srivastava N.K., Majumder C.B. Novel Biofiltration Methods for the Treatment of Heavy Metals from Industrial Wastewater. J. Hazard. Mater. 2008;151:1–8. doi: 10.1016/j.jhazmat.2007.09.101.
4. Varma G., Misra A. Copper Contaminated Wastewater—An Evaluation of Bioremedial Options. Indoor Built Environ. 2018;27:84–95. doi: 10.1177/1420326X16669397.
5. R.M. Ali *et al.*, Potential of using green adsorbent of heavy metal removal from aqueous solutions: adsorption kinetics, isotherm, thermodynamic, mechanism and economic analysis. Ecol. Eng. (2016). https://doi.org/10.1016/j.ecoleng.2016.03.015
6. Wang, C. Chen, Biosorbents for heavy metals removal and their future, Biotechnol. Adv. 27 (2009) 195–226.
7. Al-Ghouti MA, Khraisheh MA, Allen SJ, Ahmad MN.J Environ Manage. The removal of dyes from textile wastewater: a study of the physical characteristics and adsorption mechanisms of diatomaceous earth. 2003 Nov;69(3):229-38. doi:10.1016/j.jenvman.2003.09.005.PMID: 14580724
8. Hydrophobization of diatomaceous earth used to remove oil pollutants Elżbieta Vogt, Karolina Topolska, Gospodarka Surowcami Mineralnymi, Mineral Resources Management 2023;39(2):209-222, DOI: https://doi.org/10.24425/gsm.2023.145888

9. Al-Ghouti MA, Khraisheh MA, Allen SJ, Ahmad MN.J Environ Manage. The removal of dyes from textile wastewater: a study of the physical characteristics and adsorption mechanisms of diatomaceous earth. 2003 Nov;69(3):229-38. doi:10.1016/j.jenvman.2003.09.005.PMID: 14580724
10. J. Ö. Demirbas *et al.*, Removal of copper ions from aqueous solutions by hazelnut shell, J. Hazard. Mater., (2008), DOI: 10.1016/j.jhazmat.2007.09.012
11. Wang J., Guo X Adsorption isotherm models: Classification, physical meaning, application and solving method, Chemosphere • Volume 258 • 2020 • Article 127279
12. Yan Zhao, Guangyan Tian, Xinhui Duan**,** Xiuhong Liang, Junping Meng, Jinsheng Liang. Review**,** June 11, 2019 Environmental Applications of Diatomite Minerals in Removing Heavy Metals from Water.
13. Tian, L.; Zhang, J.; Shi, H.; Li, N.; Ping, Q. Adsorption of Malachite Green by Diatomite: Equilibrium Isotherms and Kinetic Studies. J. Dispers. Sci. Technol. 2016, 37, 1059–1066.
14. Wu CD, Zhang JY, Wang L, He MH. Removal of aniline and phenol from water using raw and aluminum hydroxide-modified diatomite. Water Sci Technol. 2013;67(7):1620-6. doi: 10.2166/wst.2013.038.
15. Angela F. Danil de Namor, Abdelaziz El Gamouz, Sofia Frangie, Vanina Martinez, Liliana Valiente, Oliver A. Webb, Turning the volume down on heavy metals using tuned diatomite, Journal: Journal of Hazardous Materials (2012), DOI:10.1016/j.jhazmat.2012.09.030
16. Wanga, S. and Peng, Y. 2010. Natural zeolites as effective adsorbents in water and wastewater treatment. Chemical Engineering Journal 156, pp. 11–24, DOI: 10.1016/j.cej.2009.10.029.
17. Vogt, E. and Płachta, Ł. 2017. The new method of modifying the hydrophobic properties of expanded perlite, E3S Web Conf., 14, DOI: 10.1051/e3sconf/20171402034
18. Sriram et al. 2020 – Sriram, G., Uthappa, U.T., Losic, D., Kigga, M., Jung, H.Y. and Kurkuri, M.D. 2020. Mg–Al -Layered Double Hydroxide (LDH) modified diatoms for highly efficient removal of Congo Red from aqueous solution. Applied Science 10(7), DOI: 10.3390/app10072285
19. Bilgin, M., Tulun, S., 2015. Use of diatomite for the removal of lead ions from water: thermodynamics and kinetics. May 2015. Biotechnology & Biotechnological Equipment 29(4):1-9. DOI: 10.1080/13102818.2015.1039059
20. Patil, P.; Bhat, M.P.; Gatti, M.G.; Kabiri, S.; Altalhi, T.; Jung, H.Y.; Losic, D.; Kurkuri, M. Chemodosimeter functionalized diatomaceous earth particles for visual detection and removal of trace mercury ions from water. Chem. Eng. J. 2017, 327, 725–733.
21. J. Zhu, P. Wang, X. Qu, W. Luo, M. Lei, Adsorption of Pb2+ ions on diatomite modified by polypropylene acetamide and barium chloride in aqueous solution, Afr. J. Agric. Res. 7 (2012) 3614–3620.
22. N. Ediz, I˙. Bentli, I˙. Tatar, Improvement in filtration characteristics of diatomite by calcination, Int. J. Miner. Process. 94 (2010) 129–134.

M.A. Kalantaryan, A.K. Harutyunyan
MODIFIED DIATOMACEOUS EARTH FOR EFFICIENT REMOVAL OF COPPER IONS FROM AQUEOUS SOLUTION

ՄՈԴԻՖԻԿԱՑՎԱԾ ԴԻԱՏՈՄԻՏ՝ ՋՐԱՅԻՆ ԼՈՒԾՈՒՅԹԻՑ ՊՂՆՁԻ ԻՈՆՆԵՐԻ ԱՐԴՅՈՒՆԱՎԵՏ ՀԵՌԱՑՄԱՆ ՀԱՄԱՐ

Մ.Ա. Քալանթարյան[1], **Ա.Կ. Հարությունյան**[2]
[1]*Ճարտարապետության և շինարարության Հայաստանի ազգային համալսարան*
[2]*Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ*

Ջրային միջավայրերում ծանր մետաղներով աղտոտումը հանդիսանում է զգալի էկոլոգիական սպառնալիք, ինչը անհրաժեշտ է դարձնում մշակել ծախսարդյունավետ վերականգնման տեխնոլոգիաներ: Բնական հանքային սորբենտները, ինչպիսիք են դիատոմիտը, գնահատվում են շրջակա միջավայրի վերականգնման համար՝ իրենց մատչելիության և բնածին ընտրողականության շնորհիվ: Այս աշխատանքում ուսումնասիրվել է նատրիումի սիլիկատով ձևափոխված դիատոմիտի գործընթացը և արդյունավետությունը, որը նախատեսված է կեղտաջրերից պղնձի իոնների (Cu^{2+}) ադսորբցիայի համար: Ձևափոխման գործընթացում օգտագործվել է ծախսարդյունավետ նատրիումի սիլիկատի լուծույթ: Մոդիֆիկացված նյութի կառուցվածքային ամբողջականությունը և ֆիզիկական բնութագրերը գնահատվել են ջրի կլանման արդյունքների միջոցով: Հետագայում անցկացվել են խմբաքանակային ադսորբցիայի փորձեր՝ ձևափոխված դիատոմիտի արդյունավետությունը պղնձի իոնները հեռացնելու գործում գնահատելու համար: Արդյունքները ցույց են տվել, որ նատրիումի սիլիկատով մակերևույթի ձևափոխումը զգալիորեն բարելավում է նյութի կառուցվածքային կայունությունը և ծանր մետաղների նկատմամբ հակվածությունը՝ ստեղծելով արդյունավետ լուծում, արդյունաբերական կեղտաջրերի մաքրման համար:

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МОДИФИЦИРОВАННЫЙ ДИАТОМИТ ДЛЯ ЭФФЕКТИВНОГО УДАЛЕНИЯ ИОНОВ МЕДИ ИЗ ВОДНОГО РАСТВОРА

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Загрязнение водных сред тяжелыми металлами представляет собой серьезную экологическую угрозу, что обусловливает необходимость разработки экономически эффективных технологий очистки. Природные минеральные сорбенты, такие как диатомит, ценятся для очистки окружающей среды благодаря своей доступности и присущей им селективности. В данной работе исследовались синтез и эффективность модифицированного силикатом натрия диатомита для адсорбции ионов меди (Cu^{2+}) из сточных вод. В процессе модификации использовался экономически эффективный раствор силиката натрия. Структурная целостность и физические характеристики модифицированного материала оценивались по результатам водопоглощения. Затем были проведены эксперименты по адсорбции в периодическом режиме для оценки эффективности модифицированного диатомита в удалении меди из загрязненных вод. Результаты показали, что модификация силикатом натрия значительно улучшает

структурную стабильность материала и его восприимчивость к тяжелым металлам, предлагая эффективное и масштабируемое решение для очистки промышленных сточных вод.

Ключевые слова: адсорбция; диатомитовая земля; медь; силикат натрия; термическая обработка

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ENGINEERING ASSESSMENT OF THE REALISM OF PRELIMINARY INVESTMENT COST ESTIMATES: THE CASE OF THE FERIK COMMUNITY MULTIFUNCTIONAL COMMUNITY CENTER

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Abstract

Public investment projects require realistic preliminary cost estimates to ensure effective planning, financing, and implementation. However, early-stage investment budgets are often prepared without a comprehensive engineering assessment, resulting in significant discrepancies between the proposed budget and the actual project cost.

The aim of this study is to develop an engineering approach for assessing the realism of preliminary investment cost estimates and to demonstrate its application through a case study of the proposed multifunctional community center in Ferik Community, Armavir Province, Republic of Armenia.

The research involved a comprehensive engineering assessment of all major project components, including design works, geotechnical investigations, structural systems, underground protective facilities, architectural works, building engineering systems, fire protection measures, external utilities, and site development. The evaluation was performed under theoretically most favorable engineering and construction conditions in order to determine the minimum realistic investment cost.

The results indicate that the proposed preliminary investment budget of AMD 80.0 million is insufficient to ensure complete project implementation. The engineering assessment estimated the theoretical minimum project cost at AMD 207.8 million (including VAT), while the practical investment cost, considering typical engineering and construction uncertainties, is expected to reach approximately AMD 270 million.

The study demonstrates that comprehensive engineering assessment should become an integral part of preliminary investment planning in order to improve financial realism, reduce implementation risks, and enhance the efficiency of public infrastructure investments.

***Keywords*:** public investment project; preliminary cost estimate; engineering assessment; financial realism; community infrastructure; multifunctional community center.

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ENGINEERING ASSESSMENT OF THE REALISM OF PRELIMINARY INVESTMENT COST ESTIMATES: THE CASE OF THE FERIK COMMUNITY MULTIFUNCTIONAL COMMUNITY CENTER

Introduction

Public infrastructure investment projects are among the most important instruments for regional development, the improvement of community services, and the enhancement of the population's quality of life. The effectiveness of such projects depends not only on the quality of their technical solutions but also on the accuracy of preliminary investment cost estimation. Preliminary cost estimates constitute one of the fundamental starting points for project planning, financing, procurement procedures, and subsequent implementation. Therefore, their reliability has a direct influence on the overall feasibility and successful realization of investment projects.

In practice, preliminary investment costs are frequently established on the basis of limited initial information without a comprehensive engineering assessment. In many cases, only an overall financial framework is presented, without detailed justification based on architectural and structural solutions, engineering systems, fire protection measures, or external infrastructure components. As a result, the preliminary investment estimate may differ substantially from the actual financial resources required for project implementation, leading to project redesign, additional financing requirements, phased construction, or even project cancellation.

International experience demonstrates that the underestimation of preliminary costs represents a systemic challenge in infrastructure investment projects. The scientific literature has extensively documented the phenomena of *optimism bias* and *strategic misrepresentation*, both of which contribute to preliminary budgets that frequently fail to reflect actual project costs. At the same time, most existing studies focus primarily on cost overruns observed during project implementation or after project completion, whereas the methodology for comprehensive engineering assessment at the preliminary investment planning stage remains comparatively underexplored.

This issue is particularly significant for public community buildings, where preliminary investment cost estimation requires a comprehensive engineering approach. Such projects include not only the principal building structure but also numerous interrelated engineering systems, fire protection installations, external utility networks, site development works, and, where applicable, civil protection facilities designed in accordance with applicable safety requirements. The omission of any of these essential components may significantly compromise the financial realism of the proposed investment project.

The objective of this study is to perform an engineering assessment of the realism of preliminary investment cost estimates for public infrastructure projects and to propose a systematic evaluation approach based on the sequential assessment of all mandatory structural and engineering components included in the project scope. As a case study, the research examines the investment project for the construction of a multifunctional community center in Ferik Community, Armavir Province, Republic of Armenia. The study includes a comprehensive techno-economic assessment of the project's principal design, construction, and engineering components in order to determine its theoretical minimum realistic investment cost and to compare this value with the preliminary financial framework proposed for the project.

The findings of this research may contribute not only to the evaluation of the selected case study but also to the improvement of methodologies for preliminary investment cost estimation in public infrastructure projects, thereby enhancing the reliability of investment planning, strengthening the justification of financing decisions, and promoting the more efficient use of public financial resources.

Literature Review

The assessment of preliminary investment costs has become one of the major research areas in infrastructure project management and public investment planning over the past decades. The accuracy of preliminary cost estimates is widely recognized as a fundamental prerequisite for technical feasibility, sound financing decisions, and the successful implementation of public investment projects [1–6]. Both academic literature and professional practice emphasize that decisions made during the early stages of project development largely determine the overall investment framework, the quality of engineering solutions, and the efficiency of subsequent project execution [1,2,4].

A variety of methodologies have been developed for preliminary cost estimation, differing in terms of the amount of available information and the expected level of estimation accuracy. The most widely adopted approaches include conceptual, analogous, parametric, elemental, and detailed engineering estimating methods [1,2]. The AACE International Cost Estimate Classification System categorizes estimates according to the maturity of project definition and the completeness of available information, emphasizing that estimates prepared during the early project stages inherently involve significant uncertainty and therefore require appropriate contingency allowances [3]. Similar principles are incorporated into the PMBOK® Guide and ISO 21502, where cost estimation is considered an integral component of project planning and is closely linked to risk management, decision-making, and project governance [4–6].

Preliminary cost estimation is also closely associated with the economic appraisal of public investment projects. International guidelines, including HM Treasury's *Green Book*, the European Commission's *Guide to Cost–Benefit Analysis of Investment Projects*, and OECD recommendations, emphasize the importance of reliable financial estimates, cost–benefit analysis, and the efficient allocation of public resources during investment planning [9–12]. Nevertheless, these methodologies primarily focus on economic appraisal and financial evaluation while paying comparatively limited attention to the engineering completeness of the proposed project as a prerequisite for realistic cost estimation.

A substantial body of research has investigated the causes of cost overruns in infrastructure projects. The pioneering studies of Flyvbjerg and co-authors demonstrated that the underestimation of project costs is not merely the consequence of technical uncertainty but also results from systematic phenomena such as *optimism bias* and *strategic misrepresentation* [13–15]. Their findings indicate that preliminary budgets are frequently based on overly optimistic assumptions, resulting in significant cost overruns, additional financing requirements, and schedule delays during project implementation [13–15].

More recently, increasing attention has been devoted to the Reference Class Forecasting methodology, which seeks to improve forecasting accuracy by comparing

proposed projects with statistically relevant historical project data [16]. This approach substantially reduces subjective bias and enhances the reliability of investment forecasts. However, it remains primarily based on historical comparisons and does not evaluate whether the engineering scope of the proposed project itself is complete and sufficiently defined before estimating its cost.

The reviewed literature indicates that existing methodologies mainly address three major issues: preliminary cost estimation, financial risk assessment, and the prediction of cost overruns [1–16]. However, very limited attention has been given to systematic approaches that evaluate the engineering completeness of an investment project before determining its preliminary cost. In particular, current methodologies rarely examine whether all mandatory architectural, structural, engineering, fire protection, external infrastructure, and supporting components required for project implementation have been properly identified and incorporated into the proposed investment budget. In practice, omissions at this stage frequently become one of the principal causes of unrealistic preliminary investment estimates.

The present study addresses this research gap by proposing a new methodological framework entitled **Engineering Completeness-Based Investment Assessment (ECIA)**. The proposed framework is founded on the principle that the realism of a preliminary investment cost estimate can only be ensured after systematically verifying the engineering completeness of the project. ECIA introduces a structured procedure for identifying and evaluating all mandatory structural, architectural, engineering, and supporting project components prior to cost estimation. This approach enables the determination of the theoretical minimum realistic investment cost, facilitates the identification of deficiencies in preliminary investment estimates, and contributes to more reliable public investment planning and decision-making.

Materials and Methods

Research Design

This research employs an engineering-based case study methodology to evaluate the realism of preliminary investment cost estimates for public infrastructure projects. The study combines qualitative engineering analysis with quantitative cost assessment in order to examine whether the proposed investment budget adequately reflects the complete engineering scope of the project.

Unlike conventional studies that investigate cost overruns after project implementation, the present research focuses on the earliest stage of the investment cycle, where the preliminary project budget is initially established and investment decisions are made. The proposed methodology therefore evaluates not only the monetary value of the investment estimate but also the engineering completeness of the project before construction begins.

The research is based on a single case study involving the proposed Multifunctional Community Center of Ferik Community, Armavir Province, Republic of Armenia. The project was selected because it represents a typical public investment project incorporating architectural, structural, mechanical, electrical, plumbing, fire protection, external infrastructure, landscaping, and civil protection components within a single integrated facility.

Such complexity provides an appropriate basis for evaluating the completeness and realism of preliminary investment estimates.

Engineering Completeness-Based Investment Assessment (ECIA)

The principal methodological contribution of this research is the development of the **Engineering Completeness-Based Investment Assessment (ECIA)** framework.

The ECIA methodology is based on the assumption that a preliminary investment estimate cannot be considered realistic unless every mandatory engineering component required for complete project implementation has first been identified and evaluated. Consequently, engineering completeness is regarded as a prerequisite for financial realism.

The proposed framework consists of four consecutive stages.

Stage 1. Project decomposition

The investment project is systematically decomposed into all mandatory engineering, construction, and supporting components required for implementation. Each component is considered an independent assessment unit.

Stage 2. Engineering completeness assessment

Each project component is examined to determine whether it has been included in the investment programme. The assessment covers, as applicable:

- engineering investigations;
- architectural design;
- structural design;
- electrical systems;
- heating, ventilation and air-conditioning systems;
- water supply and sewerage systems;
- fire protection systems;
- external utility networks;
- civil protection facilities;
- construction works;
- site development and landscaping;
- technical equipment and commissioning activities.

If one or more mandatory components are absent, the investment programme is considered engineeringly incomplete.

Stage 3. Component-based cost assessment

Every identified component is independently evaluated using engineering judgement, current construction practice, applicable technical standards, and realistic market-based construction costs. The objective is to determine the minimum technically feasible investment required for complete implementation of each project component.

Stage 4. Investment realism assessment

The theoretical minimum realistic investment cost is calculated as:

$$CTR = \sum C_i (i = 1 \dots n)$$

where: CTR – theoretical minimum realistic investment cost; C_i – estimated cost of the i-th mandatory project component; n – total number of mandatory project components included in the assessment.

Data Sources

The assessment was based on:

- the publicly available investment concept and project documentation;
- applicable Armenian construction regulations and technical standards;
- engineering design requirements for public buildings;
- current construction practice;
- engineering expert judgement regarding mandatory project components;
- realistic construction cost estimates under favourable implementation conditions.

No statistical forecasting or historical regression models were applied, since the objective of the study is to evaluate engineering completeness rather than predict future construction costs.

Assessment Procedure

The ECIA methodology was implemented according to the following sequence:

1. Review of the investment concept and identification of the proposed project scope.
2. Decomposition of the project into mandatory engineering and construction components.
3. Verification of the engineering completeness of the investment programme.
4. Independent engineering assessment of each mandatory project component.
5. Determination of the theoretical minimum realistic investment cost.
6. Comparison between the calculated investment value and the proposed preliminary investment budget.
7. Interpretation of the identified differences and evaluation of their implications for public investment planning.

Research Assumptions

To ensure consistency of assessment, the following assumptions were adopted:

- favourable geotechnical conditions;
- readily available utility connections;
- favourable construction logistics;
- technically compliant but economically efficient engineering solutions;
- market-based construction prices representative of normal implementation conditions.

These assumptions represent the most favourable realistic implementation scenario and therefore establish the minimum investment level required for complete project implementation.

Research Limitations

The ECIA methodology evaluates the realism of preliminary investment estimates from an engineering perspective. It does not assess procurement procedures, contractor performance, inflation, market volatility, contractual disputes, or construction-phase risks.

Accordingly, the calculated value should not be interpreted as the expected contract price. Instead, it represents the **theoretical minimum realistic investment cost** required to implement a technically complete project. This value serves as an engineering benchmark against which the adequacy of preliminary investment estimates can be objectively evaluated.

Conflict Setting

The preliminary estimation of public investment costs represents one of the most critical stages of investment planning, as it forms the basis for fundamental decisions regarding

project financing, design, procurement, and implementation. In practice, however, preliminary investment estimates are frequently developed using limited technical information and are often presented as aggregate financial values without a systematic assessment of the engineering completeness of the proposed project.

The existing scientific literature primarily focuses on cost overruns, forecasting inaccuracies, and the factors contributing to budget deviations observed during or after project implementation. Although these studies have substantially improved the understanding of project risk and cost management, they mainly address problems identified during project execution rather than the fundamental issue that exists at the earliest stage of investment decision-making.

The central conflict addressed in this research arises from the fact that the financial realism of preliminary investment estimates is commonly evaluated without first determining whether all mandatory architectural, structural, engineering, fire protection, external infrastructure, and supporting components required for complete project implementation have been identified and incorporated into the investment programme. Consequently, even a financially well-justified estimate may fail to represent the actual investment requirements if the engineering scope of the project is incomplete.

This contradiction is particularly evident in multifunctional public buildings, where numerous interrelated engineering systems must operate as a single integrated facility. The omission or inadequate consideration of any mandatory project component may lead to substantial underestimation of the preliminary investment cost and subsequently generate additional design revisions, financing requirements, and implementation challenges.

The present study addresses this research conflict by proposing the **Engineering Completeness-Based Investment Assessment (ECIA)** framework. The proposed methodology is founded on the principle that the engineering completeness of an investment project should be systematically verified before evaluating the realism of its preliminary investment cost. This approach makes it possible to distinguish genuine financial insufficiency from deficiencies in the engineering scope of the project and provides a more objective and technically justified basis for assessing the realism of preliminary investment estimates in public infrastructure projects.

Research Results

Characteristics of the Case Study Project

The case study selected for this research is the investment project for the construction of the Multifunctional Community Center in Ferik Community, Armavir Province, Republic of Armenia. The project involves the construction of a single-storey public building intended to provide administrative, cultural, educational, social, and civil protection services for the local community.

The proposed facility includes administrative offices, a multifunctional hall with a stage, a library, youth and educational spaces, a medical room, technical service rooms, sanitary facilities, and an underground multifunctional civil protection shelter designed in accordance with the applicable civil protection requirements. In addition to the building itself,

the investment project includes external engineering utility networks, site development works, and all supporting systems necessary for the complete operation of the facility.

According to the published investment proposal, the preliminary investment cost of the project is AMD 80.0 million**.** However, the available documentation does not provide a detailed engineering justification for the proposed investment estimate or a breakdown of the costs associated with individual project components. Consequently, it is not possible to determine whether the proposed financial framework is sufficient to ensure the complete implementation of the project.

These characteristics make the Ferik Multifunctional Community Center an appropriate case study for applying the proposed **Engineering Completeness-Based Investment Assessment (ECIA)** framework. The project's multidisciplinary engineering structure provides an opportunity to evaluate how engineering completeness influences the realism of preliminary investment estimates and to demonstrate the extent to which a systematic engineering assessment can improve the reliability of public investment planning and decision-making.

Engineering Completeness Assessment

The first stage of the ECIA methodology consisted of evaluating the engineering completeness of the investment project. The objective of this assessment was to determine whether the investment programme included all mandatory components required for the complete design, construction, and operation of the proposed facility.

For this purpose, the investment project was systematically decomposed into individual structural, engineering, and supporting components. The presence of each component was evaluated in accordance with applicable construction regulations, engineering design requirements, and generally accepted professional practice for the design and construction of public buildings.

The assessment identified the following principal project components:

- engineering geological and geodetic investigations;
- architectural design;
- structural design;
- external and internal electrical systems;
- heating, ventilation, and air-conditioning (HVAC) systems;
- internal and external water supply and sewerage systems;
- fire protection systems;
- underground multifunctional civil protection shelter;
- construction works;
- site development and landscaping;
- technical equipment and supporting systems;
- preparation of cost estimates and technical specifications;
- printing and submission of project documentation.

The assessment demonstrated that the complete implementation of the project requires a considerable number of interrelated design, construction, and engineering activities, each representing an independent technical and financial component of the overall investment

programme. Consequently, the realism of the preliminary investment estimate can only be evaluated when all mandatory project components are considered simultaneously.

Within the ECIA framework, each identified component was treated as an independent contributor to the total investment cost. This approach makes it possible not only to evaluate the overall financial requirements of the project but also to identify those components whose omission or underestimation may substantially affect the realism of the preliminary investment estimate.

The results of the engineering completeness assessment are summarized in Tab. 1**,** which presents all mandatory design, construction, engineering, and supporting components included in the ECIA evaluation.

Table 1

Mandatory Design, Construction, and Engineering Components Identified within the ECIA Framework

No.	Component	No.	Component	No.	Component
1	Engineering geological investigations	15	Printing and submission of project documentation	29	Sanitary fixtures and plumbing equipment
2	Geodetic investigations	16	Site preparation works	30	Installation of the heating system
3	Architectural design	17	Earthworks	31	Installation of the ventilation system
4	Structural design	18	Construction of the underground civil protection shelter	32	Internal electrical installation works
5	External electrical system design	19	Foundations and foundation structure	33	Installation of internal water supply and sewerage systems
6	Internal electrical system design	20	Structural framework	34	Installation of the automatic sprinkler fire protection system
7	Heating system design	21	External walls	35	Automatic fire detection and alarm system
8	Ventilation system design	22	Roof construction	36	Smoke extraction system (civil protection shelter)
9	Water supply and sewerage system design	23	External doors and windows	37	External site lighting
10	Fire protection system design	24	Internal partition walls	38	Septic tank construction
11	Civil protection shelter design	25	Internal doors	39	Site development and landscaping
12	Site development and landscaping design	26	Floor construction and finishing	40	Perimeter fencing and entrance gate
13	Preparation of cost estimates and technical specifications	27	Ceiling finishing works		
14	Preparation of project documentation	28	Internal finishing works		

Component-Based Investment Cost Assessment

Following the engineering completeness assessment, the second stage of the ECIA methodology involved the cost assessment of all mandatory project components. Each component was evaluated independently, taking into account its technical complexity, scope

of work, applicable regulatory requirements, current construction practices, and realistic market-based construction costs in the Republic of Armenia.

To ensure the consistency and comparability of the assessment, all calculations were performed under the same fundamental assumptions. The analysis assumed the most favorable realistic implementation conditions, including favorable geotechnical conditions, readily available utility connections, the absence of major technical constraints, and the application of technically compliant and economically efficient engineering solutions.

Under these assumptions, the objective was not to estimate the probable market value of the project, but rather to determine its **theoretical minimum realistic investment cost**, representing the minimum financial resources required to implement a technically complete project.

Particular attention was devoted to project components that are frequently omitted or insufficiently considered during the preliminary estimation stage of public investment projects. These include the underground civil protection shelter, ventilation and smoke extraction systems, fire protection systems, external engineering infrastructure, site development and landscaping works, as well as the complete preparation of design documentation, cost estimates, and technical specifications.

The estimated costs of all mandatory project components are presented in Tab. 2**.** The sum of these component costs was used to determine the theoretical minimum realistic investment cost of the project, which subsequently served as the basis for the comparative analysis presented in the following section.

Table 2

Estimated Costs of Mandatory Project Components

No.	Project Component	Cost (AMD million)	No.	Project Component	Cost (AMD million)	No.	Project Component	Cost (AMD million)
1	Engineering investigations		6	External walls, roof, doors and windows		11	Electrical systems	
2	Design services (all disciplines)	**3.2**	7	Internal partitions and finishing works		12	Fire protection systems	
3	Site preparation and earthworks		8	Heating system		13	External engineering infrastructure	
4	Underground civil protection shelter		9	Ventilation and smoke extraction systems		14	Site development and landscaping	
5	Foundations and structural framework		10	Water supply and sewerage systems		15	Perimeter fencing and entrance gate	
Total	**Theoretical minimum realistic investment cost**	**207.8**						

Comparative Analysis of the Preliminary Investment Estimate and the ECIA Assessment

The application of the ECIA methodology determined that the **theoretical minimum realistic investment cost** for the construction of the Multifunctional Community Center in Ferik Community is AMD 207.8 million**.** This value represents the minimum financial requirement necessary to implement a technically complete project incorporating all mandatory design, construction, engineering, and supporting components.

For comparison, the published preliminary investment estimate for the project amounts to **AMD 80.0 million**, which is substantially lower than the value obtained through the ECIA assessment. The difference between the two estimates is **AMD 127.8 million**, indicating that the ECIA-based estimate is approximately 2.6 times higher than the proposed preliminary investment budget.

It should be emphasized that the **AMD 207.8 million** obtained through the ECIA methodology does **not** represent the expected contract value or the final construction cost of the project. Instead, it represents the **theoretical minimum realistic investment cost** under the most favorable implementation conditions, assuming a technically complete project and economically efficient engineering solutions that fully comply with applicable technical requirements. Under actual construction conditions, factors such as site-specific characteristics, market fluctuations, inflation, logistical constraints, and other project-specific uncertainties may result in higher implementation costs.

These findings demonstrate that, even under the most favorable engineering and economic assumptions, the published preliminary investment estimate is insufficient to ensure the complete implementation of the project. Therefore, the observed discrepancy cannot be attributed solely to market price variations or normal estimation uncertainty but rather reflects a substantial inconsistency between the preliminary investment estimate and the actual engineering requirements of the proposed project.

The comparative results of the published preliminary investment estimate and the ECIA assessment are presented in Tab. 3**.**

Table 3.

Comparison of the Preliminary Investment Estimate and the ECIA Assessment

Indicator	Value
Published preliminary investment estimate	AMD 80.0 million
ECIA-based theoretical minimum realistic investment cost	AMD 207.8 million
Absolute difference	AMD 127.8 million
Ratio (ECIA / preliminary estimate)	2.60
Difference (%)	159.8%

Engineering Interpretation of the Results

The results of the ECIA assessment demonstrate that the realism of a preliminary investment estimate depends not only on the accuracy of cost calculations but, more fundamentally, on the completeness of the engineering scope considered during project planning. The comparative analysis indicates that the published preliminary investment

estimate does not adequately reflect the full range of mandatory design, construction, engineering, and supporting components required for the implementation of the proposed facility.

The identified discrepancy should not be interpreted merely as a numerical difference between two investment values. Rather, it reflects a structural inconsistency between the engineering requirements of the project and the financial framework established during the preliminary planning stage. Consequently, the principal source of the discrepancy is associated with the omission or insufficient consideration of mandatory project components rather than with ordinary uncertainty in construction pricing.

The application of the ECIA methodology demonstrates that evaluating engineering completeness before estimating investment costs provides a more objective basis for assessing the realism of preliminary investment programmes. By systematically identifying all mandatory project components, the methodology enables the recognition of potential deficiencies at the earliest stage of project development, thereby reducing the likelihood of substantial budget revisions during subsequent design and construction phases.

The findings further indicate that preliminary investment estimates should not be regarded solely as financial indicators. Instead, they should be considered engineering-based planning instruments whose reliability depends on the completeness of the underlying project definition. From this perspective, engineering completeness constitutes a prerequisite for financial realism rather than a consequence of cost estimation.

The Ferik Community case study demonstrates the practical applicability of the ECIA framework for evaluating public investment projects at the planning stage. Although the numerical results presented in this study are specific to the selected case, the proposed methodology is transferable to other public infrastructure projects where the completeness of the engineering scope directly influences the realism of preliminary investment estimates.

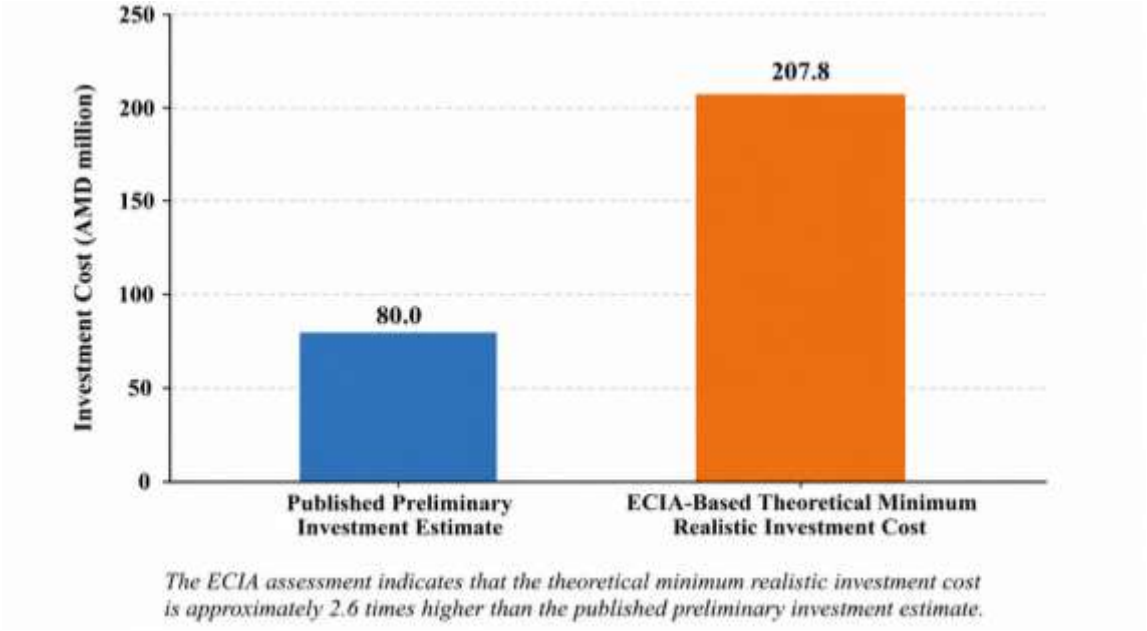

Fig. 1 Comparison of the Preliminary Investment Estimate and the ECIA-Based Investment Assessment
Published Preliminary Investment Estimate — 80.0 mln ADM
ECIA-Based Theoretical Minimum Realistic Investment Cost — 207.8 mln ADM

Discussion

The findings of the present study demonstrate that the realism of preliminary investment estimates for public infrastructure projects cannot be evaluated solely through financial calculations. The results indicate that the reliability of a preliminary investment estimate primarily depends on the engineering completeness of the proposed project, since the omission of even a single mandatory component may substantially compromise the credibility of the overall investment assessment.

The obtained results are consistent with previous studies reporting that cost overruns and budget deviations in infrastructure projects are frequently associated not only with changes in construction costs but also with inadequate project definition and incomplete planning during the early stages of project development [13–16]. However, the present research further demonstrates that one of the principal sources of unrealistic preliminary investment estimates may arise even before financial calculations are performed, namely when the mandatory engineering components required for complete project implementation have not been systematically identified.

Existing international methodologies, including the AACE International Cost Estimate Classification System, the PMBOK® Guide, and ISO 21502, place considerable emphasis on project definition maturity, risk management, and the accuracy of cost estimation [3–7]. Nevertheless, these approaches do not provide a systematic procedure for verifying the engineering completeness of an investment project prior to financial evaluation. In this respect, the proposed ECIA methodology complements existing practices by introducing a structured framework for assessing engineering completeness before preliminary investment costs are determined.

The case study of the Ferik Multifunctional Community Center demonstrates that, even under the most favorable implementation conditions, the theoretical minimum realistic investment cost substantially exceeds the published preliminary investment estimate. This finding indicates that the assessment of preliminary investment estimates should place primary emphasis not only on financial calculations but also on the structural and engineering completeness of the proposed project.

The proposed ECIA methodology is not limited to multifunctional community centers and may be applied to a broad range of public infrastructure projects, including educational, healthcare, administrative, cultural, and other public facilities. Its application can facilitate the early identification of structural deficiencies in investment programmes, improve the reliability of preliminary investment estimates, and reduce the need for subsequent design revisions and additional project financing.

Conclusions

1. The study demonstrates that the realism of preliminary investment estimates for public infrastructure projects depends not only on the accuracy of financial calculations but, more fundamentally, on the engineering completeness of the proposed project.
2. The case study of the Ferik Multifunctional Community Center shows that the published preliminary investment estimate does not adequately reflect the complete engineering scope required for project implementation. Under the assumptions adopted in this study,

the ECIA assessment determined a theoretical minimum realistic investment cost of AMD 207.8 million**,** substantially exceeding the published preliminary investment estimate of AMD 80.0 million**.**

3. The identified discrepancy indicates that unrealistic preliminary investment estimates may result not only from market uncertainty or construction cost fluctuations but also from the omission or insufficient consideration of mandatory project components during the investment planning stage.
4. The proposed Engineering Completeness-Based Investment Assessment (ECIA) framework introduces a systematic engineering approach that evaluates project completeness before financial assessment. This methodology complements existing cost estimation practices by incorporating engineering completeness as a prerequisite for realistic investment planning.
5. The ECIA methodology provides a practical decision-support tool for public investment planning by enabling the early identification of missing project components, improving the reliability of preliminary investment estimates, and reducing the likelihood of substantial cost revisions during subsequent project development.
6. Although the numerical results presented in this study are specific to the selected case study, the proposed methodology is applicable to a broad range of public infrastructure projects and may contribute to improving the technical and financial quality of preliminary investment planning.

References

1. Flanagan R, Jewell C. *New Code of Estimating Practice*. 7th ed. Chichester: Wiley-Blackwell; 2018.
2. Ashworth A, Perera S. *Cost Studies of Buildings*. 6th ed. London: Routledge; 2015.
3. AACE International. *Professional Guidance Document No. 01: Guide to Cost Estimate Classification Systems*. Morgantown (WV): AACE International; 2022.
4. Project Management Institute. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide).* 7th ed. Newtown Square (PA): Project Management Institute; 2021.
5. International Organization for Standardization. **ISO 21502:2020**. *Project, Programme and Portfolio Management—Guidance on Project Management*. Geneva: ISO; 2020.
6. International Organization for Standardization. **ISO 31000:2018**. *Risk Management—Guidelines*. Geneva: ISO; 2018.
7. Hollar DA, Rasdorf W, Liu M, Hummer JE, Arocho I, Hsiang SM. Preliminary Engineering Cost Estimation Model for Bridge Projects. *Journal of Construction Engineering and Management*. 2013;139(9):1259–1267. doi:10.1061/(ASCE)CO.1943-7862.0000668.
8. Remer DS, Buchanan HR. Estimating the Cost for Doing a Cost Estimate. *International Journal of Production Economics*. 1999;58(1):9–22.
9. HM Treasury. *The Green Book: Central Government Guidance on Appraisal and Evaluation*. London: HM Treasury; 2022.

10. European Commission. *Guide to Cost–Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2021–2027*. Luxembourg: Publications Office of the European Union; 2021.
11. OECD. *Cost–Benefit Analysis and the Environment: Further Developments and Policy Use*. Paris: OECD Publishing; 2018.
12. Boardman AE, Greenberg DH, Vining AR, Weimer DL. *Cost–Benefit Analysis: Concepts and Practice*. 5th ed. Cambridge: Cambridge University Press; 2021.
13. Flyvbjerg B, Holm MS, Buhl SL. Underestimating Costs in Public Works Projects: Error or Lie? *Journal of the American Planning Association*. 2002;68(3):279–295. doi:10.1080/01944360208976273.
14. Flyvbjerg B. Policy and Planning for Large Infrastructure Projects: Problems, Causes, Cures. *Environment and Planning B: Planning and Design*. 2007;34(4):578–597.
15. Flyvbjerg B, Ansar A, Budzier A, et al. Five Things You Should Know About Cost Overrun. *Transportation Research Part A: Policy and Practice*. 2018;118:174–190. doi:10.1016/j.tra.2018.07.013.
16. Batselier J, Vanhoucke M. Practical Application and Empirical Evaluation of Reference Class Forecasting for Project Management. *Project Management Journal*. 2016;47(5):36–51.

ՆԵՐԴՐՈՒՄԱՅԻՆ ԾՐԱԳՐԵՐԻ ՆԱԽՆԱԿԱՆ ԱՐԺԵՔԻ ԻՐԱՏԵՍԱԿԱՆՈՒԹՅԱՆ ԻՆԺԵՆԵՐԱԿԱՆ ԳՆԱՀԱՏՈՒՄ. ՖԵՐԻԿ ՀԱՄԱՅՆՔԻ ԲԱԶՄԱՖՈՒՆԿՑԻՈՆԱԼ ՀԱՄԱՅՆՔԱՅԻՆ ԿԵՆՏՐՈՆԻ ՕՐԻՆԱԿՈՎ

Է.Յու. Գալստյան
Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Հանրային ներդրումային ծրագրերի նախնական արժեքի գնահատումը հանդիսանում է ծրագրերի պլանավորման և ֆինանսավորման հիմնարար փուլերից մեկը, քանի որ այն ուղղակիորեն ազդում է ծրագրերի իրագործելիության, բյուջետային պլանավորման և հետագա իրականացման արդյունավետության վրա: Սակայն նախնական արժեքի ձևավորման գործընթացում հաճախ բացակայում է ինժեներական ամբողջական գնահատման մեթոդաբանությունը, որի հետևանքով ներդրումային ծրագրերում ներկայացվող ֆինանսական շրջանակները կարող են էականորեն տարբերվել ծրագրի իրական արժեքից:

Ուսումնասիրության նպատակն է մշակել ներդրումային ծրագրերի նախնական արժեքի իրատեսականության ինժեներական գնահատման մոտեցում և այն կիրառել որպես դեպքի ուսումնասիրություն՝ ՀՀ Արմավիրի մարզի Ֆերիկ համայնքի բազմաֆունկցիոնալ համայնքային կենտրոնի ներդրումային ծրագրի օրինակով:

Հետազոտության ընթացքում իրականացվել է նախագծով նախատեսված բոլոր շինարարական և ինժեներական աշխատանքների փուլային տեխնիկատնտեսական գնահատում՝ ներառյալ նախագծային աշխատանքները, երկրաբանական

հետազոտությունները, կրող կառուցվածքները, ստորգետնյա պաշտպանական տարածքը, ճարտարապետական և ինժեներական համակարգերը, հակահրդեհային միջոցառումները, արտաքին ենթակառուցվածքները և տարածքի բարեկարգումը: Գնահատումը կատարվել է առավել բարենպաստ նախագծային և շինարարական պայմանների ընդունմամբ՝ նպատակ ունենալով որոշել ծրագրի տեսական նվազագույն իրատեսական արժեքը:

Արդյունքները ցույց տվեցին, որ ներկայացված 80.0 մլն դրամ նախնական ֆինանսական շրջանակը չի համապատասխանում ծրագրի իրական ծավալներին: Իրականացված ինժեներական գնահատմամբ ծրագրի տեսական նվազագույն արժեքը կազմել է 207.8 մլն դրամ (ԱԱՀ-ով), մինչդեռ գործնական պայմաններում, հաշվի առնելով նախագծման և շինարարության բնական ռիսկերը, իրական ներդրումային արժեքը կարող է կազմել շուրջ 270 մլն դրամ:

Ուսումնասիրությունը ցույց է տալիս, որ ներդրումային ծրագրերի նախնական արժեքի գնահատման գործընթացում անհրաժեշտ է կիրառել ինժեներական ամբողջական մոտեցում, որը հնարավորություն կտա նախքան ֆինանսավորման հաստատումը գնահատել ծրագրերի ֆինանսական իրատեսականությունը և նվազեցնել հետագա բյուջետային, տեխնիկական և կազմակերպական ռիսկերը:

Բանալի բառեր՝ ներդրումային ծրագիր, նախնական արժեք, ինժեներական գնահատում, ֆինանսական իրատեսականություն, համայնքային ենթակառուցվածք, բազմաֆունկցիոնալ համայնքային կենտրոն:

ИНЖЕНЕРНАЯ ОЦЕНКА РЕАЛИСТИЧНОСТИ ПРЕДВАРИТЕЛЬНОЙ СТОИМОСТИ ИНВЕСТИЦИОННЫХ ПРОЕКТОВ: НА ПРИМЕРЕ МНОГОФУНКЦИОНАЛЬНОГО ОБЩЕСТВЕННОГО ЦЕНТРА ОБЩИНЫ ФЕРИК

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Предварительная оценка стоимости государственных инвестиционных проектов является одним из ключевых этапов их планирования и финансирования, поскольку непосредственно влияет на реализуемость проекта, бюджетное планирование и эффективность последующей реализации. Однако на практике предварительные бюджеты нередко формируются без комплексной инженерной оценки, что приводит к существенным расхождениям между заявленной стоимостью проекта и его фактической стоимостью.

Целью настоящего исследования является разработка инженерного подхода к оценке реалистичности предварительной стоимости инвестиционных проектов и его апробация на примере инвестиционного проекта строительства многофункционального общественного центра общины Ферик Армавирской области Республики Армения.

E.Yu. Galstyan

ENGINEERING ASSESSMENT OF THE REALISM OF PRELIMINARY INVESTMENT COST ESTIMATES: THE CASE OF THE FERIK COMMUNITY MULTIFUNCTIONAL COMMUNITY CENTER

В ходе исследования выполнена комплексная инженерная оценка всех основных составляющих проекта, включая проектные работы, инженерно-геологические изыскания, несущие конструкции, подземное защитное сооружение, архитектурные решения, инженерные системы здания, противопожарные мероприятия, наружные инженерные сети и благоустройство территории. Оценка проводилась при наиболее благоприятных проектных и строительных условиях с целью определения теоретически минимальной реалистичной стоимости проекта.

Результаты исследования показали, что заявленная предварительная стоимость проекта в размере 80,0 млн драмов не соответствует фактическому объему предусмотренных работ. Согласно выполненной инженерной оценке, теоретически минимальная стоимость реализации проекта составляет 207,8 млн драмов (с учетом НДС), тогда как практическая стоимость строительства с учетом типичных инженерных и строительных рисков может достигать около 270 млн драмов.

Полученные результаты свидетельствуют о необходимости внедрения комплексной инженерной оценки на стадии предварительного формирования инвестиционных программ, что позволит повысить реалистичность финансового планирования, снизить риски реализации проектов и повысить эффективность государственных инфраструктурных инвестиций.

***Ключевые слова*:** инвестиционный проект; предварительная стоимость; инженерная оценка; финансовая реалистичность; общественная инфраструктура; многофункциональный общественный центр.

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GLOBAL TRADE IN DRINKING WATERS (HS 2201) AND BEVERAGES DERIVED THEREFROM: MARKET CONCENTRATION, UNIT VALUES, AND ARMENIA'S EXPORT PROSPECTS THROUGH 2031

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Abstract

This article evaluates the scale, geographic structure, unit values and Armenian export potential of international trade in unsweetened waters classified under HS 2201. A country-

year panel and an Armenia partner-year panel are constructed from UN Comtrade data for 2010-2025. In 2023, the latest broadly comparable global year, reported exports amounted to USD 5.77 billion. Reporting-coverage adjustments are applied to 2024-2025 because the number of reporting exporters falls to 130 and 88, respectively. The export market is concentrated: in 2023 the five-country concentration ratio was 68.9%, while the Herfindahl-Hirschman index was 0.164. France, Italy and China formed the leading export group, whereas the United States, Hong Kong SAR, France, Germany and the United Kingdom were major import centres. Armenian exports increased from USD 5.32 million in 2010 to USD 19.42 million in 2024 and USD 23.40 million in 2025, while remaining strongly concentrated in the Russian market. A Poisson pseudo-maximum-likelihood model with partner and year fixed effects and rolling-origin forecast validation are employed. The preferred Holt linear model projects Armenian exports at USD 34.48 million in 2031, with a 95% prediction interval of USD 16.35-72.71 million. The findings suggest that Armenia's defensible opportunity lies in certified, branded and higher-value natural and mineral water rather than bulk low-value exports.

Keywords: freshwater trade, mineral water, HS 2201, PPML, unit value, Armenia, forecasting.

Introduction

Freshwater is simultaneously a vital resource, a public good, a factor of production, and a tradable commodity with important physical constraints. International merchandise statistics capture only a specific segment of it: packaged water that crosses a customs frontier [1].

HS heading 2201 covers unsweetened waters, including natural or artificial mineral and aerated waters, as well as other water, ice, and snow. The term "freshwater market" is therefore used operationally in this article and does not include cross-border transfers through pipelines or the full flow of water-supply infrastructure [2].

The scientific difficulty of the subject arises from the interaction of three distinct mechanisms. First is the geography of the natural resource: water abundance or scarcity may affect both supply and demand. Second is the high cost of transport: water is bulky and relatively low in value, so packaging and logistics often cost more than the raw resource itself. Third is product differentiation: provenance, mineral composition, brand, packaging, and safety certification generate very different values for the same physical weight.

Comparable product-level international trade databases make these differences measurable, but their use requires careful treatment of mirror flows, classification revisions, and the quality of quantity data [3].

The objective of this article is to assess the development and country structure of the HS 2201 market, identify the principal destinations of Armenian exports, and forecast exports through 2031. Five tasks follow from this objective: measuring market size and concentration; identifying leading countries; analysing unit values; estimating structural shifts in Armenia's partner composition; and developing explicitly uncertain forecast scenarios.

The contribution is threefold. First, it integrates global market concentration, exporter and importer rankings, unit values, and Armenia's bilateral export structure within a single

HS 2201 framework. Second, it explicitly corrects the decline in reporting coverage in 2024–2025 and evaluates that correction through historical coverage-profile backtesting. Third, it combines a zero-preserving PPML specification with rolling-origin forecast comparison and reports prediction intervals rather than point forecasts alone.

Conflict Setting

The gravity approach and trade costs

In modern applications of the trade gravity model, the PPML estimator is preferred to log-linear OLS because it retains zero trade flows and is more robust under heteroskedasticity [4]. Practical structural-gravity guidance recommends controlling for multilateral resistance with exporter-year and importer-year fixed effects, and for time-invariant bilateral costs with pair fixed effects [5]. The broader gravity literature shows that distance remains one of the most stable determinants of merchandise flows, even under technological progress and trade liberalisation [6]. Relative market access and multilateral resistance matter because bilateral trade depends not only on the cost between two countries but also on their positions relative to alternative markets [7].

The role of distance should be especially strong for water. The product has a low value-to-weight ratio, packaging adds considerable weight, and returnable-container options are limited. A landlocked exporter also faces trans-shipment costs. Armenia therefore cannot compete with the same strategy in nearby EAEU markets and in distant high-income destinations.

Physical and virtual water trade

The water-footprint literature treats a large share of international trade as the transfer of virtual water embodied in products, predominantly agricultural goods [8].

The concept of virtual water implies that a water-scarce country can ease its resource constraint by importing water-intensive products without transporting large physical volumes of water [9].

The global virtual-water network has become denser over time, although dependence on central countries has persisted [10].

Regional studies also warn that physical and virtual transfers may alleviate scarcity in the importing region while increasing water pressure in the exporting region [11].

This article does not equate trade in HS 2201 with virtual-water trade. Under HS 2201, water itself crosses the border in a container or another customs form; in virtual-water trade, water is embodied in food, textiles, or manufactured products. The distinction is essential for both measurement and policy interpretation.

The value and environmental cost of packaged water

Energy assessments of bottled water show that plastic production, bottling, cooling, and transport may greatly exceed the direct energy required to abstract water at the source [12].

Consumers' willingness to pay reflects perceived safety, taste, provenance, mineral composition, brand, and packaging. Consequently, international value differences for an identical physical quantity cannot be explained by water quality alone [13].

The value-to-quantity ratio observed in customs data is a unit value rather than a pure price. It may change because of product mix, contract terms, packaging, and reporting error [14].

Materials and Methods

Data structure and definitions

The main source is UN Comtrade. Annual export and import flows for HS 2201, HS 220110, and HS 220190 were retrieved for 2010–2025. The country-year database contains observations for 195 reporting economies over the study period. For Armenia, an initial balanced grid was constructed for 251 potential partners and 16 years (4,016 partner-year cells). The PPML estimation sample then retained the 59 partners with at least one positive export flow during 2010–2025, producing 944 observations; within this sample, 402 flows are positive and 542 are zero. This restriction avoids all-zero partner fixed effects while preserving intermittent zero trade for active destinations.

The aggregate HS 2201 heading already includes both subheadings and they are therefore not added when calculating total market value. The subheadings are used only for structural decomposition. The principal monetary variable is primaryValue, generally recorded on an FOB basis for exports and a CIF basis for imports. This valuation difference also explains part of the discrepancy between global export and import totals.

The external water-scarcity context is defined by the WDI/FAO SDG 6.4.2 indicator: total freshwater withdrawals as a share of available renewable freshwater resources after environmental flow requirements [15].

FAO AQUASTAT's country profile is used for the institutional interpretation of Armenia's water resources and abstraction structure [16].

Progress in water governance and drinking-water quality reform is cross-checked against UNECE National Policy Dialogue materials [17].

Armenia's customs outcomes are also compared with the logic of Armstat's four-digit external-trade database [18].

Market measurement indicators

Country i's market share in year t is calculated as its export value divided by world exports:

$$s_{it} = \frac{X_{it}}{\sum_{j=1}^{N} X_{jt}} \quad (1)$$

Market concentration is measured by the Herfindahl–Hirschman Index and by the shares of the five and ten largest exporters:

$$HHI_t = \sum_{i=1}^{N_t} {s_{it}}^2 , CR_{kt} = \sum_{i=1}^{k} s_{(i)t} \quad (2)$$

The export unit value is calculated as value divided by net weight. Zero or missing weights are not imputed, and physically implausible observations are excluded from aggregate price interpretation:

$$UV_{ijt} = \frac{V_{ijt}}{W_{ijt}} \quad (3)$$

Water density of approximately one kilogram per litre permits only an approximate reading of USD/kg as USD/litre. Packaging weight, supplementary-quantity reporting, and product mix prevent an exact conversion.

Adjustment for incomplete reporting in 2024–2025

Recent global totals decline mechanically when some reporters have not yet published their data. Missing country values for 2024 and 2025 are therefore imputed from the previous-year value multiplied by the median growth factor among countries reporting in both consecutive years. Growth observations below the 5th or above the 95th percentile are trimmed.

$$X_{it}^{*} = X_{i,t-1} \times median_{j \in R_t}\left(\frac{X_{jt}}{X_{j,t-1}}\right) \quad (4)$$

The adjusted series is a nowcast and is not presented as a final official total. Observed, preliminary, and forecast values are distinguished in the figures and accompanying text. A coverage-profile backtest was conducted for 2018–2023 by reproducing the sets of countries reporting in 2024 (130 reporters) and 2025 (88 reporters), applying the same imputation rule, and comparing the estimates with the complete historical totals. The resulting mean absolute percentage errors were 0.27% and 1.96%, respectively, with mean biases of 0.13% and 0.67%. These results support the mechanical adjustment as a short-run coverage correction, while the larger error under the 88-country profile justifies treating the 2025 estimate as exploratory and preliminary.

PPML partner model for Armenia

PPML is employed to retain zero flows and avoid the bias associated with log-linear transformation under heteroskedasticity [19].

$$E\left[X_{jt}|Z_{jt}\right] = \exp\left(\alpha_j + \lambda_t + \beta_1 D_{jt}^{EAEU} + \beta_2 D_{jt}^{RUS} + \beta_3 D_{jt}^{USA}\right) \quad (5)$$

The dependent variable is the value of Armenia's HS 2201 exports. The indicators D^{EAEU}_{jt}, D^{RUs}_{jt}, and D^{UsA}_{jt} denote, respectively, EAEU-partner × Post-2015, Russia × Post-2022, and USA × Post-2020 interactions. Partner fixed effects α_j absorb distance, common borders, language, and other time-invariant factors; year fixed effects λ_t absorb common annual shocks. Standard errors are clustered by partner. Because the interactions are not generated by a policy experiment, coefficients are interpreted as conditional structural shifts rather than unambiguous causal effects.

The theoretical basis for measuring bilateral distance is provided by the CEPII Gravity and GeoDist databases. In a single-exporter model with partner fixed effects, however, time-invariant distance cannot be identified separately [20].

Population-weighted geographic distance generally represents trade costs between economic centres more accurately than simple capital-to-capital distance [21].

Forecasting strategy

Forecast models are estimated on logarithmic series to preserve positivity and stabilise the variance of relative changes. Candidate models are compared through rolling-origin one-step-ahead validation, using RMSE as the primary selection criterion and MAE and MAPE as supplementary measures [22]. Holt linear, damped Holt, and log-linear trend specifications are evaluated for both the global and Armenian series.

$$\mathrm{RMSE} = \sqrt{\frac{1}{H}\sum_{h=1}^{H}(y_{t+h} - \widehat{y_{t+h}})^2} \quad (6)$$

$$\mathrm{MAPE} = \frac{100}{H}\sum_{h=1}^{H}\left|\frac{y_{t+h} - \widehat{y_{t+h}}}{y_{t+h}}\right| \quad (7)$$

Holt's level-trend model separates the current level of the series from its local growth trend [23].

Exponential-smoothing models are advantageous in small samples because they respond to recent observations with a limited number of parameters [24].

The global forecast is estimated on the final 2010–2023 series; the 2024–2025 nowcasts serve only as external comparative benchmarks. Armenia's forecast uses the reported national series for 2010–2025. The 95% intervals expand the log-model residual standard deviation by the square root of the forecast horizon. They capture residual innovation uncertainty but not the full uncertainty associated with model selection, parameter estimation, future reporting revisions, inflation, exchange rates, or structural breaks; they should therefore be interpreted as conditional model-based prediction intervals.

Research Results

Dynamics of the global market

The global HS 2201 export series reveals a clear long-term expansion accompanied by increasing uncertainty in the most recent reporting years. To distinguish genuine market dynamics from changes caused by incomplete country reporting,

Table 1

Global HS 2201 Export Values and Reporter Coverage, Selected Years, 2010–2025

Year	Reported, USD bn	Adjusted, USD bn	Reporting countries	Status
2010	2.77	2.77	159	observed
2015	3.35	3.35	154	observed
2020	4.47	4.47	154	observed
2021	4.97	4.97	157	observed
2022	5.04	5.04	157	observed
2023	5.77	5.77	152	observed
2024	5.80	5.87	130	nowcast/preliminary
2025	5.07	6.33	88	nowcast/preliminary

Source: Authors' calculations based on UN Comtrade.

Table 1 presents both reported and coverage-adjusted export values. This distinction is particularly important for 2024–2025, when the number of reporting countries declined substantially and the raw totals ceased to be directly comparable with the more complete observations for 2010–2023.

Between 2010 and 2023, global exports more than doubled, rising from USD 2.77 billion to USD 5.77 billion. Following a temporary decline in 2015, growth accelerated. In 2020, the export total did not replicate the full contraction observed in imports because exporter and importer declarations differ in timing and valuation.

The raw total for 2024 is USD 5.80 billion and the coverage-adjusted estimate is USD 5.87 billion. In 2025, the difference is substantial: USD 5.07 billion reported and USD 6.33 billion adjusted. It would therefore be misleading to infer a market contraction from the raw 2025 total.

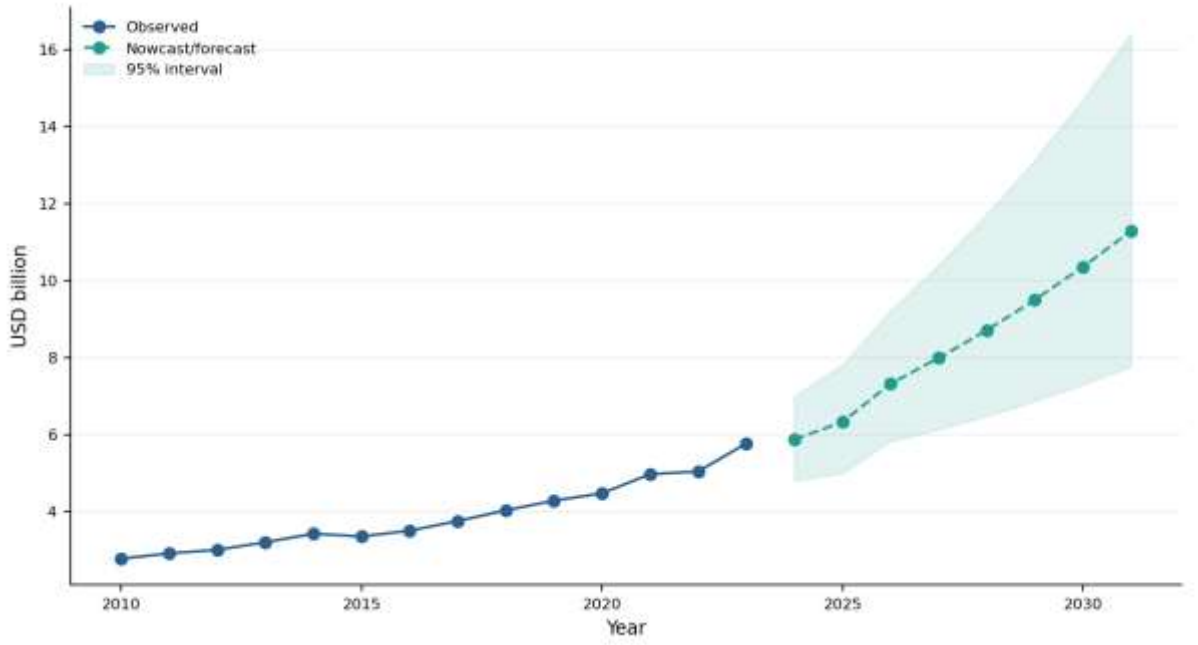

Fig. 1. Global HS 2201 exports and forecast. Source: Authors' calculations.

Fig. 1 confirms that the market's long-run expansion has not followed a uniform path: the temporary stagnation in the mid-2010s was followed by a visibly steeper nominal trajectory after 2020. At the same time, the widening forecast band shows that the projected increase should be treated as a conditional range rather than a deterministic continuation of recent growth. This distinction is especially important because the series combines changes in physical volumes, prices, exchange rates, and product composition.

Leading exporting and importing countries

The country structure of HS 2201 exports provides insight into the competitive foundations of the global packaged-water market. Export leadership may reflect not only the availability of water resources but also internationally recognised brands, certified mineral-water sources, bottling capacity, access to integrated markets, and established distribution networks. Table 2 presents the ten leading exporters in 2023 and their relative shares within this group.

The results reveal a highly asymmetric export structure. France alone accounted for 42.8% of the trade value generated by the displayed ten exporters, while France, Italy, and China jointly represented 78.0%. The remaining exporters each held shares below 5%, indicating a substantial gap between the three market leaders and the second tier. Georgia's inclusion among the leading exporters is particularly relevant for Armenia, as it demonstrates that a South Caucasian country can establish an internationally competitive position through recognised origin, product differentiation, and market-specific branding.

Table 2

Leading Exporters of HS 2201 Products by Trade Value and Market Share, 2023

Exporters	**Value, USD mn**	**Share of displayed top ten, %**
France	1983.0	42.8
Italy	885.1	19.1
China	748.6	16.1
Belgium	186.7	4.0
USA	170.4	3.7
Fiji	158.5	3.4
Germany	145.1	3.1
Mexico	144.0	3.1
Georgia	131.5	2.8
Spain	84.0	1.8

Source: Authors' calculations based on UN Comtrade. Shares refer to the displayed top ten.

The import side of the HS 2201 market reflects the combined influence of market size, household income, consumer preferences, tourism, urban concentration, and the availability of domestic alternatives. Leading importing economies are not necessarily water-scarce countries; several are high-income markets where demand is driven by differentiated natural and mineral waters.

Table 3 presents the ten principal importers in 2023 and their shares within the displayed group.

Table 3

Leading Importers of HS 2201 Products by Trade Value and Market Share, 2023

Importers	**Value, USD mn**	**Share of displayed top ten, %**
USA	1078.9	31.0
China, Hong Kong SAR	680.8	19.6
France	351.1	10.1
Germany	267.2	7.7
United Kingdom	265.0	7.6
Belgium	240.4	6.9
Netherlands	212.9	6.1

Importers	**Value, USD mn**	**Share of displayed top ten, %**
China	146.7	4.2
State of Palestine	120.0	3.4
Switzerland	115.4	3.3

Source: Authors' calculations based on UN Comtrade. Shares refer to the displayed top ten.

Import demand is also concentrated, although less strongly than exports. The United States and Hong Kong SAR jointly accounted for 50.6% of the import value represented by the ten leading markets, confirming the importance of large, affluent and import-intensive consumer centres. The presence of France, Germany, Belgium and the Netherlands among both major exporters and importers points to extensive intra-industry trade, in which differentiated waters are exchanged across markets rather than imported solely to address physical scarcity. The import structure therefore suggests that Armenia's opportunities depend more on premium positioning and reliable distribution than on targeting water scarcity alone.

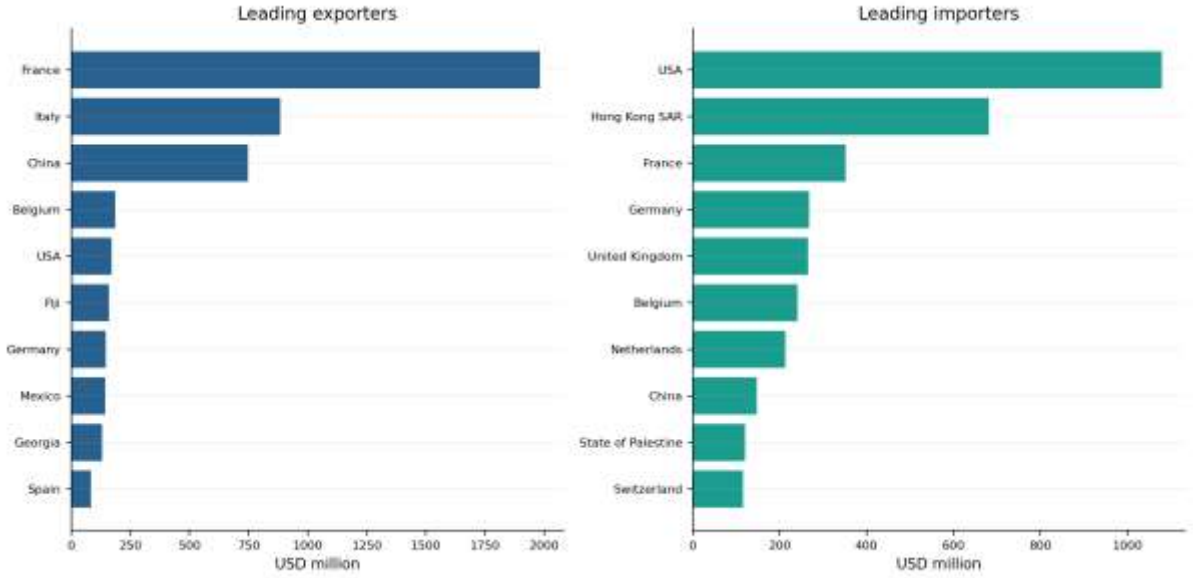

Fig. 2. Leading countries in the HS 2201 market, 2023.

The leading positions of France and Italy show that the market is shaped not only by water-resource abundance, but also by long-standing branding, recognised mineral-water origins, mature bottling capacity, and access to the European single market. China's reported value is accompanied by an evident net-weight anomaly, so its unit value is excluded from the calculation of a global average price.

On the import side, the United States leads because of the combined effects of market size, high income, and demand for differentiated premium water. Hong Kong SAR and Macao operate as import-intensive urban hubs. Simultaneous exports and imports by France, Germany, Belgium, and the Netherlands reflect intra-industry trade.

Market concentration

The evolution of export concentration provides a more systematic view of whether the expansion of the HS 2201 market has broadened competitive participation or reinforced the

position of established suppliers. Table 4 combines the Herfindahl–Hirschman Index (HHI), the shares of the five and ten largest exporters (CR5 and CR10), and the number of countries recording positive exports. These indicators jointly capture both the distribution of market shares among leading suppliers and the extent of exporter participation over time.

The 2024 concentration indicators are preliminary because only 130 exporters had reported, compared with 152 in 2023. The apparent changes in HHI, CR5, and CR10 may therefore reflect both market reallocation and incomplete reporting coverage and should not be interpreted as a fully comparable structural shift.

Table 4

Concentration of Global HS 2201 Exports: HHI, CR5, and CR10, 2010–2024 (2024 Preliminary)

Year	HHI	CR5, %	CR10, %	Positive exporters
2010	0.141	66.2	78.5	159
2015	0.133	67.8	79.9	154
2020	0.172	71.3	81.8	154
2023	0.164	68.9	80.4	152
2024	0.162	69.8	82.4	130

Source: Authors' calculations.

An HHI of 0.164 and CR5 of 68.9% in 2023 indicate substantial export concentration. This has a dual implication for a new small exporter: brand-entry costs are high and competition is intense, but high-value niches permit entry at limited scale without matching the volume of mass-market leaders.

Changes in prices and unit values

The distribution of unit values is strongly right-skewed. Large cross-border flows may be recorded at only a few cents per kilogram, whereas small consignments of high-value branded water exceed one dollar. A simple world value-to-weight ratio is therefore highly sensitive to a single large weight-reporting error. For leading exporters with available and plausible weight data, 2024 unit values were approximately USD 0.14/kg for the United States, 0.21 for Türkiye, 0.31 for France, 0.44 for Belgium, 0.50 for Norway, 0.51 for Italy, 0.64 for Georgia, and 0.72 for Lesotho. These are not identical products and must not be interpreted as pure quality-adjusted prices.

Armenia in the international market. Long-term export dynamics

Armenia's long-term export performance can be assessed more accurately by examining trade value, physical volume, and unit value jointly.

Export value alone does not reveal whether growth results from larger quantities, improved product positioning, or changes in the destination mix. Table 5 therefore presents the evolution of Armenia's HS 2201 exports between 2010 and 2025 using three complementary indicators.

The results show that Armenia's export expansion occurred in two distinct phases. Between 2010 and 2020, export value increased moderately, while the unit value declined from USD 0.418/kg to USD 0.383/kg, indicating predominantly volume-driven growth. After 2020, exports accelerated markedly: trade value reached USD 23.40 million in 2025,

approximately 4.4 times its 2010 level. Notably, net weight remained broadly unchanged between 2024 and 2025, whereas export value rose by about 20.5% and the unit value increased from USD 0.506/kg to USD 0.614/kg.

Table 5

Armenia's HS 2201 Exports: Trade Value, Net Weight, and Unit Value, 2010–2025

Year	Exports, USD mn	Net weight, mn kg	USD/kg
2010	5.32	12.71	0.418
2012	7.02	15.63	0.449
2015	5.77	14.02	0.412
2018	7.40	18.30	0.404
2020	8.60	22.45	0.383
2021	13.22	30.75	0.430
2022	16.45	28.10	0.585
2023	18.65	35.76	0.522
2024	19.42	38.41	0.506
2025	23.40	38.09	0.614

Source: Authors' calculations based on UN Comtrade.

This divergence suggests that the latest growth was driven primarily by higher realised values and changes in product or destination composition rather than by additional physical volume.

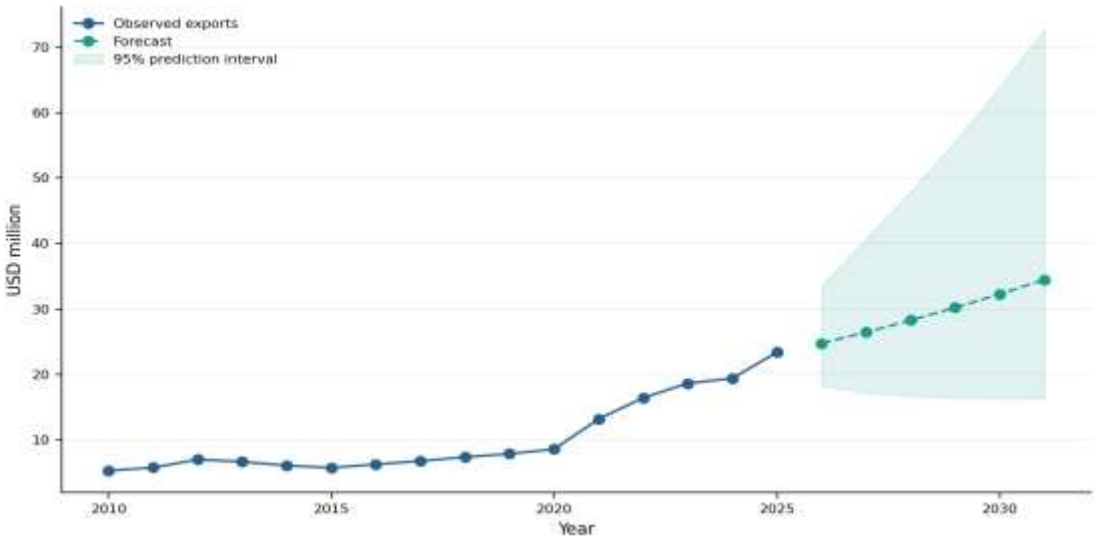

Fig. 3. Armenia's HS 2201 exports and forecast.

Fig. 3 reveals a marked acceleration in Armenia's exports after 2020, but the forecast path is smoother than the most recent observed increase. The model therefore does not mechanically extrapolate the exceptional post-2021 surge. Instead, it implies gradual growth accompanied by rapidly widening uncertainty, which is consistent with Armenia's small

export base, high partner concentration, and sensitivity to a limited number of distribution contracts.

Export geography

Armenia's export geography is examined by combining destination-specific trade values, market shares, and unit values. This approach makes it possible to distinguish large-volume core markets from smaller destinations that may offer higher-value opportunities. Table 6 presents the principal destinations of Armenia's HS 2201 exports in 2024 and highlights the degree of market concentration and variation in realised unit values across partners.

Table 6

Destination Structure of Armenia's HS 2201 Exports by Trade Value and Unit Value, 2024

Partner	Value, USD thousand	Share, %	USD/kg
Russian Federation	15059.3	77.5	0.470
USA	2927.7	15.1	0.747
Kazakhstan	401.8	2.1	0.545
Saudi Arabia	281.7	1.5	0.936
Curaçao	268.5	1.4	1.086
Belarus	140.0	0.7	0.367
Latvia	87.4	0.5	0.346
Belgium	37.3	0.2	0.843
United Arab Emirates	36.1	0.2	0.587
Bulgaria	25.6	0.1	0.416
France	23.7	0.1	0.469
Ukraine	19.9	0.1	0.385

Source: Authors' calculations based on UN Comtrade.

In 2024, the Russian Federation absorbed about 77.5% of Armenia's HS 2201 exports and the United States about 15.1%. Kazakhstan, Saudi Arabia, Curaçao, Belarus, Latvia, and Belgium formed the next group. In 2025, exports to Russia reached about USD 19.70 million, exports to Kazakhstan USD 0.96 million, while exports to the United States fell to USD 1.39 million.

Concentration generates scale advantages through established distribution networks in Russia, but it also raises exposure to exchange-rate, demand, regulatory, and logistics shocks. Diversification should not mean shipping the same low-value product over a greater distance; it requires different product positioning.

PPML results for Armenia

The PPML specification evaluates whether Armenia's bilateral HS 2201 exports experienced systematic changes following selected market and institutional shifts. Partner fixed effects control for time-invariant bilateral characteristics, while year fixed effects absorb

common annual shocks. Table 7 reports the estimated coefficients, partner-clustered standard errors, p-values, and percentage semi-elasticities for the three interaction terms.

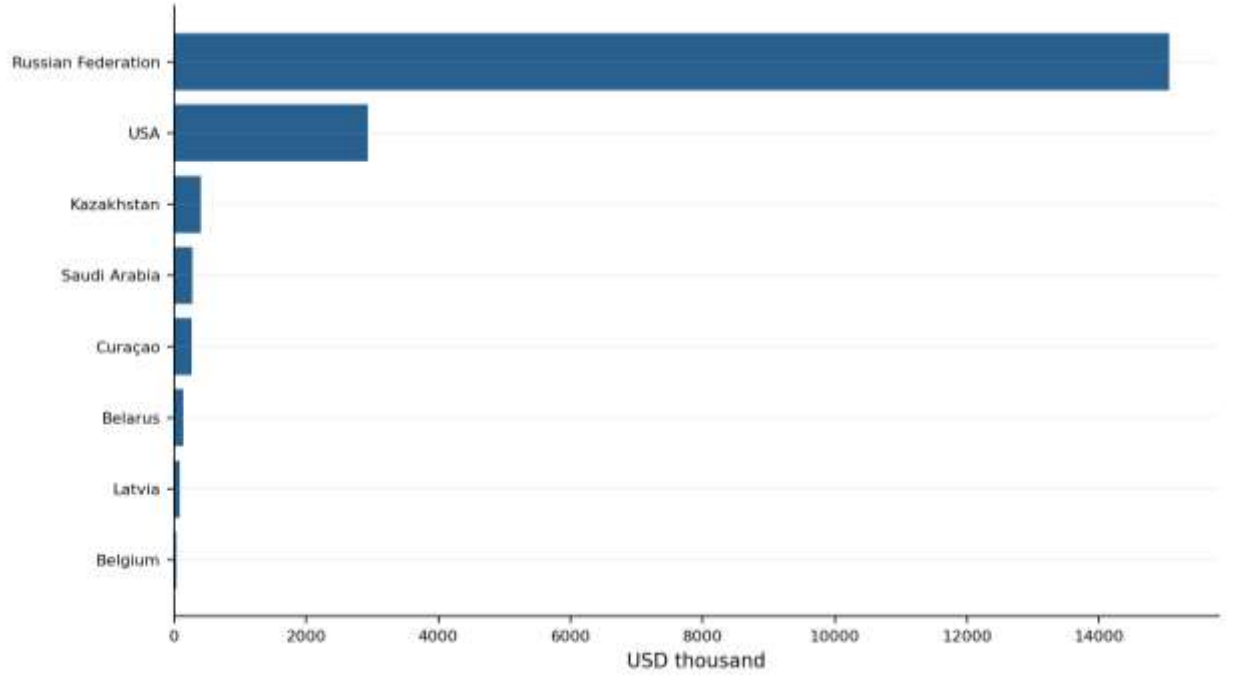

Fig. 4. Main markets for Armenian exports, 2024

Table 7

PPML Estimates for Armenia's Bilateral HS 2201 Exports, 2010–2025

Variable	Coefficient	Clustered SE	p-value	Semi-elasticity, %
EAEU × Post-2015	-0.416	0.590	0.480	-34.0
Russia × Post-2022	0.178	0.240	0.459	19.5
USA × Post-2020	0.559	0.274	0.041	74.9

Source: Authors' estimates. N = 944; 59 partner clusters; 402 positive and 542 zero flows; partner and year fixed effects; deviance explained = 0.984.

The results provide evidence of a statistically significant structural shift only for the US market. The USA × Post-2020 coefficient implies an estimated 74.9% increase relative to its preceding conditional level and is significant at the 5% level. By contrast, the EAEU × Post-2015 and Russia × Post-2022 coefficients are statistically insignificant, as reflected in their large clustered standard errors and p-values of 0.480 and 0.459. These estimates should not be interpreted as evidence that EAEU integration reduced exports or that post-2022 conditions produced no change. Rather, the model cannot identify stable average effects distinct from partner-specific characteristics, common annual shocks, and the already dominant position of the Russian market.

Partner-clustered standard errors allow arbitrary dependence across years for the same partner, provided that the number of clusters is sufficiently large [25].

Coefficient interpretation in a nonlinear fixed-effects panel requires caution, especially for destinations with few positive flows [26].

The EAEU × Post-2015 coefficient is negative but statistically insignificant (p = 0.480). This does not imply that the EAEU reduced exports. Russia's high initial level, partner fixed effects, and concurrent growth in other markets prevent identification of a stable additional average effect. Russia × Post-2022 is positive but also insignificant. USA × Post-2020 is positive and significant at 5%, but should be read as a structural shift rather than a causal policy effect.

Forecasts through 2031

Before producing the 2026–2031 projections, the three candidate specifications are evaluated through rolling-origin one-step-ahead forecasts. Table 8 reports the resulting RMSE, MAE, and MAPE values. Holt's linear trend has the lowest error under all three metrics for both series, providing a transparent empirical basis for its selection.

Table 8

Rolling-Origin One-Step-Ahead Forecast Accuracy by Series and Model

Series	Model	RMSE, USD mn	MAE, USD mn	MAPE, %
Global	Holt linear	227.89	219.44	4.51
Global	Holt damped	316.85	261.74	5.22
Global	Log-linear trend	368.19	306.42	5.96
Armenia	Holt linear	3.283	2.765	16.76
Armenia	Holt damped	3.824	3.139	19.31
Armenia	Log-linear trend	5.541	5.487	30.89

Source: Authors' rolling-origin calculations. Errors are evaluated in levels after forecasts are generated from log-transformed series.

The error ranking is stable across the three criteria. For the global series, Holt linear reduces RMSE by about 28% relative to damped Holt and by about 38% relative to the log-linear trend. For Armenia, the corresponding reductions are about 14% and 41%. Armenia's MAPE remains substantially higher than the global-market MAPE, confirming that forecasts for a small and concentrated exporter are intrinsically less stable.

Having selected Holt's linear trend through rolling-origin validation, the forecasting exercise evaluates the prospective trajectories of global and Armenian HS 2201 exports while explicitly accounting for increasing uncertainty over the projection horizon. Point estimates are reported together with conditional 95% prediction intervals in Table 9.

Table 9

Baseline Forecasts and 95% Prediction Intervals for Global and Armenian HS 2201 Exports, 2026–2031

Year	World, USD bn	World, 95% PI	Armenia, USD mn	Armenia, 95% PI
2026	7.32	5.82–9.21	24.77	18.26–33.58
2027	7.99	6.13–10.41	26.46	17.20–40.71
2028	8.71	6.48–11.71	28.28	16.69–47.92
2029	9.50	6.87–13.13	30.21	16.43–55.55
2030	10.36	7.30–14.70	32.28	16.34–63.78
2031	11.29	7.77–16.42	34.48	16.35–72.71

Source: Authors' forecasts.

The point forecasts indicate sustained nominal growth in both series. Global exports are projected to increase from USD 7.32 billion in 2026 to USD 11.29 billion in 2031, while Armenia's exports rise from USD 24.77 million to USD 34.48 million. This corresponds to an average annual increase of approximately 9.1% globally and 6.8% for Armenia.

The widening prediction intervals are equally important. By 2031, the global range reaches USD 7.77–16.42 billion, while Armenia's interval expands to USD 16.35–72.71 million. Armenia's substantially wider relative range reflects its smaller export base, high destination concentration, and sensitivity to individual contracts and market shocks. Accordingly, the point estimates should be interpreted as conditional planning benchmarks rather than fixed export targets.

Scenario interpretation

The downside scenario is close to the logic of the lower 95% bound and could materialise if Russian demand weakens, borders are disrupted, packaging costs rise, or source-use regulation tightens. The baseline assumes gradual capacity expansion and retention of the Russian market. The upside scenario additionally requires distribution contracts, certification, and higher unit values in the United States, Gulf, and European niches.

Discussion

What the HS 2201 market actually measures

The first major implication is that the term "international water market" is often used too broadly. HS 2201 does not measure the entire cross-border governance of rivers, reservoirs, or pipelines. It measures customs-declared water as merchandise. The results cannot therefore be used to infer the total size of the geopolitical water market.

Second, natural mineral water is economically similar to a differentiated food product, whereas "other water" may resemble a low-value bulk commodity in some flows. The large dispersion of unit values reflects this mixture. Aggregate HS 2201 is appropriate for total market value, but strategic recommendations require additional subheading- and firm-level evidence.

Water abundance is not a sufficient competitive advantage

Natural abundance is necessary but not sufficient for export success. France and Italy lead because of recognised origin, quality regulation, distribution, tourism imagery, and brand equity. Georgia's strong position demonstrates that South Caucasian water can attract international demand, but replication in Armenia requires long-term market investment.

Water-scarce importing countries appear attractive in theory, but large drinking-water deficits are generally addressed through domestic supply, desalination, reuse, and infrastructure rather than mass imports of distant bottled water. Opportunities in Gulf markets are primarily in differentiated consumer segments.

The cost of Armenia's landlockedness

The efficiency of maritime and inland logistics hubs is especially important for products with a low value-to-weight ratio [27].

International logistics performance is determined by customs, infrastructure, shipment organisation, tracking, and timeliness [28].

For landlocked countries, the number of borders and dependence on transit create a persistent structural cost [29].

Bulk water exports from Armenia to Europe or the Gulf require road transport, at least one transit border, and often maritime trans-shipment. When unit value is low, this chain can absorb the margin. Target-market selection should therefore be based on contribution margin per delivered kilogram, not only on gross export value.

Domestic water security and the export boundary

The sustainable-development agenda requires joint consideration of water access, quality, ecosystems, and efficient use [30].

Drinking-water safety requires risk-based management from source to consumer, rather than a one-off laboratory test of the final product [31].

Armenia's export policy should distinguish between the sustainable yield of a renewable source and physical abundance in an individual year. Export permits or abstraction charges should reflect long-run recharge, local-community supply, environmental flows, and climate scenarios.

The preferred performance measure is therefore not exported volume, but domestic value added per cubic metre abstracted—net taxes, wages, local services, and environmental restoration costs included. A small volume generating high value may dominate low-value bulk exports.

Quality, certification, and market trust

The international standard for natural mineral water defines source, treatment, hygiene, and labelling requirements that distinguish it from ordinary packaged water [32].

The EAEU technical regulation on packaged drinking water establishes the mandatory safety and labelling framework in Armenia's principal market [33].

ISO 22000 food-safety management can complement mandatory rules through supply-chain-wide risk management [34].

Certification does not create exports by itself, but it reduces the buyer's information risk. Entry into high-value markets requires source traceability, documentation of stable chemical composition, multilingual labelling, compliant bottle material, periodic independent testing, and a recall plan.

Limits of the econometric results

The model explains 98.4% of the null deviance, largely because partner and year fixed effects absorb persistent destination heterogeneity and common shocks. This high in-sample fit does not establish causality for the interaction terms. The EAEU coefficient is insignificant because Russian dominance predates 2015 and subsequent changes coincide with numerous macroeconomic and firm-level developments.

The positive USA × Post-2020 coefficient is an informative market signal, but the fall in 2025 exports shows that a short period of growth may depend on a limited number of distribution contracts. Future research should use firm-product-partner customs microdata and contract entry/exit events.

Economic interpretation and robustness of the findings

Taken together, the descriptive, concentration, PPML, and forecasting results support a coherent interpretation rather than four independent findings. The global market is expanding

in nominal terms, but entry is mediated by brand capital and distribution networks; Armenia is growing from a small base, but partner concentration remains high; and the forecast trajectory is positive, but its widening interval confirms that market access is contract-dependent. The results therefore favour a portfolio strategy in which a stable core market finances gradual experimentation in smaller, higher-margin destinations.

Unit values require particular caution in that portfolio. A higher customs unit value can signal premium positioning, but it can also reflect shipment size, packaging, route, or reporting conventions. Policy evaluation should consequently combine FOB value per kilogram with delivered margin, repeat-purchase rates, and value added per cubic metre abstracted. This triangulation prevents a statistical increase in unit value from being mistaken for a durable productivity or branding gain.

The nowcasting and forecasting exercises also address different uncertainties. The reporting-coverage adjustment estimates the current but incompletely observed market, whereas the Holt model extrapolates the future path of the completed series. Treating the 2024–2025 adjusted values as observations in model selection would understate measurement uncertainty. Their separation in the empirical design is therefore a methodological strength, although the resulting forecasts remain conditional on the persistence of recent nominal trends.

Strategic market priorities and implementation framework

The Government's agrifood-equipment leasing programme records that Armenia's 2011 export-oriented industrial strategy identified mineral waters among the priority sectors [35]. This establishes a policy precedent, but it does not by itself demonstrate the commercial viability of any specific destination or support instrument.

Implementation should follow a sequenced logic. The first stage is to protect source integrity and achieve full compliance with domestic, EAEU, Codex, and buyer-specific requirements. The second is to improve firm-level cost accounting and logistics consolidation. The third is selective market development through specialised importers rather than broad subsidisation of freight. Public support is most defensible when it finances shared testing, traceability, market intelligence, and export-readiness infrastructure that several producers can use.

Table 10

Market-Specific Export Strategies for Armenian Natural and Mineral Water

Direction	**Proposed strategy**
Russia and the EAEU	Maintain the baseline volume while reducing dependence on a single distributor; develop regional warehousing and monitor delivery time.
United States and diaspora markets	Use diaspora demand as an entry platform, then position the product in premium natural-origin and culinary-use segments.
Gulf countries	Target hotels, restaurants, and premium retail with small glass containers and Arabic labelling.
Europe	Do not compete with mass supermarket water; select specialist importers, Armenian restaurants, and a clearly documented natural-mineral-water story.
Georgia and transit cooperation	Combine market access with logistics and port consolidation, even though Georgia is also a strong competitor.

Source: Authors' elaboration.

Tab. 10 demonstrates that diversification cannot be implemented through a single uniform market-entry model. Russia and the EAEU remain scale markets, whereas the United States, Gulf countries, and Europe require premium positioning, smaller consignments, specialised distributors, and market-specific labelling. Georgia has a dual role as both competitor and potential logistics partner. These are proposed strategic options derived from the observed market structure rather than causal estimates of market-entry profitability.

Performance monitoring and adaptive policy

Effective export policy requires a monitoring system that evaluates not only growth in trade value but also market resilience, domestic value creation, logistics performance, and environmental sustainability. Reliance on a single indicator could conceal rising destination concentration, declining profitability, or excessive pressure on water sources. Table 11 therefore proposes an integrated set of key performance indicators for assessing Armenia's HS 2201 export strategy.

Table 11

Monitoring Framework and Key Performance Indicators for Armenia's HS 2201 Export Strategy

Direction	**Proposed measure**
Export concentration	Russia's share, HHI, and share of the three largest buyers
Value creation	FOB USD/kg, gross margin/kg, value added/m³ of water abstracted
Market stability	share of repeat buyers, average contract duration, frequency of export interruptions
Logistics	average delivery days, border-delay variance, transport cost/kg
Water security	source abstraction/sustainable yield, open level and quality data, restoration charge
Environmental footprint	packaging weight/litre, recycled-material share, CO_2e/litre delivered

Source: Authors' elaboration.

Tab. 11 converts the proposed strategy into a balanced monitoring framework. Export value alone would provide an incomplete signal because it could increase while concentration, logistics costs, or pressure on water sources also rise. Joint monitoring of market concentration, delivered margins, repeat buyers, transport performance, source sustainability, and packaging emissions would allow policymakers to distinguish durable export upgrading from short-lived nominal growth and to revise support instruments when trade and environmental objectives diverge.

Limitations, robustness, and research agenda

The first limitation concerns product coverage: HS 2201 excludes sweetened or flavoured water classified elsewhere and does not measure all physical cross-border water transfers. Second, customs mirror data differ because of FOB/CIF valuation, re-exports, timing, and confidentiality. Third, quantity fields have uneven quality.

Fourth, the global series for 2024–2025 are incomplete. The nowcast is a transparent mechanical adjustment, but it cannot recover the true shock for every missing reporter. Fifth, the current-dollar forecast combines real quantity, prices, inflation, and product mix. Sixth, Armenia's PPML model omits firm capacity, tariffs, route-specific freight costs, and branding expenditure.

Future work should assemble a complete global bilateral matrix at the HS six-digit level together with CEPII distances, importer water stress, GDP per capita, population, tariffs, and trade agreements. These data would permit a structural PPML model with exporter-year, importer-year, and pair fixed effects and a counterfactual estimate of Armenia's unrealised potential.

These limitations do not overturn the central qualitative result, because it is supported by several independent patterns: the dominance of branded European exporters, the high concentration of Armenia's destinations, the premium observed in selected small markets, and the wide forecast intervals. They do, however, limit causal interpretation and the precision of numerical targets. The 2031 estimate should therefore be used as a periodically updated planning benchmark rather than as a fixed policy commitment.

Data and reproducibility statement

The reproducibility package contains the cleaned country-year trade data, the full 251-partner balanced grid, the 59-partner PPML estimation sample, concentration and unit-value calculations, 2024–2025 coverage adjustments, rolling-origin model-comparison results, and forecast intervals. Missing net weights are not imputed. The package should accompany the manuscript so that the reported tables and figures can be independently reconstructed.

Conclusions

The international HS 2201 market more than doubled in nominal value between 2010 and 2023, reaching approximately USD 5.77 billion. Exports are concentrated, and the position of leading countries reflects not only water resources but also branding, reputation of origin, bottling capacity, access to integrated markets, and logistics.

Armenia recorded rapid export growth, reaching USD 23.40 million in 2025. Russia remains dominant, while the United States, Kazakhstan, Gulf, and European destinations are still small or volatile. The PPML estimates do not identify a separate persistent average stimulus after EAEU accession, but they do indicate a positive post-2020 shift in the US market.

The baseline projection places Armenia's exports at USD 34.48 million in 2031, but uncertainty is substantial. A realistic strategy should combine retention of the Russian market with diversification, higher unit values, sustainable source management, quality certification, and transparent logistics-cost accounting. The evidence suggests that Armenia's most plausible export opportunity lies in limited-volume, higher-value natural and mineral water with certified quality and credible origin, rather than in large-scale exports of low-value water.

References

1. United Nations Statistics Division. (2026). UN Comtrade Database. https://comtradeplus.un.org/ (accessed August 9, 2026).
2. United Nations Statistics Division. (2022). Harmonized System classification, heading 2201. https://unstats.un.org/unsd/classifications/Econ

3. Gaulier, G., & Zignago, S. (2010). BACI: International Trade Database at the Product-Level. CEPII Working Paper No. 2010-23.
4. Santos Silva, J. M. C., & Tenreyro, S. (2006). The log of gravity. The Review of Economics and Statistics, 88(4), 641–658. https://doi.org/10.1162/rest.88.4.641
5. Yotov, Y. V., Piermartini, R., Monteiro, J.-A., & Larch, M. (2016). An Advanced Guide to Trade Policy Analysis: The Structural Gravity Model. WTO and UNCTAD.
6. Head, K., & Mayer, T. (2014). Gravity equations: Workhorse, toolkit, and cookbook. In G. Gopinath, E. Helpman, & K. Rogoff (Eds.), Handbook of International Economics (Vol. 4, pp. 131–195). Elsevier.
7. Anderson, J. E., & van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. American Economic Review, 93(1), 170–192. https://doi.org/10.1257/000282803321455214
8. Hoekstra, A. Y., & Mekonnen, M. M. (2012). The water footprint of humanity. Proceedings of the National Academy of Sciences, 109(9), 3232–3237. https://doi.org/10.1073/pnas.1109936109
9. Allan, J. A. (1998). Virtual water: A strategic resource. Ground Water, 36(4), 545–546.
10. Dalin, C., Konar, M., Hanasaki, N., Rinaldo, A., & Rodriguez-Iturbe, I. (2012). Evolution of the global virtual water trade network. Proceedings of the National Academy of Sciences, 109(16), 5989–5994. https://doi.org/10.1073/pnas.1203176109
11. Zhao, X., Liu, J., Liu, Q., Tillotson, M. R., Guan, D., & Hubacek, K. (2015). Physical and virtual water transfers for regional water stress alleviation in China. Proceedings of the National Academy of Sciences, 112(4), 1031–1035. https://doi.org/10.1073/pnas.1404130112
12. Gleick, P. H., & Cooley, H. S. (2009). Energy implications of bottled water. Environmental Research Letters, 4(1), 014009. https://doi.org/10.1088/1748-9326/4/1/014009
13. Carlucci, D., De Gennaro, B., & Roselli, L. (2016). What is the value of bottled water? Empirical evidence from a conjoint choice experiment. Water Resources and Economics, 16, 1–14.
14. Berthou, A., & Emlinger, C. (2011). The Trade Unit Values Database. CEPII Working Paper No. 2011-10.
15. World Bank. (2026). World Development Indicators: Level of water stress (ER.H2O.FWST.ZS). https://databank.worldbank.org/metadataglossary/world-development-indicators/series/ER.H2O.FWST.ZS
16. Food and Agriculture Organization. (2026). AQUASTAT Country Profile: Armenia. https://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/ARM/
17. United Nations Economic Commission for Europe. (2026). National Policy Dialogue on Water in Armenia. https://unece.org/environment-policy/water/areas-work-convention_protocol/country-dialogues/armenia
18. Statistical Committee of the Republic of Armenia. (2026). External trade database according to the Commodity Nomenclature at 4-digit level. https://armstat.am/en/?nid=148

19. World Trade Organization & United Nations Conference on Trade and Development. (2012). A Practical Guide to Trade Policy Analysis. WTO Publications.
20. Conte, M., Cotterlaz, P., & Mayer, T. (2022). The CEPII Gravity Database. CEPII Working Paper No. 2022-05.
21. Mayer, T., & Zignago, S. (2011). Notes on CEPII's distances measures: The GeoDist database. CEPII Working Paper No. 2011-25.
22. Hyndman, R. J., & Athanasopoulos, G. (2021). Forecasting: Principles and Practice (3rd ed.). OTexts.
23. Hyndman, R. J., Koehler, A. B., Snyder, R. D., & Grose, S. (2002). A state space framework for automatic forecasting using exponential smoothing methods. International Journal of Forecasting, 18(3), 439–454.
24. Gardner, E. S. (1985). Exponential smoothing: The state of the art. Journal of Forecasting, 4(1), 1–28.
25. Cameron, A. C., & Miller, D. L. (2015). A practitioner's guide to cluster-robust inference. Journal of Human Resources, 50(2), 317–372.
26. Wooldridge, J. M. (2010). Econometric Analysis of Cross Section and Panel Data (2nd ed.). MIT Press.
27. United Nations Conference on Trade and Development. (2024). Review of Maritime Transport 2024. United Nations.
28. World Bank. (2023). Connecting to Compete 2023: Trade Logistics in an Uncertain Global Economy. World Bank.
29. United Nations. (2014). Vienna Programme of Action for Landlocked Developing Countries for the Decade 2014–2024. United Nations.
30. United Nations. (2024). The Sustainable Development Goals Report 2024. United Nations.
31. World Health Organization. (2022). Guidelines for Drinking-water Quality: Fourth Edition Incorporating the First and Second Addenda. WHO.
32. Codex Alimentarius Commission. (2019). Standard for Natural Mineral Waters (CXS 108-1981, amended 2019). FAO/WHO.
33. Eurasian Economic Commission. (2017). Technical Regulation of the Eurasian Economic Union TR EAEU 044/2017 on the Safety of Packaged Drinking Water, Including Natural Mineral Water.
34. International Organization for Standardization. (2018). ISO 22000:2018 Food safety management systems — Requirements for any organization in the food chain. ISO.
35. Government of the Republic of Armenia. (2018, amended 2022). Decision No. 893-L of 19 July 2018 on approving the Support Programme for leasing of agrifood equipment in the Republic of Armenia [official English translation]. ARLIS. https://www.arlis.am/hy/acts/193644

A.Kh. Markosyan, V.G. Khachaturyan, M.A. Markosyan, E.N. Matevosyan, H.V. Tokmajyan
GLOBAL TRADE IN DRINKING WATERS (HS 2201) AND BEVERAGES DERIVED THEREFROM: MARKET CONCENTRATION, UNIT VALUES, AND ARMENIA'S EXPORT PROSPECTS THROUGH 2031

ԽՄԵԼՈՒ ՋՐԵՐԻ (HS 2201) ԵՎ ԴՐԱՆՑ ՀԻՄԱՆ ՎՐԱ ՍՏԱՑՎԱԾ ԸՄՊԵԼԻՔՆԵՐԻ ՀԱՄԱՇԽԱՐՀԱՅԻՆ ԱՌԵՎՏՈՒՐԸ. ՇՈՒԿԱՅԻ ԿԵՆՏՐՈՆԱՑՎԱԾՈՒԹՅՈՒՆԸ, ՄԻԱՎՈՐ ԱՐԺԵՔՆԵՐԸ ԵՎ ՀԱՅԱՍՏԱՆԻ ԱՐՏԱՀԱՆՄԱՆ ՀԵՌԱՆԿԱՐՆԵՐԸ ՄԻՆՉԵՎ 2031 ԹՎԱԿԱՆԸ

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Հոդվածում գնահատվում են HS 2201 ապրանքախմբին դասվող չքաղցրացված ջրերի միջազգային առևտրի ծավալը, աշխարհագրական կառուցվածքը, պայմանական միավոր արժեքները և Հայաստանի արտահանման ներուժը: UN Comtrade-ի 2010–2025 թթ. տվյալների հիման վրա կառուցվել են երկիր–տարի և Հայաստանի գործընկեր–տարի պանելներ: 2023 թ.՝ վերջին առավել համադրելի համաշխարհային տարում, արտահանման հայտարարագրված արժեքը կազմել է 5.77 մլրդ ԱՄՆ դոլար: 2024–2025 թթ. համար կիրառվել է հաշվետվությունների ծածկույթի ճշգրտում: 2023 թ. արտահանման CR5 ցուցանիշը կազմել է 68.9%, իսկ Հերֆինդալ–Հիրշմանի ինդեքսը՝ 0.164: Հայաստանի արտահանումը 2010 թ. 5.32 մլն դոլարից աճել է մինչև 19.42 մլն դոլար 2024 թ. և 23.40 մլն դոլար 2025 թ.՝ պահպանելով ռուսական շուկայի գերակշռող կշիռը: Գործընկերային և ժամանակային հաստատուն ազդեցություններով PPML գնահատումը լրացվել է rolling-origin կանխատեսման ստուգմամբ: Holt-ի գծային մոդելով Հայաստանի արտահանումը 2031 թ. գնահատվում է 34.48 մլն դոլար՝ 95% կանխատեսման 16.35–72.71 մլն դոլար միջակայքով: Արդյունքները ցույց են տալիս, որ Հայաստանի պաշտպանելի մրցակցային հնարավորությունը կապված է հավաստագրված, բրենդավորված և բարձրարժեք բնական ու հանքային ջրի հետ, ոչ թե ցածրարժեք զանգվածային արտահանման:

Բանալի բառեր. քաղցրահամ ջուր, հանքային ջուր, HS 2201, միջազգային առևտուր, PPML, միավոր արժեք, Հայաստան, կանխատեսում:

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GLOBAL TRADE IN DRINKING WATERS (HS 2201) AND BEVERAGES DERIVED THEREFROM: MARKET CONCENTRATION, UNIT VALUES, AND ARMENIA'S EXPORT PROSPECTS THROUGH 2031

МИРОВАЯ ТОРГОВЛЯ ПИТЬЕВЫМИ ВОДАМИ (HS 2201) И НАПИТКАМИ НА ИХ ОСНОВЕ: КОНЦЕНТРАЦИЯ РЫНКА, УДЕЛЬНАЯ СТОИМОСТЬ И ПЕРСПЕКТИВЫ ЭКСПОРТА АРМЕНИИ ДО 2031 ГОДА

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В статье оцениваются объем, географическая структура, условная удельная стоимость и экспортный потенциал Армении на международном рынке несладких вод товарной группы HS 2201. На основе данных UN Comtrade за 2010–2025 гг. сформированы панели «страна–год» и «партнер Армении–год». В 2023 г., последнем наиболее сопоставимом глобальном году, заявленная стоимость экспорта составила 5,77 млрд долл. США. Для 2024–2025 гг. применена корректировка охвата отчетности. В 2023 г. коэффициент концентрации пяти крупнейших экспортеров составил 68,9%, а индекс Херфиндаля–Хиршмана — 0,164. Экспорт Армении увеличился с 5,32 млн долл. в 2010 г. до 19,42 млн долл. в 2024 г. и 23,40 млн долл. в 2025 г., сохраняя высокую зависимость от российского рынка. Оценивание PPML проведено с фиксированными эффектами партнеров и лет и дополнено rolling-origin проверкой прогнозов. Линейная модель Холта прогнозирует экспорт Армении на уровне 34,48 млн долл. в 2031 г. при 95%-ном прогнозном интервале 16,35–72,71 млн долл. Результаты показывают, что конкурентная возможность Армении связана с сертифицированной, брендированной и более дорогой природной и минеральной водой, а не с массовым экспортом дешевой воды.

Ключевые слова: пресная вода, минеральная вода, HS 2201, международная торговля, PPML, удельная стоимость, Армения, прогнозирование.

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REDUCTION OF WATER PERCOLATION THROUGH MINE TAILINGS USING «PMM» MODIFIED GRANULAR MATERIAL: AN EXPERIMENTAL ASSESSMENT

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Abstract

Reducing water percolation through mine tailings is important for limiting water infiltration and the potential migration of contaminants within tailings storage facilities. This study aims to experimentally assess the effect of "PMM" modified granular material on water outflow through a mine-tailings substrate. Laboratory experiments compared a tailings substrate containing "PMM" modified granular material with a control tailings substrate. In each experiment, 4 L of water was applied to the substrate surfaces by simulated rainfall, and the mass of the discharged liquid was measured until the outflow ceased. In all six experiments, the outflow from the "PMM"-containing substrate was lower than that from the control. The cumulative discharged mass was 5,811 g for the "PMM" substrate and 11,240 g for the control, corresponding to an approximately 48.3% reduction in outflow**.** Variability among individual experiments was also associated with unequal intervals between experiments and the resulting differences in the initial moisture content of the substrates due to evaporation. The results indicate that the application of "PMM" modified granular material can substantially reduce water percolation through mine-tailings substrates and provide a basis for further investigation of its hydrophysical properties.

***Keywords**:* mine tailings, PMM modified granular material, water percolation, outflow, filtration, experimental study.

Introduction

Mine tailings are fine-grained residues generated during mineral processing and represent one of the major waste streams associated with mining activities. The increasing volumes of tailings produced worldwide, particularly as lower-grade ores are exploited, create substantial long-term environmental and engineering challenges related to their storage, treatment, and rehabilitation [1, 2]. Fine mineral tailings may contain large proportions of silt-

and clay-sized particles, while their long-term storage can create significant environmental liabilities [1].

Water plays a particularly important role in the environmental behaviour of tailings. Water infiltration and seepage through tailings deposits may contribute to contaminant transport and, in sulphide-bearing materials, provide conditions favourable for acid mine drainage formation [2, 6]. Consequently, limiting the contact of tailings with infiltrating water and controlling water movement through tailings deposits are important components of environmentally sustainable tailings management.

One approach used to control water movement within mine-waste facilities is the application of cover systems designed to reduce net percolation into the underlying waste. Water-balance covers operate principally by storing infiltrating water within the cover material and subsequently returning a portion of this water to the atmosphere through evaporation and evapotranspiration [4]. Their effectiveness therefore depends strongly on the hydrophysical characteristics and water-retention capacity of the materials used.

Recent studies indicate that the hydrophysical behaviour of cover materials can be improved through the incorporation of water-retaining additives. Sun et al. [6], for example, investigated compacted clay modified with clinoptilolite and sodium polyacrylate and demonstrated increased water-holding capacity compared with unmodified material. Their results showed that modification changed the soil-water characteristic behaviour and increased the volumetric moisture content retained at equivalent matric suction. Such findings indicate that modifying a substrate with suitable water-retaining materials can alter its capacity to store water and consequently affect water movement through the material [6].

The hydraulic response of such systems is also influenced by the moisture condition preceding water application. This aspect becomes particularly important under repeated wetting and drying conditions, because water retained within the material and water subsequently lost through evaporation affect the initial moisture state before the next precipitation or water-input event [4, 6]. Consequently, comparative experiments involving repeated fixed-volume water applications can provide useful information on the capacity of modified materials to reduce water passage through tailings under variable antecedent moisture conditions.

In this context, the use of modified granular materials capable of retaining part of the incoming water may provide a practical means of reducing water percolation through mine tailings. However, the effectiveness of such materials must be established experimentally by comparison with untreated tailings under equivalent water-input conditions.

Conflict Setting

The aim of the present study is to experimentally assess the effect of «PMM» modified granular material applied at a rate of 3 kg/m² on water percolation through a mine-tailings substrate. A laboratory experiment was conducted by comparing a tailings substrate containing a 5-cm layer of tailings mixed with “PMM” with an untreated control tailings substrate. Both substrates were subjected to repeated applications of the same fixed water volume, and the discharged liquid was measured until outflow ceased. The study provides a

quantitative experimental assessment of the potential of "PMM" modified granular material to reduce water passage through mine tailings.

Materials and methods

The experimental studies were conducted in the Hydraulic Research Laboratory of the Academician I.V. Yeghiazarov Institute of Water Problems and Hydro-Engineering.

Experimental setup

A laboratory experimental stand divided into three segments was used to comparatively assess water percolation through the investigated substrates. The first segment contained a 5-cm-thick layer of mine tailings mixed with "PMM" modified granular material applied at a rate of 3 kg/m².

The second segment served as a separating section, while the third segment contained a 5-cm-thick layer of untreated mine tailings and was used as the control. The surface areas of the first and third segments were equal, ensuring comparable conditions for water application and outflow measurements.

Fig. 1 Experimental setup for comparative assessment of water percolation through PMM-modified and control mine-tailings substrates

The experimental stand had a longitudinal slope of 4°.

Thus, two substrate variants were investigated:

- PMM substrate – mine tailings containing «PMM» modified granular material;
- Control substrate – untreated mine tailings without «PMM».
-

Experimental procedure

Water was applied to the surface of both substrates by simulated rainfall. During each experiment, a fixed volume of 4 L of water was applied to each substrate. The discharged liquid was collected separately until the outflow ceased.

The mass of the discharged liquid was then determined. The mass of each empty collection vessel was 300 g and was accounted for when determining the discharged liquid mass.

A total of six experimental runs were performed. The same water volume and experimental configuration were maintained for the PMM-modified and control substrates during each run, allowing direct comparison of their response to water application.

The intervals between consecutive experiments were not uniform. Consequently, evaporation occurring during the inter-experimental periods resulted in differences in the initial moisture content of the substrates.

Because the substrates were not brought to a predefined initial saturation or moisture level before each experiment**,** part of the fixed 4L water input replenished moisture lost by

evaporation before the formation of outflow. This factor was considered when interpreting the variability between individual experimental runs.

Data analysis

The effectiveness of the PMM-modified substrate was assessed by comparing the mass of discharged liquid with that obtained from the control substrate. For each experimental run, the relative reduction in outflow was calculated as:

$$R_i = \frac{M_{C,i} - M_{PMM,i}}{M_{C,i}} \times 100$$

where Ri - is the reduction in outflow for experimental run i(%), $M_{C,i}$ - is the discharged liquid mass from the control substrate (g), and $M_{PMM,i}$ - is the discharged liquid mass from the PMM-modified substrate (g).

The overall reduction was calculated from the cumulative discharged masses obtained during all six experiments:

$$R_{\Sigma} = \frac{\sum_{i=1}^{6} M_{C,i} - \sum_{i=1}^{6} M_{PMM,i}}{\sum_{i=1}^{6} M_{C,i}} \times 100$$

This approach was selected because the experimental procedure measured discharged water mass rather than the hydraulic conductivity or filtration coefficient directly. Therefore, the results are interpreted as a comparative assessment of water percolation and outflow reduction caused by the addition of PMM.

Research Results

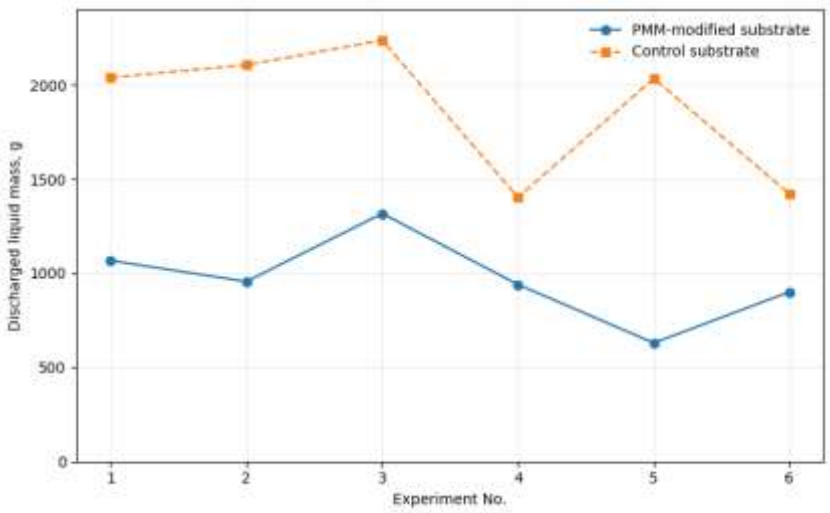
The results of the six experimental runs demonstrate a consistent difference between the PMM-modified and control tailings substrates. In every experiment, the mass of liquid discharged from the substrate containing “PMM” was lower than that from the untreated control substrate. The measured values reported in the experiments are presented in Tab. 1

Table 1

Experimental results and reduction in water outflow

Experiment	PMM substrate, g	Control substrate, g	Reduction, %
1	1067	2039	47.7
2	956	2106	54.6
3	1317	2237	41.1
4	940	1403	33.0
5	630	2034	69.0
6	901	1421	36.6
Total	**5811**	**11240**	**48.3**
Mean	**968.5**	**1873.3**	—

The cumulative mass of discharged liquid over the six experiments was 5811 g for the PMM-modified substrate and 11240 g for the control substrate. Thus, the cumulative outflow from the PMM-modified substrate was approximately 48.3% lower than that from the untreated tailings.



The individual experiments showed reductions ranging from 33.0% to 69.0%**.** Importantly, despite this variability, the direction of the response remained unchanged: the PMM-modified substrate produced less outflow than the control in all six experiments**.**

Fig. 2 Comparison of discharged liquid mass from PMM-modified and control mine-tailings substrates during six experimental runs.

This consistency indicates a systematic effect of the modified material rather than a result driven by a single experimental run. The variation in the absolute outflow values between individual experiments should be interpreted in relation to the experimental conditions. The intervals between consecutive experiments were not equal. Consequently, different amounts of water could evaporate from the substrates between experimental runs, resulting in different initial moisture conditions. Since the substrates were not restored to a predefined moisture or saturation level before each experiment and a constant 4L of water was applied in every run, part of the supplied water replenished the moisture lost during the preceding inter-experimental period. The remaining portion contributed to water retention and outflow. Therefore, variability in absolute outflow between experiments cannot be interpreted solely as variability in the effectiveness of PMM.

For this reason, the paired comparison between the PMM-modified and control substrates within each individual experimental run is particularly informative. Both substrates received the same water volume under the same experimental conditions, while the PMM substrate consistently discharged less water. The observed response is compatible with the general principle underlying water-retaining cover systems, in which increased storage of infiltrating water within a material reduces the quantity available for subsequent percolation [4]. Studies involving water-retaining amendments have likewise demonstrated that modification of a substrate can significantly alter its moisture-retention characteristics and hydraulic behaviour [6].

However, the present experiment did not directly determine saturated hydraulic conductivity or a conventional filtration coefficient. The measured parameter was the mass of liquid discharged after the application of a fixed volume of water**.** Therefore, the observed

48.3% reduction should be interpreted specifically as a reduction in cumulative outflow under the experimental conditions rather than as a 48.3% reduction in the filtration coefficient.

The experimental results nevertheless provide evidence that the addition of "PMM" at 3 kg/m² substantially modifies the water response of the investigated tailings substrate. Further experiments with controlled initial moisture content, fixed intervals between water applications, and direct measurements of hydraulic conductivity would allow the mechanisms responsible for the observed reduction to be quantified more precisely.

Study limitations and further research

The present study provides a preliminary experimental assessment of the effect of «PMM» modified granular material on water passage through mine tailings. The initial moisture content of the substrates was not standardized before each experimental run, and the time intervals between successive experiments were not uniform; therefore, evaporation resulted in differences in antecedent moisture conditions. In addition, the experiments quantified discharged liquid mass rather than hydraulic conductivity directly. Further studies should therefore include controlled initial moisture conditions, uniform intervals between water applications, direct measurements of hydraulic conductivity, and additional PMM application rates to establish the relationship between material dosage and water-retention performance.

Conclusions

The experimental study evaluated the effect of "PMM" modified granular material, applied at a rate of 3 kg/m², on water outflow through a mine-tailings substrate under repeated fixed-volume water applications.

The main conclusions are as follows:

1. In all six experimental runs, the mass of liquid discharged from the PMM-modified substrate was lower than that from the untreated control substrate, demonstrating a consistent effect of PMM on water passage through the investigated tailings.
2. The cumulative discharged liquid mass was 5811 g from the PMM-modified substrate and 11240 g from the control substrate. Thus, under the experimental conditions, the application of PMM resulted in an overall 48.3% reduction in cumulative water outflow**.**
3. The reduction observed in individual experiments ranged from 33.0% to 69.0%**.** This variability was influenced by unequal intervals between successive experiments and the associated evaporation, which resulted in different initial moisture conditions before the application of each fixed 4-L water volume.
4. Since the study measured discharged liquid mass rather than hydraulic conductivity directly, the obtained 48.3% reduction should not be interpreted as an equivalent reduction in the filtration coefficient. It represents a reduction in cumulative water outflow under the specific experimental conditions.
5. The results indicate that "PMM" modified granular material has potential as a water-retaining amendment for reducing water passage through mine-tailings substrates. Further experiments under controlled initial moisture conditions and with direct determination of hydraulic

conductivity are required to quantify its hydrophysical effect and assess its applicability under field conditions.

Overall, the results provide an experimental basis for considering "PMM" modified granular material as a potential component of systems intended to control water movement through mine tailings.

References

1. Wang, C., Harbottle, D., Liu, Q., Xu, Z. Current state of fine mineral tailings treatment: A critical review on theory and practice. *Minerals Engineering*, 2014, 58, 113–131. DOI: 10.1016/j.mineng.2014.01.018.
2. Edraki, M., Baumgartl, T., Manlapig, E., Bradshaw, D., Franks, D.M., Moran, C.J. Designing mine tailings for better environmental, social and economic outcomes: A review of alternative approaches. *Journal of Cleaner Production*, 2014, 84, 411–420. DOI: 10.1016/j.jclepro.2014.04.079.
3. Williams, D.J. Placing Soil Covers on Soft Mine Tailings. In: *Ground Improvement Case Histories*. Elsevier, 2015.
4. Qiu, Y., Sego, D.C. Sustainable Reuse of Mine Tailings and Waste Rock as Water-Balance Covers. *Minerals*, 2017, 7(7), 128.
5. Valorisation of Partially Oxidized Tailings in a Cover System to Reclaim an Old Acid Generating Mine Site. *Minerals*, 2021, 11(9), 987.
6. Water-Holding Properties of Clinoptilolite/Sodium Polyacrylate-Modified Compacted Clay Cover of Tailing Pond. *International Journal of Environmental Research and Public Health*, 2022, 19(23), 15554.
7. Monitoring moisture dynamics in multi-layer cover systems for mine tailings reclamation using autonomous and remote time-lapse electrical resistivity tomography. 2024.
8. Effects of Cementitious Amendments on the Mechanical Strength and Hydraulic Conductivity of Mine Tailings for Reclamation Cover Systems. *Geotechnical and Geological Engineering*, 2026, 44, Article 353.

ՊՈՉԵՐԻ ՋՐԱԹԱՓԱՆՑԵԼԻՈՒԹՅԱՆ ՆՎԱԶԵՑՈՒՄԸ «PMM» ՄՈԴԻՖԻԿԱՑՎԱԾ ՍՈՐՈՒՆԻ ԿԻՐԱՌՄԱՄԲ. ՓՈՐՁԱՐԱՐԱԿԱՆ ԳՆԱՀԱՏՈՒՄ

Վ.Ռ. Գրիգորյան

Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Հանքարդյունաբերական պոչերի ջրաթափանցելիության նվազեցումը կարևոր նշանակություն ունի պոչամբարներում ջրի ներթափանցման և աղտոտիչների հնարավոր միգրացիայի սահմանափակման տեսանկյունից: Աշխատանքի նպատակն է փորձարարական եղանակով գնահատել «PMM» մոդիֆիկացված սորունի ազդեցությունը պոչային սուբստրատի միջով ջրի արտահոսքի վրա: Լաբորատոր ստենդում համեմատվել են «PMM» մոդիֆիկացված սորուն պարունակող և ստուգիչ պոչային սուբստրատները: Յուրաքանչյուր փորձի ընթացքում սուբստրատների վրա անձրևացման եղանակով ավելացվել է 4 լ ջուր և չափվել արտահոսած հեղուկի զանգվածը մինչև արտահոսքի դադարումը: Կատարված վեց փորձերում «PMM» պարունակող սուբստրատից արտահոսքը բոլոր դեպքերում եղել է ստուգիչ տարբերակից փոքր:

Ընդհանուր արտահոսքը կազմել է համապատասխանաբար 5811 և 11240 գ, ինչը համապատասխանում է արտահոսքի մոտ 48.3% նվազմանը: Առանձին փորձերի արդյունքների տատանումները պայմանավորված են նաև միջփորձային ժամանակահատվածների տարբերությամբ և դրա հետևանքով սուբստրատների նախնական խոնավության փոփոխությամբ: Ստացված արդյունքները ցույց են տալիս, որ «PMM» մոդիֆիկացված սորունի կիրառումը կարող է էապես նվազեցնել պոչային սուբստրատի միջով ջրի արտահոսքը և հիմք է ստեղծում նյութի հիդրոֆիզիկական հատկությունների հետագա ուսումնասիրության համար:

Բանալի բառեր. հանքարդյունաբերական պոչեր, PMM մոդիֆիկացված սորուն, ջրաթափանցելիություն, արտահոսք, ֆիլտրացիա, փորձարարական հետազոտություն:

СНИЖЕНИЕ ВОДОПРОНИЦАЕМОСТИ ХВОСТОВ С ПРИМЕНЕНИЕМ МОДИФИЦИРОВАННОГО СЫПУЧЕГО МАТЕРИАЛА «PMM»: ЭКСПЕРИМЕНТАЛЬНАЯ ОЦЕНКА

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Снижение водопроницаемости отходов горнодобывающей промышленности имеет важное значение для ограничения инфильтрации воды и потенциальной миграции загрязняющих веществ в хвостохранилищах. Целью работы является экспериментальная оценка влияния модифицированного сыпучего материала «PMM» на фильтрационный сток через субстрат из хвостов. В лабораторных условиях проведено сравнительное исследование субстрата, содержащего модифицированный материал «PMM», и контрольного субстрата из хвостов. В каждом эксперименте на поверхность субстратов методом дождевания подавалось 4 л воды, после чего измерялась масса вытекшей жидкости до полного прекращения стока. В шести проведённых экспериментах величина стока из субстрата с «PMM» во всех случаях была ниже, чем в контрольном варианте. Суммарная масса вытекшей жидкости составила соответственно 5811 и 11240 г, что соответствует снижению стока примерно на **48,3%**. Разброс результатов отдельных экспериментов также связан с различной продолжительностью межэкспериментальных периодов и обусловленными испарением различиями исходной влажности субстратов. Полученные результаты показывают, что применение модифицированного сыпучего материала «PMM» способно существенно уменьшить прохождение воды через субстрат из хвостов и обосновывают необходимость дальнейшего исследования его гидрофизических свойств.

Ключевые слова: хвосты горнодобывающей промышленности, фильтрация, модифицированный материал PMM, водопроницаемость, сток, экспериментальные исследования.
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MARKET-BASED MANAGEMENT OF FERTILE TOPSOIL ACCUMULATED FROM THE AKHURYAN RESERVOIR BASIN: A SYSTEMIC MODEL FOR VALUATION, LOT FORMATION, PUBLIC SALE, REVENUE DISTRIBUTION, AND LEGAL REFORM

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Abstract

The article develops a scientific and practical model for the legal and economic circulation of 212,532 m³ of fertile topsoil that has been stockpiled in the vicinity of the Akhuryan Reservoir for approximately four decades. According to field measurements and laboratory analyses conducted in 2026, the average humus content of the stockpiled soil is 3.54%, compared with 4.54% in the background soil. This finding confirms the high resource potential of the stockpile but does not justify classifying the entire volume uniformly as *chernozem* without additional vertical and horizontal sampling.

The legal-dogmatic analysis shows that Article 36 of the Land Code of the Republic of Armenia and Government Decision No. 676-N permit the sale of fertile topsoil removed during construction activities and provide that the entire proceeds from the sale of topsoil obtained from state- and community-owned land plots be allocated to the community budget. At the same time, the existing regulatory framework does not establish a comprehensive mechanism for competitive price formation, public lot formation, earmarked use of revenues, or identification of ownership of long-standing historical stockpiles.

A two-stage solution is proposed: first, an immediately applicable open electronic auction, with quality-based grading and a starting price separated from logistics costs; and second, a legislative reform establishing a dedicated Land Resource Restoration Subaccount. Scenario-based valuation indicates that, within the considered price range of AMD 4,000–8,000/m³, the gross value of the stockpile amounts to approximately AMD 850.1 million–1.700 billion. However, this range cannot be mechanically adopted as an official price, since it requires comparable adjustments for legally documented transactions, soil quality, VAT, loading, and transportation conditions.

The study combines legal-dogmatic analysis, a synthesis of international Scopus-indexed literature, quality-adjusted comparative and residual valuation methods, scenario sensitivity analysis, and a multidimensional public net value model. Given the availability of only a single stockpile and unverified informal price observations, econometric coefficients are not estimated. Instead, an identifiable hedonic valuation model is formulated for future microdata generated through legally conducted auctions.

Keywords*:* fertile topsoil, chernozem, natural capital, public auction, pricing, community budget, land restoration, circular economy, Akhuryan Reservoir.

Introduction

The fertile topsoil layer is not an ordinary movable commodity. It constitutes a slowly forming form of natural capital whose private economic value is intertwined with public values related to food security, ecosystem services, erosion prevention, and carbon storage. Consequently, introducing it into market circulation should not be regarded as privatization for its own sake; a legally sound model must simultaneously prevent the dissipation of the resource, reveal actual demand, and ensure its targeted use [1].

The 212,532 m³ stockpile recorded in the territory of Aghin settlement, adjacent to the Akhuryan Reservoir, is distinctive for three reasons. First, it is a historical stockpile that has been stored for approximately 40 years. Second, the scale of the stockpile is nearly eight times greater than the combined 27,309 m³ flow of legally identified demand and illegal removal recorded in the report for 2025. Third, the stockpiling area encompasses land plots with different legal statuses; therefore, the location of the soil does not, in itself, automatically determine the ownership of the soil mass once it has become movable property.

Contemporary research considers long-term stockpiled topsoil to be a recoverable but qualitatively variable secondary soil resource. Valliere et al. demonstrate that plant growth and water-use efficiency may deteriorate even when conventional chemical analyses reveal no substantial differences. Fischer et al. confirm depth-related differences in nutrient availability and microbial communities. Amir et al. further associate the effects of stockpiling with changes in microbial diversity, while D'Agui et al. substantiate the need for multidimensional

biological assessment. The 2025 findings of Ledesma et al. highlight the importance of vertical heterogeneity within deep stockpiles [3-6].

The international policy framework follows the sequence: "inventory → characterization → classification → conditioning → matching to end use → controlled reuse → monitoring." The UK DEFRA Code requires the separation of topsoil and subsoil and the protection of soil structure. New South Wales gives preference to direct soil return, while stockpiling is regarded as a resource for future land rehabilitation. The EU Joint Research Centre (JRC) incorporates the reuse of excavated soils into the framework of the circular economy and life-cycle costing. The experience of Helsinki demonstrates the potential of digital supply–demand coordination and closed-loop soil reuse in public procurement [7-11].

Topsoil Stockpiling and Changes in Functional Quality

A key conclusion of contemporary international literature on fertile topsoil is that stockpiling is not a neutral practice. Justin Valliere, Haylee D'Agui, Kingsley Dixon, and co-authors demonstrated in Plant and Soil that plant growth, water-use efficiency, and the formation of nitrogen-fixing root nodules decline in stockpiled soils, even when individual physicochemical parameters show no substantial differences. Therefore, an average humus content of 3.54%, although an important indicator, is not sufficient evidence in itself to classify the entire 212,532 m³ stockpile as high-quality agricultural chernozem [7].

Haylee D'Agui and co-authors, in *Restoration Ecology*, simultaneously compared microbial community structure, biological activity, and a plant-growth bioassay. Their findings demonstrate that different biological indicators may lead to different conclusions regarding the same soil. For the Akhuryan stockpile, this implies that valuation should be based not on a single indicator, but on an integrated profile combining physical, chemical, biological, and plant-growth characteristics [3].

Pamela Block, Kaylee Gush, and Ryan Limb, in their study of long-term stockpiled grassland soils published in *Applied Soil Ecology*, documented changes in the abundance and composition of microbial communities. Importantly, depth within the stockpiled soil mass may be a determining factor: the properties of the upper, aerated layer cannot be mechanically extrapolated to the middle and deeper layers of the stockpile [12].

Jamie Ledesma, Joseph Neilson, Raina Maier, and co-authors, in their 2025 study, used boreholes extending to depths of more than 20 m to identify vertical biogeochemical heterogeneity resulting from long-term stockpiling. Their approach is particularly relevant to the characteristics of the historical Akhuryan stockpile and supports the need for three-dimensional inventorying and depth-stratified sampling [6].

Ashley Fischer, Jay P. Singh, Jonathan Van Hamme, and co-authors demonstrate that microbial community structure and diversity vary with stockpile height and depth. This finding is important not only for environmental assessment but also for economic valuation: quality heterogeneity implies that assigning a single uniform price to the entire stockpile would constitute a valuation error; therefore, the stockpile should be marketed in quality-homogeneous lots [5].

Excavated Soil as a Secondary Resource in the Circular Economy

Sarah Hale, António José Roque, and co-authors, in their assessment of international practices for the reuse of soils generated by construction and demolition projects, identify four

major barriers: fragmented regulation, uncertainty regarding material quality, logistical mismatches, and the lack of supply–demand coordination. In the Akhuryan case, all four barriers are present simultaneously: the stockpile has been inventoried, but there is still no classified marketable product, transparent price signal, or digital marketplace connecting potential end users [13].

Benedetto Rugani and Claudio Petucco, using a spatial life-cycle model in *Science of the Total Environment*, demonstrate that the local reuse of excavated soil can substantially reduce the environmental burden associated with transportation and disposal. Therefore, maximizing the market price of the Akhuryan stockpile should not result in sales to distant destinations where tonne-kilometre-related emissions outweigh the environmental benefits of reuse. Under an auction-based system, a logistics-related carbon indicator should be disclosed, while in tenders for public projects it should be incorporated into the evaluation criteria [2].

The study conducted by the European Commission's Joint Research Centre (JRC) conceptualizes excavated soil as a circular material flow and integrates life-cycle assessment (LCA) with life-cycle costing (LCC). Under this approach, the sale price does not represent the full social value of the resource. Decision-making therefore requires an integrated assessment of monetary revenue, the value of substituted primary soil resources, avoided disposal, carbon impacts, and the ecosystem benefits generated by restored land [9].

Soil Quality, Natural Capital, and Pricing

Oshadi Samarasinghe and Suzie Greenhalgh, using a hedonic approach in *Soil Research*, demonstrated that intrinsic soil characteristics—such as drainage, rooting depth, and water availability—are reflected in the value of agricultural land. Their findings support the use of quality adjustment coefficients. However, the price of a movable stockpile of fertile topsoil cannot be derived directly from the per-hectare sale price of agricultural land, because the values attributable to location, development potential, and property rights must be excluded [14].

Luise Meißner and Oliver Mußhoff, in a study published in *Q Open* using German data for 1991–2020 and FMOLS and DOLS estimators, demonstrated a long-run relationship between soil quality and agricultural land prices. This finding provides an important theoretical basis for the quality-adjusted valuation of the Akhuryan stockpile, but it cannot substitute for data from legally documented local transactions. Directly transferring internationally estimated coefficients to the Armenian market would be econometrically unjustified [15]. Kritika Sen Chakraborty, Avinandan Chakraborty, and Robert P. Berrens, in a study published in *World Development*, used a hedonic model to estimate the value of investments in soil erosion control. An important implication of their research is that market land prices may capitalize some soil conservation attributes, while public ecosystem benefits are not fully reflected in private willingness to pay. Therefore, reserving a portion of the stockpile for public land restoration outside the market auction mechanism should not be regarded as contrary to economic efficiency [16].

Auction Design, Competition, and Public Revenue

Pantelis Koutroumpis and Martin Cave, in a study published in the *Journal of Regulatory Economics* based on data from 371 auctions across 85 countries and more than

10,000 lots, demonstrated that auction design has a significant effect on final normalized revenues, while administrative allocations generally provide a weaker mechanism for revealing the true value of a scarce resource. Although their study focuses on radio spectrum, its institutional implication is also applicable to the Akhuryan case: a divisible and scarce resource under public control should not be allocated on a large scale through individually negotiated arrangements [17].

Decio Coviello and Mario Mariniello, in a study published in the *Journal of Public Economics*, used a natural experiment to demonstrate that increased publicity of auctions raised the number of participants and improved price outcomes for the government**.** This finding supports not merely compliance with minimum legal notice requirements, but the establishment of a comprehensive data room containing laboratory reports, maps, the draft contract, questions and answers, and machine-readable auction results [18].

Paul Klemperer's seminal work on auction design emphasizes that the optimal auction is not a technical format that can be applied independently of context; rather, priority should be given to preventing insufficient participation, collusive behavior, and barriers to entry for new bidders**.** Therefore, selling the Akhuryan stockpile as a single large lot does not guarantee a higher price; instead, it may restrict competition and create market power for a single buyer [19].

The synthesis of this literature leads to the article's central theoretical proposition**:** the optimal management of the Akhuryan stockpile is not a simple choice between «selling» and «free allocation». Rather, it is a sequential decision-making process comprising clarification of legal ownership, quality-based segmentation, reservation for public land restoration, competitive lot formation, auction-based price discovery, and the earmarked reinvestment of net proceeds**.**

Natural Capital and the Informational Limitations of Informal Prices

An informal price provides information about scarcity and effective demand, but does not constitute legal or valuation evidence. It may incorporate a risk premium associated with illegal extraction, unknown quality, loading and delivery costs, tax avoidance, or, conversely, a high retail margin. Therefore, the AMD 4,000–8,000/m³ range is used in this article solely as an observed price signal and a scenario range, rather than as an automatic basis for determining the starting price.

Scientific Novelty of the Study

- The legal characterization of a long-standing historical stockpile is linked not merely to its designation as "chernozem," but to its current functional quality and origin.
- A quality-adjusted residual value formula is proposed, separating the value of the soil itself from loading, transportation, and restoration costs.
- A dual-track allocation model is developed: auctioning of commercial lots, and competitive selection/public allocation for projects that commit to measurable land-restoration outcomes.
- Revenue distribution is structured through a two-tier legal framework: under the currently applicable Government Decision No. 676-N, 100% of the proceeds are allocated to the community budget, while intergovernmental revenue-sharing formulas would become possible only following legislative amendments.

Conflict Setting

The research question is as follows: Is it economically rational and legally justified to continue allocating this high-value stockpile through administrative distribution without

competitive price discovery, given that informal market offers range from AMD 4,000 to 8,000/m³, and what institutional model can effectively integrate legality, economic efficiency, social equity, and environmental outcomes?

Data and methodology

The primary empirical basis of the study comprises field measurements of the stockpiling area, cadastral data, sampling conducted on March 24, 2026, and results obtained from an accredited laboratory. The study applies legal-dogmatic, systemic, and teleological interpretation, comparative institutional analysis, scenario-based valuation, sensitivity analysis, and multidimensional decision-making logic. The article does not substitute for a definitive legal determination of property ownership; prior to any sale, a separate legal audit of the chain of provenance and ownership status of each sub-area is required.

Table 1

Key Quantitative and Qualitative Indicators of the Fertile Topsoil Stockpile in the Vicinity of the Akhuryan Reservoir

Indicator	Value	Comment
Estimated volume	212,532 m³	Result of field measurements reported in the study
Stockpiling area	approx. 2.52 ha	Includes land plots with different cadastral statuses
Average humus content	3.54%	High/good agricultural potential
Background humus content	4.54%	Natural reference value
Relative difference	−22.0%	(3.54/4.54 − 1) × 100
Legal applications in 2025	2,716 m³	20 applications
Illegal removal	24,593 m³	Recorded through monitoring and enforcement activities
Observed informal price	AMD 4,000–8,000/m³	Delivery and tax conditions not verified

Source: Compiled from the 2026 report on the Akhuryan stockpile and the authors' calculations.

The unit value should be estimated by combining at least three approaches: comparable sales, cost/replacement value, and residual value. The income approach is applicable only to those end uses for which incremental crop yields or savings in landscaping costs can be reliably quantified.

$$P_i = \max\{P_i^{\text{cost}},\ \tilde{P}^{\text{comp}} Q_i L_i - C_i^{\text{r}} - R_i\} \quad (1)$$

where P_i - is the estimated ex-stockpile price per 1 m³ of soil in quality class; P_i^{cost} - the minimum recoverable cost of inventorying, testing, safe storage, and sale; $\tilde{P}^{\text{comp}}$ -is the median price of legally documented and comparabl transactions; Q_i_- is the quality adjustment coefficient; L_i - is the location/accessibility coefficient; C_i^{r} - is the required conditioning cost; and R_i - is the discount reflecting legal, contamination, and marketability risks. Transportation is treated separately and borne by the buyer, so that the logistics costs of distant purchasers do not distort the price of the public asset.

$$V = \sum_{i=1}^{n} q_i\, P_i - C_0 - \sum_{i=1}^{n} q_i\, c_i \quad (2)$$

Here, q_i - is the volume sold, C_0 - is the fixed preparatory cost, and c_i - represents the variable costs of measurement, loading, monitoring, and transaction administration. This formulation distinguishes gross revenue from the community's net public benefit.

Quality Classification

The economic utilization of the stockpile requires the formation of quality-homogeneous lots**.** The classification presented below links measurable soil characteristics **to** permissible end uses and the corresponding price-adjustment ranges**.**

Table 2

Quality Classification, Intended Uses, and Price-Adjustment Coefficients for Fertile Topsoil

Class	Mandatory Criteria	Primary Use	Price Adjustment Coefficient (Q)
A	No contamination; adequate soil structure; high organic matter content; positive bioassay results	Improvement of agricultural soils	1.00–1.20
B	Safe, but requires structural and/or biological conditioning	Land reclamation, afforestation, urban greening	0.70–0.95
C	Limited functionality; suitable for controlled technical applications	Landscape cover and slope stabilization after improvement	0.35–0.65
X	Contamination or non-compliance	Sale prohibited; special management required	0

The methodological framework is based on the studies of Valliere et al. (2022), D'Agui et al. (2022), Hale et al. (2021), Rugani and Petucco (2025), Cristóbal et al. (2024), Samarasinghe and Greenhalgh (2013), Meissner and Musshoff (2022), and Chakraborty and Chakraborty (2023), as well as Government Decisions No. 124-N and No. 676-N of the Republic of Armenia**.**

Feasibility and Limitations of Econometric Estimation

The structure of the available data does not permit the reliable estimation of an econometric model with empirically derived coefficients. The analysis concerns a single stockpile, while the AMD 4,000–8,000/m³ range is based on market observations and does not constitute a series of transaction-level microdata. Estimating a regression model using only a few assumed prices would create an illusion of numerical precision. Accordingly, econometric analysis is presented in this article as an estimation strategy to be applied after pilot sales have generated sufficient data, rather than as an already obtained empirical result.

Consequently, the AMD 5,000 and AMD 2,000 payments**,** the 15% profitability threshold, the quality coefficients, and the quantitative limits imposed on individual lots presented below are normative scenario-based parameters rather than empirically estimated optima. Their final values should be recalibrated using data from pilot auctions and subjected to sensitivity analysis.

Once a unified database of auction results and legally documented contracts has been established, the hedonic price per 1 m³ can appropriately be estimated using the following semi-logarithmic model:

$$\ln P_{jt} = \alpha + \beta_1 H_j + \beta_2 SOC_j + \beta_3 pH_j + \beta_4 EC_j + \beta_5 D_j + \beta_6 \ln Q_j + \beta_7 C_t + \mu_m + \tau_t + \varepsilon_{jt} \quad (3)$$

where Pjt - is the final price of lot j lat time t; H- denotes humus content; SOC - represents soil organic carbon; pH - and EC- denote soil acidity and electrical conductivity, respectively; D- is the distance to the buyer's intended destination; Q- is the lot volume; C- is an indicator

of auction competition; μ_m - captures use- or region-specific fixed effects; and τ_t represents time fixed effects. Standard errors should be clustered at the auction level.

This model will subsequently make it possible to determine empirically whether smaller lot sizes and more comprehensive quality disclosure enhance price competition. Until sufficient empirical evidence becomes available, the starting price should be based on an independent valuation and a pilot auction [20].

Measurement of Public Net Value and Multidimensional Efficiency

$$\boldsymbol{NPV_s = \sum_{t=0}^{T} \frac{R_t - C_t - E_t + B_t}{(1+r)^t}} \quad (4)$$

Here, R_t - represents revenues from sales and avoided disposal costs; C_t- denotes the costs of inventorying, testing, loading, and management; E_t represents transportation costs and potential environmental externalities; B_t - denotes the measurable ecosystem benefits generated by restored land; and rr is the social discount rate. This calculation avoids the erroneous assumption that the option yielding the highest nominal sale price is automatically the most efficient alternative**.**

$$W_k = 0.35NREV_k + 0.25LAND_k + 0.15COMP_k + 0.15TRACE_k + 0.10CARB_k \quad (5)$$

For comparing alternative options, a normalized multidimensional index on a 0–100 scale is proposed, where NREV represents net community revenue, LAND denotes land-restoration outcomes, COMP reflects the level of competition, TRACE represents traceability, and CARB denotes carbon efficiency. The weights assigned to these dimensions are a matter of policy choice and should be established through public consultation; however, their ex ante disclosure limits ex post discretion**.**

Assessment of the current legal framework

Permissibility and limits of sale

Under the current wording of Article 36(5) of the Land Code of the Republic of Armenia, the sale of fertile topsoil removed during mineral extraction activities is prohibited, whereas the procedure for the sale of fertile topsoil removed as a result of construction activities is established by the Government. Government Decision No. 676-N constitutes this specific regulatory framework: it requires authorization from the head of the community, documentation issued by an accredited laboratory and submitted by the seller, a sale and purchase agreement, designated end use, and proper record-keeping [21, 22].

For the Akhuryan stockpile, it is essential to document that the soil mass was removed as a result of reservoir construction rather than mineral extraction activities. In addition, it must be established who owned the land at the time of removal, who carried out the removal and subsequent stockpiling, and whether ownership of the stockpiled soil was subsequently transferred. The current owner of the cadastral land plot is not necessarily, by virtue of that fact alone, the owner of the soil that has been removed and transformed into movable property. This legal audit constitutes a mandatory “Phase Zero” prior to the auction.

Legal and Economic Assessment of Free Allocation

The primary environmental function of fertile topsoil is to improve degraded, disturbed, or less productive land. Therefore, free allocation is not inherently irrational,

provided that it serves a pre-approved public land-restoration programme, delivers measurable outcomes, applies a transparent beneficiary-selection process, and includes post-use monitoring. However, the complete administrative allocation of a high-value, commercially usable stockpile that substantially exceeds existing demand, without competitive selection, fails to ensure adequate compensation for public property, creates risks of selective preferential treatment and informal resale, and is inconsistent with the objectives of efficient and accountable resource management.

Accordingly, a legally sound policy should distinguish between two allocation streams. A public restoration reserve may be allocated free of charge or on subsidized terms through a competitive, results-based procedure, whereas lots intended for commercial and private use should be sold through public auction. Recipients of free allocations should be prohibited from reselling the soil, while its actual use should be verified through geographic coordinates, an acceptance certificate, and monitoring for at least one season.

Auction or Competitive Tender?

Under the Law of the Republic of Armenia "On Public Auctions," the winner of an auction is the bidder offering the highest price, whereas in a competitive tender, the winner is the participant offering the best terms and conditions. Therefore, the choice of instrument should be determined by the objective pursued rather than by administrative preference.

Table 3

Comparative Assessment of the Intended Application of Auction and Competitive Tender Mechanisms

Objective	Recommended Mechanism	Winner Selection Criterion	Rationale
Commercial sale	Open electronic ascending-price auction	Highest price	The resource is classified and comparable
Public land reclamation	Open competitive tender or two-stage tender	Best price–outcome combination	Location, restoration outcomes, and co-financing are important
Access for small farmers	Auction of standardized small lots with quantity limits	Highest price, subject to a per-buyer quantity cap	Prevents concentration of the entire stockpile in the hands of a single buyer
Urgent environmental need	Justified targeted allocation	Public necessity	Exception subject to full public disclosure

Source: Author's compilation based on the provisions of the Law of the Republic of Armenia "On Public Auctions."

The proposed primary mechanism is an open electronic ascending-price auction. A competitive tender is appropriate not for ordinary sales, but for lots where the community also seeks to obtain a public benefit, such as the restoration of eroded land, carbon storage, urban greening, or co-financing. Combining price and qualitative commitments within a single non-transparent evaluation process increases administrative discretion; therefore, tender criteria should be quantified in advance.

Mandatory Destination of Sale Proceeds

Paragraph 5 of Government Decision No. 676-N explicitly provides that proceeds from the sale of fertile topsoil removed from state- and community-owned land plots shall be credited to the community budget. Accordingly, under the current legal framework, a proposal to distribute gross proceeds on a percentage basis among the state, the region, the community,

and the organizer would not be legally permissible. Nor does the region constitute a separate budgetary beneficiary for the purposes of this specific regulatory framework.

The organizer's remuneration should therefore take the form of a pre-determined service fee or an actually incurred and duly substantiated expense, financed through the community budget and governed by public procurement rules, rather than a share automatically withheld from the sale proceeds [21].

Systemic Interrelationship of the Legal Acts

Article 36 of the Land Code of the Republic of Armenia defines the substantive legal boundaries; Government Decision No. 676-N establishes the specific procedure for the sale of fertile topsoil removed as a result of construction works; Government Decision No. 1396-N sets the requirements for its use and conservation; and Government Decision No. 124-N establishes the minimum safety thresholds for contamination assessment. The Law of the Republic of Armenia "On Public Auctions" applies where the right holder chooses an auction or competitive tender as the contractual allocation mechanism. These legal acts should be applied in conjunction with one another, rather than as mutually substitutable regulatory instruments [22].

The wording in Paragraph 4 of Government Decision No. 676-N, allowing the price to be determined "by mutual agreement," does not preclude the use of a public auction. On the contrary, the highest bid established through an auction constitutes the mutually agreed contractual price between the owner and the winning bidder. In the case of a large publicly controlled stockpile, an auction fills a gap in the specific regulatory framework by ensuring equal access and verifiable price discovery. However, community decisions concerning the use of an auction, approval of lots, and determination of the starting price must be adopted with strict observance of the respective legal competences [22].

The most important legal prerequisite is the establishment of ownership of the stockpile. The current cadastral ownership of the land plot underlying the stockpiled material is not, by itself, sufficient to identify the legal owner of the soil once it has been removed and transformed into movable property. It is necessary to reconstruct the chronology of soil removal, determine the legal status of the client and contractor responsible for reservoir construction, examine soil inventory records and subsequent transfers, and establish whether the stockpile was recognized on the community's balance sheet. Until these issues are resolved, any formula for allocating potential revenues remains conditional.

Solutions Permissible under Current Law and Those Requiring Legislative Amendment

Under the current legal framework, it is possible to commission an independent valuation, divide the stockpile into lots, organize an open electronic auction, credit the entire proceeds to the community budget, and pay for laboratory, organizational, and monitoring services through applicable budgetary and public procurement procedures. It is also possible, through a programme approved by the community council, to earmark net proceeds for land restoration, provided that budget classification requirements and public accountability are maintained.

Legislative amendment would be required to introduce automatic percentage-based transfers of gross proceeds to the state budget or the regional level, direct allocation to the

organizer of a share of the resource rent generated by the sale, exemptions from the general procedure governing authorization of sales, or the transfer of community revenues to a private extra-budgetary fund. These options are presented in this article as reform scenarios rather than descriptions of the law currently in force.

Price and financial scenarios

Sensitivity of Gross Value

Since no verified transaction price is available for the entire stockpile, its gross value is initially assessed through sensitivity analysis using alternative unit-price scenarios. The table presents indicative valuation ranges rather than projected final proceeds.

Table 4

Sensitivity of the Gross Value of the Stockpile to Alternative Price-per-Cubic-Metre Scenarios

Price, AMD/m³	Gross Revenue, AMD million	Gross Revenue, AMD billion
3,000	637.6	0.638
4,000	850.1	0.850
5,000	1,062.7	1.063
6,000	1,275.2	1.275
7,000	1,487.7	1.488
8,000	1,700.3	1.700

Source: Author's calculations based on the verified volume of 212,532 m³ and the scenario-based prices.

The scenario of AMD 4,000/m³ yields a gross value of AMD 850.128 million, while AMD 6,000/m³ results in AMD 1.275 billion, and AMD 8,000/m³ in AMD 1.700 billion. Actual proceeds will depend on the shares of Classes A, B, and C, the phasing of sales, the portion reserved for non-commercial public use, and the market's absorption capacity. Offering the entire volume simultaneously could depress the market price and lead to oligopsonistic concentration.

Formation of the Proposed Starting Price

It is proposed that the independent appraiser provide not a single value, but a price range by quality class. For the first pilot auction lot of 5,000–10,000 m³, the preliminary policy range may be set at AMD 3,500–4,500/m³, on an ex-stockpile basis, provided that verification against legally valid comparables and relevant costs supports this threshold. A price of AMD 4,000/m³ may be used as the central pilot scenario rather than as a predetermined final price. A Class A lot may carry a 15–25% premium, Class B may be priced at the base level or at a 10–25% discount, while Class C may be offered at a 35–60% discount.

The auction bid increment is recommended to be set at 2–5% of the starting price, with the bid security/deposit equal to 5% of the lot's starting value. During the first stage, the maximum share that may be acquired by a single buyer should be limited to 20–25% of the volume offered. Following an unsuccessful auction, any reduction in the starting price should be gradual and justified, not exceeding 10% at each subsequent auction, and in no case falling below the cost-recovery floor.

Logistics and Spatial Pricing

$$P_i^{\text{deliv}} = P_i^{\text{ex}} + C_i^{\text{load}} + d_i t_i + C_i^{\text{loss}} \quad (6)$$

The delivered price is equal to the ex-stockpile price plus loading costs, transportation costs calculated as the product of distance and transport tariff, and costs associated with material losses. In distant markets, transportation costs may exceed the value of the soil itself. Therefore, the auctioned asset should be the soil "ex-stockpile", while loading and transportation services should either be arranged by the buyer or procured separately under a transparent framework contract.

Practical Algorithm for Determining the Value per 1 m³

The first step is to clearly define the valuation date and the conditions of sale—whether the price refers to 1 m³ of soil available at the stockpile or includes loading, VAT, and delivery. Without such standardization, offers of AMD 4,000 and AMD 8,000/m³ are not directly comparable.

The second step is to collect sales offers and completed transaction data from at least three independent and legally verifiable sources. Informal market advertisements may be included only as a secondary market signal, subject to a substantial risk discount.

The third step is quality adjustment. It is proposed that adjustment coefficients relative to the base price be applied for humus content, organic carbon, salinity, particle-size distribution, bulk density, contamination, and biological test results. The combined effect of these coefficients should not result in an unlimited increase in price. At the initial stage, it is advisable to constrain the overall adjustment coefficient within the range of 0.50–1.25 and subsequently recalibrate it using actual auction results.

$$P_{\text{start},i} = \max\left\{C_{\text{floor},i},\ \tilde{P}_{\text{legal}} Q I_i L I_i - R C_i - \rho_i\right\} \quad (7)$$

were $\tilde{P}_{legal}$- is the median of comparable legally verified prices, Q - is the composite quality index, L_i - is the accessibility coefficient, RC_i- represents the required conditioning costs, ρ_i - is the monetary discount reflecting legal and marketability risks, and C_{floor} - is the minimum cost-recovery price covering inventory, laboratory testing, storage, and marketing costs. The use of the median reduces the influence of individual exceptionally high or low price observations.

Proposed Price and Its Legally Appropriate Interpretation

Based on the available materials, AMD 4,000/m³ may serve as a working central scenario for the first pilot auction, but it should not be treated as a final official valuation. In practice, it is advisable to commission an independent appraiser to establish a justified range of AMD 3,500–4,500/m³ for Class B soil on an ex-stockpile basis, with a premium of up to 20% for Class A and a discount of at least 35% for Class C. If legally valid comparables do not support this range, the starting price should be revised accordingly.

The upper informal-market price of AMD 8,000/m³ may plausibly include small-volume retail sales, loading, urban delivery, and the seller's margin. Applying this price to the entire bulk stock of 212,532 m³ would yield a theoretical value of approximately AMD 1.700 billion, but this may overestimate the stock's actual market absorption potential. A phased auction process allows the market price to be discovered without oversupplying the market all at once.

Demand Absorption and Phased Sales

The 2,716 m³ of documented legal requests in 2025 and the recorded 24,593 m³ of unauthorized removal reported in the study do not imply that sustainable annual effective demand is precisely 27,309 m³.

Unauthorized flows may reflect supply rather than demand, and any double counting of the same cases must be excluded. Nevertheless, these figures indicate that selling the entire 212,532 m³ stock within a single year would not be realistic.

It is proposed to sell no more than 15,000–25,000 m³ during the first year, followed by 25,000–35,000 m³ in the second stage, depending on the results of the auctions, and 30,000–40,000 m³ annually in subsequent years. After each stage, the number of participants, the ratio of final to starting prices, unsold lots, and compliance with the intended end use should be reassessed.

Proposed architecture of the sales process

1. Legal audit of ownership and origin. Map the stockpile by cadastral parcels and document its construction-related origin.
2. 3D geodetic survey and mass balance. Assign each lot a unique identification code, volume, and coordinates.
3. Stratified sampling. Collect samples from the upper, middle, and deeper zones and assess their physical, chemical, biological, and botanical characteristics.
4. A/B/C/X classification and a publicly available "soil passport." Provide laboratory test reports, photographs, volume, restrictions, and designated end uses.
5. Public-needs allocation plan. Set aside in advance a 15–25% restoration reserve, to be used exclusively for approved projects.
6. Lotting. Establish small lots of 50–100 m³, medium lots of 500–1,000 m³, and large lots of 5,000–10,000 m³ to ensure diversity among potential buyers.
7. Electronic notification and auction. Publish the complete data package, declarations of conflicts of interest, and questions and answers.
8. Weighing/volumetric measurement and digital dispatch documentation. Link each outgoing vehicle to the relevant contract and designated destination.
9. Post-use verification. Require a buyer's acceptance certificate, geotagged photograph, and report confirming the intended end use.
10. Annual independent audit. Assess volume discrepancies, prices, revenues, environmental outcomes, and complaints.

Minimum Data Disclosure Package

- Lot volume, classification, sampling scheme, and the complete laboratory test report;

- Starting-price valuation report, including comparable prices and applied adjustments;
- Loading and transportation conditions, restrictions, and responsibilities;
- Participants, bid history, winning bidder, and final sale price;
- Amount paid, revenue transferred to the community budget, and a report on the targeted use of the proceeds.

Preferred Auction Format and Anti-Concentration Rules

For commercial lots, the preferred format is an open electronic English auction with ascending bids. This format is straightforward for participants, makes price competition transparent, and reduces discretion associated with closed valuation procedures. A sealed first-price bid may be used only where the risk of collusive behavior is high and the number of participants is sufficient; however, a single-round sealed bid is more vulnerable to information asymmetry.

To prevent concentration of the stock in the hands of a single large buyer, during the first two stages it is proposed to impose a maximum quantitative limit of 20% per group of related persons, require disclosure of beneficial owners, and prohibit the consolidation of lots until compliance with the contractual intended-use requirement has been confirmed. 10–15% of the small lots may be reserved for farms or other entities requiring up to 200 m^3, without directly subsidizing the price.

A competitive selection procedure should be applied to the public restoration reserve. The proposed evaluation weights are: ecological priority of the area to be restored – 35%; own co-financing – 25%; efficiency of soil use per hectare – 15%; logistical carbon efficiency – 15%; and monitoring and maintenance plan – 10%. Selection of the winner should not be based on a generic formulation such as the “best offer.”

Exceptional Cases of Free-of-Charge Allocation

Free-of-charge allocation is economically justified only where the community effectively obtains a public benefit of at least equivalent value.

The recipient should submit a land restoration project, the legal basis for use of the receiving site, a calculation of the required volume, its own financial contribution, and a commitment to subsequent maintenance. The soil should not be allocated merely on a first-come, first-served basis, since such a procedure does not compare public benefits and increases the risk of resale.

The contract for a free-of-charge or subsidized lot should include a prohibition on resale or other disposal, a deadline for the intended use, the right to conduct on-site inspections, an obligation to return any unused volume or pay its market value, and liability for compensation for any environmental damage caused.

OPTIMAL OPTIONS FOR REVENUE DISTRIBUTION AND USE

Option A. Community-Based Earmarked Management under the Existing Legal Framework (Preferred)

Under the existing legal framework, revenue allocation should be distinguished from the initial budgetary receipt of proceeds and their subsequent program-based expenditure. The following table presents a directly applicable community-level model.

Table 5

Community Model for the Allocation of Sales Proceeds in Compliance with the Existing Legal Framework

Flow	Proposed Share	Legal Form
Gross sales revenue	100% to the Ani Community budget	Mandatory requirement under Decision No. 676-N
Organizational, laboratory, and audit costs	At actual/competitively determined cost; target: ≤10%	Budget allocation and procurement contract
Land restoration and irrigation	50% of net revenue as a policy target	Program/sub-budget approved by the Council of Elders
Infrastructure in Aghin and adjacent settlements	20%	Community program
Reserve and stockpile maintenance	15%	Annual budget
Social support/co-financing for small farmers	15%	Program based on transparent eligibility criteria

Source: Author's proposal based on Paragraph 5 of RA Government Decision No. 676-N.

In this option, the percentages refer to intra-budgetary programming within the community budget, rather than to the distribution of proceeds at the time of sale. The model is fully applicable while maintaining the existing special regulatory framework, provided that the Council of Elders adopts an earmarked program and an annual report.

Option B. Community–State Co-Financed Land Restoration Fund

Following legislative amendments, the following allocation could be established: 70% to the community, 20% to a national land restoration fund, 5% to a competitive funding window for regional programs, and up to 5% for administration and oversight costs. This model is appropriate only if the state's share is reinvested in measurable land-conservation projects within the same region. Otherwise, it may weaken the incentives of the community that owns the resource. The regional share should not constitute revenue freely disposable by the regional administration, but rather a program-based allocation.

Option C. Environmental Outcome-Based 60/30/10 Model

Under this model, 60% of net proceeds would remain available for community development and land restoration programs, 30% would form a competitive national "soil circularity" fund, and 10% would cover classification, the digital database, monitoring, and independent auditing.

A private company acting as the organizer would not receive a share of the resource rent. Instead, it would be paid a performance-based service fee, for example capped at 2–4% of verified transactions, but only following competitive procurement and subject to savings/revenue KPIs. Implementation of this option would require amendments to Decision No. 676-N and the relevant budgetary regulations.

Performance Criteria for the Effective Use of Proceeds

Earmarking the funds for specific purposes is not sufficient; it is also necessary to measure the outcomes achieved through their use. The indicators summarized below combine financial returns, competition, traceability, and environmental performance.

Table 6

Performance Indicators and Proposed Targets for the Use of Proceeds from Sales

Criterion	Formula / Indicator	Proposed Target
Net recovered value	(Revenue − all costs) / m³ sold	Increasing across successive stages
Price discovery	Final price / starting price	≥1.05, provided there is sufficient competition
Competition	Valid bidders per lot	At least 3
Intended use	Verified volume used / volume sold	≥95%
Community return	Expenditure on restoration / net revenue	≥50% under Option A
Loss	Recorded volume − sold volume − remaining stock	≤2%
Carbon efficiency	CO_2e/m^3 or tonne·km	Annual reduction

Source: Author's synthesis based on the analysis of legal, economic, and environmental risks.

Within this system, effectiveness is measured not by the largest amount of expenditure, but by the verified land-conservation outcome achieved per unit of net revenue. Publication of these indicators will make it possible to compare programs and revise priorities accordingly.

Four Legally Compatible Scenarios for Revenue Allocation

Scenario 1 – Existing legal framework and full allocation to the community. One hundred percent of gross revenue is transferred to the Ani Community budget. Administrative and organizational costs are paid separately under procurement contracts, while at least 50% of net revenue is allocated, through a program approved by the Council of Elders, to land restoration, irrigation, and green infrastructure. This is the immediately applicable option with the lowest legal risk.

Scenario 2 – Community revenue with a performance-based organizer. Gross revenue remains 100% community revenue, while the organizer's contract provides for a fixed base fee and a performance-based bonus of up to 2%, applicable only to additional net revenue generated above the initially appraised value. Total remuneration should be subject to a monetary cap to prevent the organizer from effectively becoming a co-recipient of the natural-resource rent.

Scenario 3 – 70/20/5/5 formula following legislative amendments. Under this scenario, 70% is allocated to the community budget, 20% to a targeted national land-restoration program, 5% to competitive inter-community projects in Shirak Region, and a maximum of 5% to inventory, monitoring, and administration. This option may promote territorial solidarity, but only if the national and regional shares do not become non-transparent sources for financing general expenditures.

Scenario 4 – 60/30/10 natural-capital model. Under this model, 60% remains within the community, 30% is allocated to a national revolving land-restoration fund, and 10% is used for data management, laboratory testing, auditing, and the digital management system. This model is more systematic for managing national stocks amounting to millions of cubic metres, but for the single Akhuryan stockpile it may create a disproportionate administrative burden.

Principles for the Earmarked Use of Sales Proceeds

The first principle is additionality: the proceeds should not replace already approved mandatory community expenditures, but should generate additional land-conservation outcomes.

The second principle is intergenerational equity: revenue derived from the sale of non-renewable or slowly renewable natural capital should not be allocated entirely to current consumption.

The third principle is territorial return: Aghin settlement and the area directly affected by the stockpile should receive tangible benefits.

For each program, it is proposed to publish both input and outcome indicators, including hectares restored, changes in humus content, reduction in erosion, improvement in irrigability, survival rate of plantings, cost per hectare, and three-year maintenance costs. The amount of money spent alone is not an indicator of effectiveness.

Annual programming of the proceeds should be accompanied by an independent financial and performance audit. The audit should reconcile the volumes sold with the volumes actually transported, contractual and budgetary revenues, organizational costs, and the achieved restoration outcomes.

DISCUSSION

The Akhuryan case reveals the principal strengths and weaknesses of the existing regulatory framework. Its strength lies in the fact that the sale already has a legal gateway comprising community authorization, laboratory documentation, a contract, record-keeping, and transfer of proceeds to the community budget. Its weakness is that “mutual agreement” is not a sufficient price-discovery mechanism for a large public stock. Bilateral agreement may be appropriate for small and occasional volumes originating from construction sites, but for a public resource of 212,532 m³, it should be supplemented by public bidding, independent valuation, and conflict-of-interest controls.

Maximizing sales revenue is not the sole criterion of optimality. If all Class A material is purchased by a distant landscaping company offering the highest price while local eroded lands remain unrestored, the overall public benefit may be lower. Therefore, the proposed 15–25% public reserve, combined with auctioning of the commercial share, provides a balance between resource rent and ecosystem outcomes.

At the same time, extensive use of free-of-charge allocation may displace the legal market and encourage resale. Under a targeted competitive selection procedure, the subsidy should be determined not by the status of the recipient but by the documented public outcome, such as hectares restored, erosion prevented, green area created, or the level of co-financing provided.

Interpretation of the Legal Findings

The principal legal finding of the analysis is twofold. On the one hand, the existing regulatory framework does not prevent market circulation: Article 36 of the RA Land Code and Decision No. 676-N provide a legal basis for the sale of fertile soil removed as a result of construction activities. On the other hand, the same framework does not provide a comprehensive price-discovery mechanism for a large historical stockpile. Determining the

price by "mutual agreement" may be sufficient for a small and isolated transaction, but in the case of a 212,532 m³ publicly owned resource, it does not ensure equal access for potential buyers or verifiability of the best attainable price.

This gap should not be interpreted as a prohibition on sale. The legally more consistent solution is for the community to reach the contractual agreement envisaged by Decision No. 676-N through a public bidding procedure. In that case, the final auction bid becomes the price agreed between the parties, while the laboratory documentation, intended-use requirement, and authorization of the head of the community continue to apply as specific legal conditions. Thus, a public auction does not replace the special regulatory procedure; rather, it supplements it with a competitive component.

Economic Interpretation of the Pricing Results

The informal range of AMD 4,000–8,000/m³ indicates that fertile topsoil in Armenia has effective demand and generates positive economic rent. However, the breadth of this range also reflects the lack of market transparency: quoted prices may refer to soils of different quality, different lot sizes, loading arrangements, urban delivery, tax conditions, and retail margins. Therefore, extrapolating AMD 8,000/m³ to the entire stockpile would be as unjustified as assigning the resource a zero value.

The pilot starting-price range of AMD 3,500–4,500/m³ is presented in this article as a working decision threshold rather than a definitive appraised market value. The rationale is conservative: the starting price should be high enough to prevent unjustified transfer of public resource rent, but not so high as to reduce the number of bidders and increase the risk of unsuccessful auctions. The only reliable next step for actual price discovery is to conduct pilot auctions involving small and medium-sized lots of comparable quality.

Pricing policy should also respond to the volume supplied to the market. If the entire 212,532 m³ stock is released simultaneously, the resulting supply shock may reduce the final price irrespective of soil quality. A phased sale over 5–7 years is therefore not merely a technical convenience but also an instrument of intertemporal price management. The results of each stage should be used to update the valuation for the subsequent stage, taking into account the final-to-starting price ratio, number of participants, and unsold volume.

Institutional Choice between Auction and Competitive Selection

For commercial use, preference for an auction derives from the uniformity of the evaluation criterion: the quality, volume, and conditions of the lot are standardized in advance, and the highest bidder wins. A competitive selection procedure is more appropriate where the community is not merely selling or allocating soil but also expects an additional public benefit, such as restoration of eroded land, greening, co-financing, or a lower carbon footprint. Where no such additional outcome is expected, evaluation based on vaguely defined "best conditions" merely increases administrative discretion.

The lotting structure may be as important as the starting price. Offering only large lots reduces opportunities for small farms to participate and increases the market power of one or two buyers. Conversely, offering only small lots increases transaction costs. The proposed three-tier lotting system—small, medium, and large lots—balances competition with administrative costs. During the initial stages, the 20% quantitative limit for a single group of

related persons is intended to preserve a competitive market structure for subsequent sales rather than artificially restrict demand from an efficient buyer.

Revenue Allocation and Reinvestment in Natural Capital

Under Decision No. 676-N, the requirement that sales proceeds be transferred to the community budget is not merely a legal constraint but also a mechanism of local accountability. The community is the principal area affected by the location, storage, and external impacts of the stockpile; therefore, local retention of revenue is justified by the principles of origin and territorial impact. At the same time, using the entire amount for current consumption may undermine intergenerational equity because the asset being sold represents natural capital formed over a long period.

Accordingly, under the existing legal framework, the preferred approach is not an extra-budgetary division of gross revenue but earmarked programming within the community budget. Allocating at least 50% of net revenue to land restoration, irrigation, and green infrastructure converts one form of natural capital into another, more durable form. Scenarios involving fixed national or regional shares should be considered only after legislative amendments and in the context of establishing a national system covering multiple stockpiles.

Policy Transferability and National Scale

The Akhuryan case is exceptional in terms of its volume and duration of storage, but the underlying problem is national in scope. Fertile soil layers generated by road construction, reservoir development, industrial projects, and residential construction are affected by recurring information gaps, including incompatible inventory systems, limited accessibility of laboratory data, locally concentrated demand, and high transportation costs. Therefore, a single successful auction would not constitute a complete solution. A national digital database is needed in which both available stocks and demand are represented using the same quality-classification system.

At the same time, the findings from Akhuryan cannot be transferred to all stockpiles without adjustment. The historical origin associated with reservoir construction, average humus content, stockpile depth, and the distance of Ani Community from major markets create a specific context. A national framework should therefore standardize the valuation procedure, while preserving the price effects of differences in local quality, logistics, and intended end use.

Risks and Mitigation Instruments

The effectiveness of the proposed model depends on the proactive management of ownership, quality, volume, and competition risks. In the following table, each major risk is linked to a specific mitigation instrument.

Table 7

Key Risks in the Market-Based Management of Fertile Soil and Corresponding Mitigation Instruments

Risk	Consequence	Mitigation Measure
Ownership dispute	Invalidity of the auction	Preliminary legal audit and mapping
Quality heterogeneity	Buyer disputes and inappropriate use	Stratified sampling and lot-specific soil passport
Bid collusion	Depressed sale price	Electronic auction and disclosure of relationships among bidders

Volume misreporting	Budgetary losses	3D model and digital traceability of weighing/dispatch records
Resale or inappropriate use	Environmental damage	Intended-use conditions, GPS-based evidence, and penalties
Market oversupply	Price decline	Phased supply over **5–7 years**
Excessive organizer profit	Leakage of public resource rent	Fixed/capped competitively determined fee and transparent disclosure of costs

Source: Author's synthesis based on the analysis of legal, economic, and environmental risks.

The combined assessment of the risks indicates that the most vulnerable stage is not the sale itself, but the verification of ownership and quality prior to the sale. Without these foundations, even a fully transparent public auction cannot guarantee legal certainty or accurate price discovery.

Limitations

The proposed monetary scenarios estimate the potential gross value and do not substitute for an independent valuation. The analysis is limited by the absence of a database of comparable legal transactions, a comprehensive depth-based laboratory map of the entire stockpile, an accurate assessment of bulk density, loading costs, a transaction-specific determination of the applicable tax regime, and a stated-preference study of market demand. The reported "black-market" prices have not been verified through primary contracts and therefore cannot be presented as the average prices of actual completed transactions. These limitations provide the rationale for conducting a pilot auction and progressively updating the underlying data.

Proposed package of legal and legislative amendments

Implementation of the proposed market-based model cannot be limited to an administrative decision or the organization of a single auction. The existing legal framework recognizes the possibility of selling fertile soil removed as a result of construction activities; however, its principal mechanisms are structured around individual transactions, a price agreed between the owner and the buyer, and subsequent reporting requirements. In the case of the historical, large-scale stockpile adjacent to the Akhuryan Reservoir, a specific legal framework is required to bridge the entire process—from identification of origin and ownership to inventory, valuation, public sale, earmarked allocation of revenues, and control over final use.

The logic of legal reform should respect the hierarchy of legal norms. The ownership regime, entitlement to public revenues, the fundamental requirement for mandatory auctioning, and the essential elements of liability should be established by law. Measurement methodology, quality classification, calculation of the starting price, operation of the electronic platform, and contractual monitoring may be detailed through government decisions. Within the community, the selection of annual earmarked programs may be made by a decision of the Council of Elders, but only within the framework previously established by law and government regulations.

The legal roadmap presented below distinguishes the substantive objective of each reform, the legal act to be amended, and the required level of legal intervention. This

distinction is also important for ensuring legal certainty: a subordinate legal act cannot alter the allocation of budget revenues established by law or create new administrative liability, whereas amending a law merely to establish a technical measurement protocol would constitute an unnecessarily burdensome intervention.

Table 8

Systematic Roadmap of Proposed Legal and Legislative Amendments

Reform Area	Legal Act to Be Amended or Adopted	Proposed Legal Solution	Level and Responsible Authority
1. Legal status and ownership of the stockpile	Supplement to Article 36 of the RA Land Code and, if necessary, a special transitional provision; RA Government Decision No. 1396-N	Define the concepts of "removed fertile soil layer," "historically accumulated stockpile," and "large-scale public stockpile." Require a legal audit of origin, ownership, balance-sheet attribution, and third-party rights prior to sale. Establish a one-time inventory and state/community registration procedure for the Akhuryan stockpile.	Amendment to the Land Code — National Assembly. Implementing procedure — RA Government, Ministry of Environment, Ministry of Territorial Administration and Infrastructure, Cadastre Committee, and community.
2. Mandatory certification of volume, quality, and suitability	Amendments to RA Government Decisions No. 1396-N and No. 124-N, together with a new methodological annex	Require 3D geodetic surveying, stratified sampling, accredited laboratory testing, and an A/B/C/X quality passport. For each lot, disclose volume, moisture content, organic matter, contamination indicators, and permitted end uses. Exclude Class X from market sale until remediation.	Government decision, without legislative amendment where the ownership regime is clear. Methodology — Ministry of Environment, with participation of the Ministry of Economy and the National Accreditation Body.
3. Independent valuation and starting price	Revision of Paragraph 4 of RA Government Decision No. 676-N or a separate annex on "Valuation and Starting-Price Methodology"; harmonization with the Law on Valuation Activity	For large state- and community-owned stockpiles, replace mutually agreed pricing with independent valuation and a reserve price. Separate the price into ex-stock value, loading, transportation, and tax components. Apply a reference formula based on a quality coefficient, the median of legally comparable transactions, restoration value, and sales costs. Revaluation at least every 90 days or following a material market change.	Government decision. Independent appraiser selected competitively. Valuation report and underlying data disclosed in a public data room.
4. Mandatory electronic auction and the exceptional role of competitive selection	Supplement to RA Government Decision No. 676-N and a special auction procedure based on the Law on Public Auctions; if necessary, amendment concerning specific natural-resource lots	State/community lots exceeding 1,000 m^3 or a monetary threshold established by the Government should be sold through an open electronic ascending-price auction. Competitive selection should be permitted only for allocating the public land-restoration reserve where the winner is determined not solely by price but also by	Government decision for the procedure. Targeted legislative amendment by the National Assembly if mandatory auction requirements or exceptions conflict with existing law. Platform operator — authorized body or competitively selected operator.

		measurable environmental outcomes. Establish a 5% bid security, a 2–5% bid increment, disclosure of related parties, a volume cap per buyer, and rules for repeated auctions.	
5. Public land-restoration reserve and limits on free allocation	Supplement to Article 36 of the RA Land Code; amendments to Decisions No. 676-N and No. 1396-N; harmonization with the Law on Local Self-Government	Allow 15–25% of the stockpile to be reserved exclusively for approved restoration projects. Free or preferential allocation should be conducted through a public competitive procedure based on quantitative land-improvement indicators, beneficiary co-financing, and time-bound obligations. Establish a resale prohibition, electronic proof of intended use, and repayment of market value in case of non-compliance (clawback).	Fundamental rights and restrictions — by law. Criteria and contractual terms — by government decision. Project selection — by a public decision of the Council of Elders.
6. Revenue ownership and earmarked use — conservative option	Clarification of Paragraph 5 of Decision No. 676-N; amendments to the laws on the RA Budgetary System and Local Self-Government; relevant budget-classification regulation	Preserve the existing principle that 100% of gross proceeds from the sale of stock originating from state or community land is transferred to the community budget. After verified direct costs, earmark at least 50% of net revenue for land restoration, irrigation, erosion prevention, and green infrastructure. Give priority to the settlement directly affected by the stockpile. Establish a separate treasury sub-account and performance indicators.	Legislative amendments to protect earmarked revenue on a multi-year basis. Annual programs — Council of Elders. Reporting — open-budget format.
7. Revenue allocation — 70/20/5/5 reform option	RA Land Code; Law on the RA Budgetary System; Paragraph 5 of Decision No. 676-N; annual State Budget Law and budget classification	Allocate net revenue as follows: 70% community; 20% national targeted land-restoration program; 5% competitive environmental window for communities of Shirak Region; and up to 5% for actual surveying, auction, and monitoring costs. The “regional 5%” should not be treated as freely disposable revenue of the regional administration, but as a state-budget program allocation distributed through regional competition.	Mandatory legislative package and annual budget implementation. Adoption — National Assembly; implementation — Ministry of Finance, Ministry of Environment, Ministry of Territorial Administration and Infrastructure, and communities.
8. Organizer remuneration and prevention of conflicts of interest	Implementing regulations under the Law on Procurement; supplement to Decision No. 676-N; standard auction-operator contract	Select the private organizer through competitive procurement. Set remuneration as a fixed amount or at no more than 2% of additional net revenue, without assigning any share of gross sales revenue. Require disclosure of beneficial	Government decision and contractual regulation. Legislative amendment only if a special exception to general procurement rules is created, which is not recommended.

		ownership, related parties, and conflicts of interest. Where possible, separate measurement, valuation, and auction-organization functions.	
9. Digital traceability and oversight	Amendments to Decisions No. 676-N and No. 1396-N; targeted amendments to environmental-control legislation and the statute of the inspection authority	Establish a unified digital stockpile register with a unique lot code, electronic dispatch document, weight/volume data, transportation route, and confirmation of final placement. Provide the supervisory authority with direct data access and powers for on-site inspection, transaction suspension, and post-sale verification of intended use. Publish contracts, winners, prices, and implementation status, except for legally protected information.	Digital procedure — government decision. New supervisory powers — by law where they restrict rights or constitute a basis for enforcement. Operator — authorized state body.
10. Liability, compensation, and recovery	Amendment to Article 54.2 of the RA Code of Administrative Offences; contractual annex to Decision No. 676-N; harmonization with existing provisions of the RA Criminal Code in cases of major damage or fraud	Link penalties to the volume unlawfully disposed of or its market value so that violations are not economically profitable. Establish recovery of unlawful proceeds, confiscation of unused soil or in-kind restoration, and separate offences for falsified laboratory documentation, absence of dispatch documentation, resale, and violation of intended-use requirements. Provide stricter liability for public officials and disqualification for repeated violations.	Administrative liability — exclusively by law. Contractual penalties and recovery of market value — through a standard contract approved by the Government.
11. Tax and accounting certainty	RA Tax Code only where necessary; otherwise, official clarification by the State Revenue Committee/Ministry of Finance and practical accounting guidance	Clarify whether the sale price is quoted including or excluding VAT, who is considered the supplier, which document formalizes the sale of state/community property, and how the organizer's services are taxed. No tax exemption should be introduced without a cost-benefit analysis; preferential supply for land restoration should preferably be addressed through a budget subsidy rather than a hidden tax exemption.	Initially — official clarification and standardized accounting treatment. Tax Code amendment only where a clear legal gap exists. Responsible authorities — Ministry of Finance and State Revenue Committee.

Source: Authors' elaboration based on a systematic analysis of the existing legal acts of the Republic of Armenia.

As follows from Table 8, most of the proposed measures can be implemented in stages, without waiting for the adoption of the entire legislative package. At the first stage, within the existing legal framework, the community may complete the ownership audit,

conduct independent surveying and laboratory assessment, select the organizer through a procurement procedure, and design the public auction in accordance with the general principles of the Law on Public Auctions. At this stage, the allocation of sales proceeds should remain consistent with the existing logic of Decision No. 676-N, and no interbudgetary redistribution may be introduced solely through a contract or a decision of the Council of Elders.

At the second stage, within 3–6 months, it would be advisable to amend Decisions No. 676-N and No. 1396-N through a single integrated government decision and approve unified annexes governing the quality passport, valuation, lotting, electronic auction, digital dispatch documentation, and oversight. Amendments to Decision No. 124-N should be limited to the technical linkage between contamination testing and restrictions on the circulation of Class X material, without duplicating general environmental regulations.

At the third stage, within 6–12 months, an integrated rather than fragmented legislative package should be submitted to the National Assembly, including amendments to the Land Code, the Law on the Budgetary System of the Republic of Armenia, the Law on Local Self-Government, and the Code of Administrative Offences. If the 70/20/5/5 allocation model is selected, the same package should also establish the interbudgetary transfer formula, treasury sub-accounts, eligible expenditure categories, performance auditing, and procedures for the return of unused funds. Otherwise, the proposed allocation percentages would remain merely a policy declaration without a legal basis for actual payments.

For the Akhuryan stockpile, the initial solution involving the lowest legal risk is the conservative option: transfer all sales proceeds to the community budget, ensure transparent reimbursement of actual costs, and provide legally protected reinvestment of at least half of the net revenue in natural capital. The 70/20/5/5 model may be introduced from the second auction stage or following implementation of a nationwide framework, once the national targeted program, regional competitive funding window, and digital accountability system are operational. This sequencing makes it possible to bring the stockpile to market without compromising the principles of legality of public revenues, community autonomy, and budgetary integrity.

Selection of operators for organizing lot sales and the tripartite revenue-sharing model

Under the proposed structure, a private or public operator is selected for each lot to organize the sale of the soil, including advertising, buyer outreach, documentation, loading, and record-keeping. This approach may improve the speed and professional quality of sales, but only if the operator is legally separate from the final buyer. If the successful bidder for a lot is simultaneously granted the right to resell the soil in its own name and determine the final price, the public authority will lose the incremental value generated through auction-based price discovery, while the 15% profit-margin cap will be difficult to enforce in practice.

A two-stage structure is therefore proposed. In the first competitive procedure, an operator providing sales-management services is selected; in the second stage, the final buyers of the soil are selected through separate electronic auctions. The owner of the stockpile, or the public authority legally authorized to act on its behalf, remains the seller. Buyers make payments directly into a Treasury transit account, while the operator does not receive the

entire sales revenue and subsequently redistribute it. This structure reduces the risks associated with holding public funds, underreporting volumes, and related-party transactions.

The illustrative payments of AMD 5,000 to the State and AMD 2,000 to the community should be treated not as fixed policy figures but as minimum public obligations established per cubic metre. Under Paragraph 5 of the existing Decision No. 676-N, proceeds from the sale of fertile soil originating from state- and community-owned land are transferred to the community budget. Therefore, directing AMD 5000/m³ to the State Budget would first require amendments to the Land Code, budgetary legislation, and Decision No. 676-N; neither a contract nor a competitive tender notice alone can create a new revenue entitlement for the State Budget.

Let q_i- l denote the volume actually sold from lot ll and verified by independent measurement; g_s=5000 AMD/m³ the statutory payment to the State Budget; g_c=2000 AMD/m³ the payment to the community; c_i - the allowable organizational cost per cubic metre proposed by bi; and r=0.15 - the permitted profit margin on that cost. The minimum amount payable to the public budgets is therefore:

$$R_l^{\text{pub}} = (g_s + g_c)q_l = 7000q_l \tag{8}$$

The operator's remuneration should be calculated on the basis of the **verified cost base**, rather than as 15% of the total sales revenue. Otherwise, when the sale price is high, private earnings would increase without a corresponding increase in the amount of work performed, while at a low sale price the actual costs could be obscured. The operator's fee per cubic metre and the profit component included therein are calculated, respectively, as follows:

$$f_i = (1 + r)c_i = 1.15c_i \tag{9}$$

$$\pi_i = rc_iq_l = 0.15c_iq_l \tag{10}$$

Here, c_i - should include only those costs explicitly permitted in advance by the tender documentation, including publication, use of the electronic platform, supervision of measurements, documentation, loading, and other activities assigned to the operator under the contract. The acquisition cost of the soil, penalties, payments to related parties, and unjustified administrative mark-ups should **not** be included in the eligible cost base.

The minimum payable price for the final buyer, excluding separately calculated transportation and tax components, will therefore be:

$$p_l^{\min} = g_s + g_c + (1 + r)c_i + \tau_l \tag{11}$$

where τ_i - represents the tax or mandatory transaction-related component borne by the seller. If transportation is paid by the buyer directly to the carrier, it should not be included in the auction price of the soil; otherwise, differences in transportation distances would make lot prices incomparable.

Moreover, if the estimated upper price supported by legal market demand is below $p_l^{\min}$, the lot should not be sold merely as a formality or by reducing the established public obligations. Instead, the lot structure, eligible costs, or the AMD 5,000/2,000 statutory payment parameters should be reconsidered.

The alternative methods of selecting the operator do not produce the same economic outcome. The following table compares three institutional structures, taking into account the

protection of public revenue, the nature of competition, and the enforceability of the 15% profit-margin cap.

Table 9

Comparative Assessment of Alternative Models for Selecting the Operator for the Sale of Fertile Soil

Selection Model	Winner Selection Criterion	Advantages and Risks	Assessment
A. Two-Stage Service Tender (Proposed)	Among participants meeting the minimum technical threshold, the bidder offering the lowest cic_i or the lowest fif_i wins. Final buyers are selected through a separate auction.	The public authority retains ownership and captures the entire incremental value generated through price discovery. The 15% profit margin is measurable and enforceable. Requires a clearly defined cost audit and two separate procedures.	Most appropriate for a large-scale, multi-lot stockpile.
B. Guaranteed Public Payment Tender	The qualified bidder offering the highest guaranteed public payment above AMD 7,000/m³ and accepting the 15% cost-based profit-margin cap wins.	Public revenue may increase, but comparison of bids becomes more complex where bidders have different cost bases. Performance security should be required.	Applicable to pilot lots as an additional selection criterion.
C. Full Transfer of the Lot to a Reseller	The dealer offering the highest upfront payment for the lot wins and subsequently resells the material at its own risk.	Simple and fast, but the 15% profit margin can no longer be effectively controlled, while subsequent price appreciation accrues to the dealer. There is a significant risk of related-party transactions.	Not recommended where the objective is to preserve incremental price gains for the public sector.

Source: Authors' proposal based on the separation of competitive procurement and public sale procedures.
Source: Authors' proposal based on the separation of competitive procurement and public sale procedures.

The comparison demonstrates that the concept of a "lot winner" should be divided into two distinct roles in the legal documentation: the operator and the final buyer. The operator selection procedure constitutes the procurement of a service and should be conducted within the framework of the Law on Procurement, whereas selection of the final buyer constitutes the disposal of property and should be organized in accordance with the Law on Public Auctions and the relevant special procedure. A public-private partnership structure would be justified only where the contract is long-term, involves substantial private investment, and provides for risk sharing. Treating an ordinary sales operator for one or several lots as a project would unnecessarily complicate the procedure.

Under the proposed tender procedure, a qualification stage is applied first, requiring at least three years of relevant experience, tax compliance, disclosure of beneficial owners, adequate technical capacity, 10% performance security, and independence from final buyers. Among the qualified participants, the winner is then selected through reverse price competition, as follows:

$$i^* = \arg\min_{i \in Q} c_i \qquad (12)$$

where Q denotes the set of participants that satisfy all qualification and conflict-of-interest requirements. An abnormally low bid should be subject to justification; if c_i does not cover the estimated cost of the mandatory activities, the bid should be rejected as unrealistic.

At the same time, it is advisable that no single operator be awarded more than 25–30% of the total stockpile, provided that a sufficient number of qualified participants is available. This limit prevents an organizational monopoly and generates comparable performance data across operators.

The practical feasibility of the AMD 5,000/2,000 statutory payment parameters depends on the organizational cost per cubic metre. In the following scenario analysis, taxes and transportation are treated separately, while the operator's 15% profit margin is calculated on the basis of the eligible cost c_i.

Table 10

Impact of the Operator's Allowable Cost and 15% Profit Margin on the Minimum Sale Price

c_i AMD/m³	Operator Fee: $1.15c_i$	Included Profit: $0.15c_i$	Minimum Sale Price, AMD/m³	Price Feasibility within the AMD 4,000–8,000 Range
500	575	75	7,575	Feasible
800	920	120	7,920	Borderline
1,000	1,150	150	8,150	Above the upper market threshold
1,500	1,725	225	8,725	Above the upper market threshold

Source: Author's calculations. Note: Transportation and taxes are calculated separately.

The calculation reveals an important limitation of the proposed figures. If the operator's allowable cost is AMD 1,000/m³, the minimum sale price already reaches AMD 8,150/m³, even before transportation and any applicable tax additions. This exceeds the stated upper limit of the informal market range of AMD 8,000/m³. Therefore, the AMD 5,000 and AMD 2,000 payments cannot be applied mechanically to all quality classes and all lots. They should either be established as indexed reserve payments differentiated by quality and location, or be incorporated within an overall minimum public payment of AMD 7,000/m³, excluding the operator's fee where that fee is financed from another budgetary source.

If the average actual price achieved at the final auction exceeds the minimum price, allowing the operator to retain the entire increment would contradict the logic of the 15% profitability cap. The additional public revenue generated by lot ll is calculated as:

$$S_l = \max\{0, [\bar{p}_l - g_s - g_c - (1 + r)c_i - \tau_l]q_l\} \quad (13)$$

It is proposed that 70% of S_l be allocated additionally to the community and 30% to a targeted national land-restoration program. The operator may receive only a limited performance bonus—for example, no more than 3% of the incremental amount—but this bonus should be included within the overall 15% profitability ceiling rather than added on top of it. In this way, the private operator is incentivized to increase legitimate demand without appropriating the market rent generated by the public resource.

The payment system should operate according to the principle of «no funds passing through the operator's account». The buyer makes a single payment into a Treasury transit account, specifying the unique lot code. No payment or profit is calculated for unsold volume. In the event of delay in performance, the operator's payment is reduced; in cases of volume falsification or preferential treatment of a related buyer, contractual termination, forfeiture of performance security, and temporary exclusion from participation in tenders should apply.

For legal implementation, Decision No. 676-N should be supplemented with the concepts of «sales operator», «final buyer», «minimum public payment», «allowable cost», and «Treasury transit account», together with two separate standard-form contracts. The Law

on the Budgetary System of the Republic of Armenia and the Land Code should establish the allocation of the State and community statutory payments and the distribution of incremental revenue. The operator-selection notice and contract should be approved under procurement legislation, whereas the rules governing the auction for final sale should be established under the Law on Public Auctions. Amendment of the Tax Code is not necessarily required if the Ministry of Finance and the State Revenue Committee jointly clarify, through a unified procedure, the treatment of VAT, invoicing, and taxation of the operator's services[1].

Limitation on the number and volume of lots per participant

In a multi-lot tender, one of the most direct instruments for preventing concentration is to impose a quantitative limit on the number of lots in which a single participant may participate or win. For example, each participant may be permitted to submit a bid for only one lot or, under a more flexible approach, to bid for several lots but win no more than one or two. This rule prevents a single technically or financially stronger company from gaining control over the sale of the entire stockpile.

However, the «maximum number of bids» and the «maximum number of lots awarded» are not equivalent concepts. If a participant is allowed to bid for only one lot, it must anticipate at the selection stage which lot is likely to attract less competition. As a result, some attractive lots may receive numerous bids while others receive none. To preserve overall competition, it is more efficient to allow participants to bid, for example, for up to two or three lots**,** indicating their order of preference, while contractually limiting each participant to winning one lot. Where a large number of lots is offered, the award cap may be increased to **two lots**.

Let x_i equal 1 if participant ii wins lot l, and 0 otherwise. Each lot should be assigned to only one operator, while the number of lots awarded to any single participant must not exceed the limit K:

$$\sum_i x_{il} = 1 \quad \forall l, \qquad \sum_l x_{il} \le K_i \quad \forall i, \qquad K_i \in \{1,2\} \tag{14}$$

The quantitative limit should be supplemented by a volume-based restriction, since the lots may differ substantially in size. If a participant wins only one but exceptionally large lot, the K=1rule is formally satisfied, while market concentration may nevertheless remain high. It is therefore advisable to establish an additional requirement that the total volume attributable to a participant and its related parties should not exceed an α share of the total stock offered for sale:

$$\sum_l V_l x_{il} \le \alpha V^T, \qquad \alpha \in [0.20, 0.25] \tag{15}$$

where V_l - is the certified volume of lot l, and V^T - is the total volume offered during the relevant tender stage. A 20–25% volume cap should be regarded as an initial policy threshold and adjusted according to the number of lots, the actual number of participants, and their

[1] See: RA Land Code — https://www.arlis.am/hy/acts/224001; RA Government Decision No. 676-N — https://www.arlis.am/hy/acts/152162; Law on the Budgetary System of the Republic of Armenia — https://www.arlis.am/hy/acts/219259; Law on Procurement — https://www.arlis.am/hy/acts/110820; Law on Public Auctions — https://www.arlis.am/hy/acts/75480

technical capacities. If only three or four large lots are offered, a 20% cap may be impracticable. In such cases, it is preferable to restructure the stockpile into smaller lots rather than mechanically grant an exemption from the concentration limit to a single participant.

The three practical options for limiting participation are presented below. The applicable model should be selected before the tender is announced and applied uniformly to all participants. Any retroactive modification of the limits or an exemption granted to a specific participant would undermine the principle of equal treatment in the tender procedure.

Table 11

Alternative Models for Limiting Bids and Awards in a Multi-Lot Tender

Model	Bid Submission Limit	Award Limit	Assessment of Applicability
I. Strict Single-Lot Model	A participant selects and submits a bid for only one lot.	Maximum 1 lot and no more than 20–25% of the total volume.	Simple and effective in preventing concentration, but increases the risk of some lots receiving no bids. Suitable for a small pilot stage with comparable lots.
II. Two Bids–One Award (Proposed Pilot Model)	A participant may submit bids for a maximum of 2 lots, indicating first and second preference.	Maximum 1 lot and no more than 20–25% of the total volume.	Maintains competition while preventing concentration. The most balanced option for the first stage of the Akhuryan sales process.
III. Multiple Bids–Two Awards	A participant may submit bids for all lots or for a maximum of 3–4 lots.	Maximum 2 lots, but no more than 20–25% of the total volume.	Applicable where there are numerous small lots and a sufficient number of participants. Requires a simultaneous electronic allocation al

Source: Author's proposal based on the principles of anti-concentration and volume limitation.

Based on the comparison presented in the table, the "two bids–one award" rule is recommended for the first stage of the Akhuryan stockpile sales process. A participant may select a maximum of two lots and must indicate the order of preference in its bid. However, once the participant is declared the winner of one lot, its bid for the other lot is excluded from further allocation. If the participant does not win the lot indicated as its first preference, its bid remains valid for the second-preference lot. In subsequent stages, once the actual number of participants, operating costs, and quality of performance are known, the award limit may be increased to two lots while maintaining the 20–25% volume cap.

The lots should not be allocated through a sequence of independent auctions, but within a single integrated tender window. Otherwise, the winner of the first lot could participate in subsequent auctions before the system confirms that the applicable award limit has been reached, while the sequence in which the auctions are conducted could influence the final allocation. Based on the qualified bids, the system should select the allocation that, while satisfying all applicable constraints, minimizes the total operator remuneration or maximizes the net public benefit.

If several permissible allocations produce the same result, preference should first be given to the allocation involving a larger number of independent operators, followed by the allocation with the higher technical quality score. Only as a final tie-breaking mechanism should a pre-disclosed randomization procedure or the earliest-bid rule be applied. This hierarchy should be explicitly established in the tender documentation, thereby eliminating subsequent discretionary selection by the evaluation committee.

The limitation should apply not only to an individual legal entity but to the economic group as a whole. Entities with the same beneficial owner, controlled or affiliated entities, members of a consortium, and sole proprietors controlled by them should be treated as a single participant for the purposes of the lot-award limits. A declaration of beneficial ownership should be required at the bid-submission stage. In the event of false or incomplete disclosure, all affiliated bids should be rejected, the performance security forfeited, and a temporary prohibition on participation imposed. Transfer of an awarded contract, ownership interest, or operator rights should be permitted only with the prior approval of the authorized body and should not be used to circumvent the applicable limits.

For lots that remain unsold or fail to attract a sufficient number of bids, any exception should be introduced gradually. A repeat tender should first be conducted with a revised timeframe or lot size. Only thereafter may a participant that has already won one lot be permitted to receive a second lot, provided that the 25% volume cap is not exceeded. Any such exception should be formally recorded and published on the electronic platform, together with the justification demonstrating the lack of sufficient competition.

From a legal perspective, Decision No. 676-N and the special procedure governing operator selection should explicitly establish the maximum number of bids and awarded lots, the volume cap, the aggregation of related parties for purposes of calculating the limit, the procedure for indicating lot preferences, and the phased exception procedure for unsuccessful lots. The tender notice should disclose the volumes and quality classes of all lots, applicable limits, and the allocation algorithm. Establishing these requirements through a subordinate legal act is sufficient, provided that the legal basis for mandatory competitive selection and the competence of the authorized body have already been established by law[2].

In summary, the proposed model is viable under three conditions: first, the AMD 5,000 and AMD 2,000 payment rates are supported by an independent valuation and periodically reviewed; second, the 15% margin is applied to auditable eligible costs rather than to sales revenue; and third, the competitive procedures for selecting the operator and the final buyer are legally and technically separated**.** In the absence of these conditions, the system may effectively become a private resale concession in exchange for a fixed public payment, in which case the State and the community would lose the incremental value generated by the market price**.**

Conclusions and recommendations

Based on the results obtained, the following main conclusions and recommendations are formulated.

From the perspective of economic efficiency, the separation of the final buyer from the operator organizing the sale is essential. The operator should be selected through competitive procurement of services and remunerated on the basis of controlled eligible costs, while the final buyers of the soil should be selected through a separate electronic auction. This structure preserves the incremental value generated through public price discovery and reduces the

[2] Legal basis for separating the procedures for selecting the operator and the final buyer**:** Law of the Republic of Armenia on Procurement**;** Law of the Republic of Armenia on Public Auctions**;** RA Government Decision No. 676-N**.**

risks of revenue underreporting, related-party transactions, and uncontrolled private resale rents.

The existing legal framework provides, in principle, for the sale of fertile soil removed as a result of construction activities, but it does not fully address the inventory, lotting, mandatory auctioning, concentration of participants, and earmarked reinvestment of revenues associated with large historical stockpiles. The proposed model therefore operates on two horizons: an immediately applicable pilot auction under the existing legal framework, followed by a package of legislative and subordinate regulatory reforms.

The results of the study demonstrate that management of the fertile soil stockpile accumulated in the vicinity of the Akhuryan Reservoir is simultaneously a legal, environmental, and public-finance issue. The economic value of the stockpile is significant; however, it cannot be determined solely on the basis of offers circulating in the informal market. A legally defensible price should be established only after verification of ownership and origin, independent measurement, stratified laboratory testing, quality classification, and competitive price discovery.

1. The 212,532 m³ Akhuryan stockpile represents an economically valuable, long-stored historical topsoil resource rather than an automatically homogeneous commercial «chernozem».
2. Where its construction-related origin is properly documented, its sale is permissible within the framework of Article 36 of the RA Land Code and Decision No. 676-N.
3. Free administrative distribution of the entire stockpile is not advisable. Such allocation should be limited to a defined public restoration reserve and implemented through an open, outcome-based selection procedure.
4. The principal mechanism for commercial lots should be an open electronic auction. Competitive selection should be used where the award criterion also includes measurable environmental outcomes.
5. The informal price range of AMD 4,000–8,000/m³ indicates the existence of demand but does not constitute a sufficient legal or valuation basis for establishing the starting price. It should be adjusted using legally verifiable comparables, quality, location, and the services included in the quoted price.
6. A pilot starting-price range of AMD 3,500–4,500/m³ may be applied only after independent valuation, on an ex-stockpile basis, with appropriate premiums or discounts according to quality class.
7. Under the AMD 4,000–8,000/m³ scenarios, the theoretical gross value of the stockpile amounts to approximately AMD 850.1 million–1.700 billion. However, phased sales and the public reserve will reduce the volume actually offered for sale while helping protect market prices.
8. Under the existing legal framework, 100% of gross sales proceeds should be transferred to the community budget. Any direct percentage allocation to the State, regional level, or organizer requires appropriate legal amendments.
9. The organizer should be selected through competitive procurement and remunerated through an actual-cost-based or performance-based service fee rather than an unrestricted share of the resource rent.

10. The preferred immediately applicable model consists of a 15–25% public restoration reserve, 75–85% phased auction-based sale, and allocation of at least 50% of net community revenue to land restoration, irrigation, and green infrastructure.
11. A national digital soil exchange/database should be established to integrate stock availability, quality, supply, demand, dispatch documentation, and final use within a unified traceability system.
12. Legislative reform should supplement Decision No. 676-N with mandatory auction requirements for large public stockpiles, minimum valuation standards, quality classification, earmarked revenue reporting, and transitional rules for historical stockpiles.

Thus, the proposed system does not amount to the simple commercialization of fertile soil. Rather, it uses the market as an instrument for demand and price discovery, while preserving the public character of natural capital, community interests, and post-sale control over intended use.

Under the conservative budget-management option, sales proceeds remain within the community budget, with at least half of net revenue earmarked for land restoration, irrigation, erosion prevention, and green infrastructure. A model based on fixed State, community, and organizational shares may be introduced only after the necessary legislative amendments. Moreover, the operator's 15% profit margin should be calculated exclusively on documented eligible costs, not on gross sales revenue.

The recommendations follow a unified sequence: the public authority first establishes the legal and quality passport of the stockpile, then divides it into homogeneous and economically accessible lots, defines the public restoration reserve, and places only the remaining volume on the market. During the first competitive stage, the "two bids–one award" rule should be applied, together with an aggregate 20–25% volume cap per economic group. This restriction should also apply to entities under the same beneficial ownership and to related parties.

During the pilot stage of a multi-lot tender, each participant may submit bids for a maximum of two lots, but may win only one lot, without exceeding 20–25% of the total volume offered.

The operator's 15% profitability margin should be calculated solely on the basis of eligible costs identified through competition and subject to audit, while any incremental value generated by the auction price should remain with the public budgets.

Practical roadmap

The implementation of the proposed recommendations should be divided into successive stages of legal preparation, pilot sales, and phased scaling-up. The proposed timeline and responsible authorities are presented below.

The logic of the roadmap is that the sale of the entire stockpile should not commence before the results of the pilot stage have been evaluated. This approach makes it possible to refine the pricing, lot structure, and size of the public restoration reserve.

Table 12

Phased Roadmap for the Implementation of the Proposed Recommendations

Timeline	Action	Responsible Party	Expected Outcome
0–3 months	Legal audit, 3D inventory, additional sampling	Ani Community + authorized body + independent experts	Legal and quality passports
3–6 months	Valuation, public restoration reserve program, auction regulations	Council of Elders and Head of the Community	Approved lotting structure and prices
6–12 months	Pilot auctions of 5,000–10,000 m^3	Competitively selected organizer	Actual market price discovery and testing of the sales process
1–3 years	Phased sale of 30,000–40,000 m^3 annually	Community and supervisory authority	Managed market circulation
3–7 years	Optimization of the remaining stock and audit of restoration outcomes	Community / State	Targeted completion of stockpile management and restored lands

Source: Author's proposal.

The current versions of the relevant legal acts were verified through the Armenian Legal Information System as of 24 August 2026. The baseline data and assumptions used in the pricing scenarios should be revalidated immediately prior to publication, accompanied by the laboratory test reports, digital lot passports, and an anonymized database of pilot-auction results.

References

1. FAO. (2015). Status of the World's Soil Resources: Main Report. Rome: FAO; IPBES. (2018). The IPBES Assessment Report on Land Degradation and Restoration. Bonn: IPBES; UNCCD. (2022). Global Land Outlook (2nd ed.). Bonn: UNCCD; European Commission. (2021). EU Soil Strategy for 2030. COM(2021) 699 final.
2. Rugani, B., & Petucco, C. (2025). Environmental benefits of re-using excavated soil flows: The case of Luxembourg. Science of the Total Environment, 958, 177867. https://doi.org/10.1016/j.scitotenv.2024.177867
3. D'Agui, H. M., van der Heyde, M. E., Nevill, P. G., et al. (2022). Evaluating biological properties of topsoil for post-mining ecological restoration: Different assessment methods give different results. *Restoration Ecology*, *30*(S1), e13738. https://doi.org/10.1111/rec.13738
4. Amir, H., Bordez, L., Cavaloc, Y., Jourand, P., Ducousso, M., & Juillot, F. (2022). Effects of ultramafic topsoil stockpiling during mine activities on its microbial diversity and other microbiological and physicochemical characteristics. *Ecological Engineering, 177*, 106563. https://doi.org/10.1016/j.ecoleng.2022.106563
5. Fischer, A., Singh, J. P., Van Hamme, J., Bottos, E., & Fraser, L. H. (2025). Investigating impacts from topsoil stockpile height on soil microbial communities. *Frontiers in Microbiomes, 4*, 1607677. DOI; Ledesma, J., et al. (2025). Effects of stockpiling on topsoil biogeochemistry for semiarid mine reclamation. *Mining, Metallurgy & Exploration, 42*, 15–26. https://doi.org/10.3389/frmbi.2025.1607677
6. Ledesma, J., et al. (2025). Effects of stockpiling on topsoil biogeochemistry for semiarid mine reclamation. Mining, Metallurgy & Exploration, 42, 15–26. https://doi.org/10.1007/s42461-024-01164-2

7. Valliere, J. M., D'Agui, H. M., Dixon, K. W., et al. (2022). Stockpiling disrupts the biological integrity of topsoil for ecological restoration. Plant and Soil, 471, 409–426. https://doi.org/10.1007/s11104-021-05217-z
8. City of Helsinki. (n.d.). Supporting the reuse of excavated soil in construction projects. European Circular Economy Stakeholder Platform. https://circulareconomy.europa.eu/platform/en/good-practices/city-helsinki-supporting-reuse-excavated-soil-construction-projects
9. Cristóbal, J., Foster, G., Caro, D., et al. (2024). Management of excavated soil and dredging spoil waste from construction and demolition within the EU: Practices, impacts and perspectives. European Commission, Joint Research Centre. https://publications.jrc.ec.europa.eu/repository/handle/JRC138483
10. NSW Resources Regulator. (2021). Materials and Soil Management to Support the Post-Mining Land Use: Consolidated Audit Report. New South Wales Government.
11. Department for Environment, Food & Rural Affairs. (2009). Construction Code of Practice for the Sustainable Use of Soils on Construction Sites (PB13298). London: DEFRA.
12. Block, P. R., Gasch, C. K., & Limb, R. F. (2020). Biological integrity of mixed-grass prairie topsoils subjected to long-term stockpiling. Applied Soil Ecology, 145, 103347. https://doi.org/10.1016/j.apsoil.2019.08.009
13. Hale, S. E., Roque, A. J., Okkenhaug, G., et al. (2021). The reuse of excavated soils from construction and demolition projects: Limitations and possibilities. Sustainability, 13(11), 6083. https://doi.org/10.3390/su13116083
14. Samarasinghe, O., & Greenhalgh, S. (2013). Valuing the soil natural capital: A New Zealand case study. Soil Research, 51(4), 278–287. https://doi.org/10.1071/SR12246
15. Meissner, L., & Musshoff, O. (2022). Revisiting the relationship between farmland prices and soil quality. Q Open, 2(2), qoac017. https://doi.org/10.1093/qopen/qoac017
16. Sen Chakraborty, K., Chakraborty, A., & Berrens, R. P. (2023). Valuing soil erosion control investments in Nigerian agricultural lands: A hedonic pricing model. World Development, 170, 106313. https://doi.org/10.1016/j.worlddev.2023.106313
17. Koutroumpis, P., & Cave, M. (2018). Auction design and auction outcomes. Journal of Regulatory Economics, 53, 275–297. https://doi.org/10.1007/s11149-018-9358-x
18. Coviello, D., & Mariniello, M. (2014). Publicity requirements in public procurement: Evidence from a regression discontinuity design. Journal of Public Economics, 109, 76–100. https://doi.org/10.1016/j.jpubeco.2013.10.008
19. Klemperer, P. (2002). What really matters in auction design. Journal of Economic Perspectives, 16(1), 169–189. https://doi.org/10.1257/0895330027166
20. Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. Journal of Political Economy, 82(1), 34–55. https://doi.org/10.1086/260169
21. Government of the Republic of Armenia. (2021). Decision No. 676-N of 29 April 2021 «On Establishing the Procedure for the Sale of Fertile Topsoil Removed as a Result of Construction Works». https://www.arlis.am/hy/acts/152162
22. Land Code of the Republic of Armenia, Article 36, current consolidated version. https://www.arlis.am/hy/acts/224001

23. Law of the Republic of Armenia "On Public Auctions," Article 2 — Definitions of Auction and Competitive Tender. https://www.arlis.am/hy/acts/75480
24. European Commission. (2020). *A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe*. COM(2020) 98 final.
25. European Environment Agency. (2020). *Soil and Land in Europe: State and Pressures*. Luxembourg: Publications Office of the European Union. European Environment Agency
26. ISO. (2015). *ISO 11074:2015 Soil Quality—Vocabulary*. Geneva: International Organization for Standardization.
27. ISO. (2018–2022). *ISO 18400 Series: Soil Quality—Sampling*. Geneva: International Organization for Standardization.
28. OECD. (2019). *Making Decentralisation Work: A Handbook for Policy-Makers*. Paris: OECD Publishing.
29. TEEB. (2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. London: Earthscan.
30. World Bank. (2021). *The Changing Wealth of Nations 2021: Managing Assets for the Future*. Washington, DC: World Bank.
31. Republic of Armenia. (1997). *Law of the Republic of Armenia "On the Budgetary System of the Republic of Armenia," HO-137, 24 June 1997.*
32. Republic of Armenia. (2016). *Law of the Republic of Armenia "On Procurement," HO-21-N, 16 December 2016.*
33. Republic of Armenia. (2002). *Law of the Republic of Armenia "On Local Self-Government," HO-337, 7 May 2002, current consolidated version.*
34. Republic of Armenia. (2019). *Law of the Republic of Armenia "On Public-Private Partnership," HO-113-N, 28 June 2019.*
35. Government of the Republic of Armenia. (2011). *Decision No. 1396-N of 8 September 2011 on the Procedure for the Use of Fertile Topsoil.*
36. Government of the Republic of Armenia. (2018). *Decision No. 124-N of 8 February 2018 on Requirements for the Protection of Soil from Pollution and the Procedure for Assessing Soil Contamination.*
37. Republic of Armenia. *Code of Administrative Offences, Article 54.2, current consolidated version.*
38. Environmental Protection and Mining Inspection Body of the Republic of Armenia. (2022). *Order No. 127-A of the Head of the Inspection Body of 20 September 2022 on the Procedure for Soil Sampling* (official departmental source).

Primary Research Document

Report on the Effective Management of the Fertile Topsoil (Chernozem) Accumulated in the Vicinity of the Akhuryan Reservoir. Yerevan, 2026.

APPENDIX. DRAFT KEY TERMS AND CONDITIONS OF THE AUCTION

The terms and conditions presented in this Appendix may serve as the basis for preparing the auction regulations and the technical specifications for the sale and purchase agreement. They are subject to legal review by the competent authority.

Table 13

Draft Provisions of the Key Terms and Conditions of the Public Auction

Condition	Proposed Provision
Seller	The legal owner confirmed through an ownership audit, acting pursuant to a decision of the competent community authority
Subject of sale	A lot identified by a unique code, quality class, certified volume, and laboratory passport
Price	AMD/m³, ex-stockpile, with VAT status explicitly specified
Participation	Open to eligible natural and legal persons, subject to submission of a conflict-of-interest declaration
Bid security	5% of the starting value of the lot
Auction increment	2–5% of the starting price
Payment	100% prior to loading, or phased payment secured by a bank guarantee
Transportation	At the buyer's expense, with a digital waybill and volume/weight control
Intended use	Only for uses compatible with the lot's quality class; resale restrictions apply to subsidized lots
Liability	Penalties for unused or improperly used volumes, compensation for damages, and restrictions on participation in subsequent procedures
Reporting and transparency	Contract, payment, dispatch, destination, and acceptance certificate recorded in an open database

Source: Author's elaboration. The proposed provisions are subject to legal review by the competent authority.

Upon final approval of the draft, the agreement should explicitly incorporate the lot quality passport, the digital traceability of payment and transportation, evidence of intended use, and the applicable liability measures in the event of non-compliance.

ԱԽՈՒՐՅԱՆԻ ՋՐԱՄԲԱՐԻ ԹԱՍԻՑ ԿՈՒՏԱԿՎԱԾ ՀՈՂԻ ԲԵՐՐԻ ՇԵՐՏԻ ՇՈՒԿԱՅԱԿԱՆ ԿԱՌԱՎԱՐՈՒՄԸ. ԳՆԱՀԱՏՄԱՆ, ԼՈՏԱՎՈՐՄԱՆ, ՀՐԱՊԱՐԱԿԱՅԻՆ ԻՐԱՑՄԱՆ, ԵԿԱՄՈՒՏՆԵՐԻ ԲԱՇԽՄԱՆ և ԻՐԱՎԱԿԱՆ ԲԱՐԵՓՈԽՈՒՄՆԵՐԻ ՀԱՄԱԿԱՐԳԱՅԻՆ ՄՈԴԵԼԸ

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Հոդվածում բերվում է Ախուրյան ջրամբարի շրջակայքում շուրջ չորս տասնամյակ պահեստավորված 212,532 մ³ հողաբուսական շերտի իրավական և տնտեսական շրջանառության գիտագործնական մոդելը: Դաշտային չափագրումների և 2026 թ. լաբորատոր ուսումնասիրության համաձայն՝ պաշարի հումուսի միջին պարունակությունը 3.54% է, մինչդեռ ֆոնային հողի ցուցանիշը 4.54% է: Այդ փաստը հաստատում է ռեսուրսային բարձր ներուժը, սակայն չի արդարացնում ամբողջ զանգվածը միատարր «սևահող» համարելը՝ առանց ուղղաձիգ ու հորիզոնական լրացուցիչ նմուշառման: Իրավադոգմատիկ վերլուծությունը ցույց է տալիս, որ ՀՀ հողային օրենսգրքի 36-րդ հոդվածը և ՀՀ կառավարության N 676-Ն որոշումը շինարարական աշխատանքներից հանված բերրի շերտի վաճառքը թույլատրում են, իսկ պետական և համայնքային հողամասերից ստացված վաճառքի ամբողջ գումարը նախատեսում են համայնքային բյուջեի համար: Միաժամանակ գործող կարգավորումը չի սահմանում մրցակցային գնի ձևավորման, հրապարակային լոտավորման, եկամուտների նպատակային

օգտագործման կամ երկարատև պատմական պաշարի սեփականության նույնականացման ամբողջական մեխանիզմ: Առաջարկվում է երկաստիճան լուծում՝ անհապաղ կիրառելի բաց էլեկտրոնային աճուրդ՝ որակային դասերով և լոգիստիկայից զատված մեկնարկային գնով, ապա օրենսդրական բարեփոխում՝ Հողային ռեսուրսների վերականգնման նպատակային ենթահաշվով: Սցենարային գնահատմամբ 4,000–8,000 դրամ/մ³ դիտարկվող գների դեպքում համախառն արժեքը կազմում է 850.1 մլն–1.700 մլրդ դրամ, սակայն այդ միջակայքը չի կարող մեխանիկորեն ընդունվել որպես պաշտոնական գին, քանի որ պահանջում է օրինական գործարքների, որակի, ԱԱՀ-ի, բեռնման և փոխադրման պայմանների համադրելի ճշգրտում: Հետազոտությունը համադրում է իրավադոգմատիկ վերլուծությունը, միջազգային Scopus գրականության սինթեզը, որակով ճշգրտված համեմատական ու մնացորդային գնահատումը, սցենարային զգայունությունը և հանրային զուտ արժեքի բազմաչափ մոդելը: Մեկ պաշարի ու չստուգված ոչ ֆորմալ գների պայմաններում էկոնոմետրիկ գործակիցներ չեն գնահատվում. փոխարենը ձևակերպվում է օրինական աճուրդների ապագա միկրոտվյալների հեդոնիկ գնահատման նույնականացվող մոդել:

Բանալի բառեր. հողի բերրի շերտ, սևահող, բնական կապիտալ, հրապարակային աճուրդ, գնագոյացում, համայնքային բյուջե, հողի վերականգնում, շրջանաձև տնտեսություն, Ախուրյան ջրամբար:

РЫНОЧНОЕ УПРАВЛЕНИЕ ПЛОДОРОДНЫМ СЛОЕМ ПОЧВЫ, НАКОПЛЕННЫМ ИЗ ЧАШИ АХУРЯНСКОГО ВОДОХРАНИЛИЩА: СИСТЕМНАЯ МОДЕЛЬ ОЦЕНКИ, ФОРМИРОВАНИЯ ЛОТОВ, ПУБЛИЧНОЙ РЕАЛИЗАЦИИ, РАСПРЕДЕЛЕНИЯ ДОХОДОВ И ПРАВОВЫХ РЕФОРМ

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В статье приводится научно-практическая модель правового и экономического оборота 212 532 м³ плодородного слоя почвы, складированного в окрестностях Ахурянского водохранилища на протяжении примерно четырех десятилетий. Согласно результатам полевых измерений и лабораторных исследований, проведенных в 2026 г., среднее содержание гумуса в складированном грунте составляет 3,54%, тогда как соответствующий показатель фоновой почвы равен 4,54%. Данный факт подтверждает высокий ресурсный потенциал накопленного запаса, однако не дает оснований рассматривать весь его объем как однородный *чернозем* без проведения дополнительного вертикального и горизонтального отбора проб.

Праводогматический анализ показывает, что статья 36 Земельного кодекса Республики Армения и постановление Правительства Республики Армения № 676-Н допускают продажу плодородного слоя почвы, снятого при проведении строительных работ, и предусматривают направление всей суммы, полученной от реализации плодородного слоя, снятого с земельных участков государственной и муниципальной

собственности, в муниципальный бюджет. Вместе с тем действующее регулирование не устанавливает комплексного механизма конкурентного формирования цены, публичного формирования лотов, целевого использования доходов или идентификации права собственности на исторически сформировавшиеся долгосрочные запасы.

Предлагается двухэтапное решение: на первом этапе — непосредственно применимый открытый электронный аукцион с классификацией по качественным категориям и стартовой ценой, отделенной от логистических затрат; на втором этапе — законодательная реформа с созданием целевого субсчета восстановления земельных ресурсов. Согласно сценарной оценке, при рассматриваемом диапазоне цен 4 000–8 000 драмов/м³ валовая стоимость запаса составляет приблизительно 850,1 млн–1,700 млрд драмов. Вместе с тем данный диапазон не может механически приниматься в качестве официальной цены, поскольку требует сопоставимой корректировки с учетом юридически оформленных сделок, качества почвы, НДС, условий погрузки и транспортировки.

Исследование объединяет праводогматический анализ, синтез международной литературы, индексируемой в Scopus, скорректированные по качеству сравнительный и остаточный методы оценки, сценарный анализ чувствительности и многомерную модель чистой общественной ценности. В условиях наличия одного запаса и непроверенных неформальных ценовых данных эконометрические коэффициенты не оцениваются. Вместо этого формулируется идентифицируемая гедоническая модель оценки для будущих микроданных, формируемых по результатам юридически оформленных аукционных сделок.

Ключевые слова: плодородный слой почвы, чернозем, природный капитал, публичный аукцион, ценообразование, муниципальный бюджет, восстановление земель, циркулярная экономика, Ахурянское водохранилище.

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RESEARCH OF A MODEL COMPUTATION SYNCHRONIZATION IN A HETEROGENEOUS CLUSTER

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Abstract

The paper presents the results of a research on the impact of different CPU time quantum values on the behavior of a heterogeneous computing cluster. Two cluster configurations are considered: (1) a control node running the Windows operating system with compute nodes running Linux, and (2) a control node running Linux with compute nodes running Windows.

It is shown that inconsistency in task scheduling parameters leads to increased latency, response time instability, and performance degradation during parallel data processing.

Keywords: CPU time quantum, heterogeneous cluster, interaction model, cluster node, p95, p99, CFS.

Introduction

Modern computing systems increasingly employ hybrid architectures in which master nodes and compute nodes operate under different operating systems (OS) [1]. This heterogeneity arises from the need to integrate infrastructure components, utilize specialized solutions, and ensure cross-platform compatibility. To effectively distribute computational workloads and align task scheduling policies within such diverse hardware and software environments, a deep adaptation of task schedulers to the specific characteristics of each operating system is required. This challenge becomes particularly critical in computing clusters used for processing large volumes of data during the training of machine learning models.

One of Central Processing Unit (CPU) time quanta[1] between nodes. This issue has been addressed in various studies, though each comes with certain limitations [2-7]. In particular,

[1] **The CPU time quantum** is the minimum time slice during which a process is allowed to execute on the CPU before the scheduler decides whether to switch control to another process.

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research [6-7] analyzed the behavior of homogeneous computing clusters running either Windows or Linux while varying the CPU time quantum values. A special focus should be placed on the measurement of p95[2] and p99[3] metrics in heterogeneous clusters. Since these clusters are built on diverse hardware and software platforms, determining effective p95 and p99 values becomes a relevant task for more accurate cluster configuration. This research examines changes in cluster performance in mixed configurations - where the master node runs Windows and compute nodes run Linux, and vice versa - and measures various performance metrics, including p95 and p99.

The novelty of this research lies in identifying optimal values for the p95 and p99 metrics in a heterogeneous cluster during neural network training.

Conflict Setting

It is necessary to determine the optimal p95 and p99 values for a heterogeneous cluster during the training of a convolutional neural network.

Boundary condition

- At the current stage, only one neural network was trained.
- All computations were performed exclusively on the CPU.
- The heterogeneity of the cluster was defined solely by the software layer, as the hardware components of the cluster were built using nodes[4] with identical specifications.

Experimental procedures

For the research, a heterogeneous cluster consisting of 12+1 nodes was deployed with the following configuration:

- 1 master node based on either Ubuntu 22.04 or Windows Server 2022 [12].
- 12 compute nodes running either Windows or Linux accordingly.
- The cluster was configured using a Storage Area Network (SAN) architecture [13].

The computers are connected via two network interfaces, forming two local networks - for control and data transfer. The research was conducted under conditions of maximum asymmetry in CPU time quantum:

Option I

- master node based on a Windows Server 2022 OS. CPU time quantum set to 120 ms,
- compute nodes based on a Linux OS with enable CFS (Completely Fair Scheduler). CPU time quantum set to 10 ms.

Option II

- master node based on a Linux OS with enable CFS. CPU time quantum set to 10 ms,
- compute nodes based on a Windows Server 2022 OS. CPU time quantum set to 120 ms.

[2] **The p95 metric** value (response time) represents the threshold below which 95% of all measurements fall. It indicates the upper bound of typical system behavior and is useful for evaluating latency and stability.

[3] **The p99 metric** value represents the threshold below which 99% of all measurements fall. This indicator reflects extreme latency and is used to assess system reliability under peak loads [8-11].

[4] Single computer (node) parameters: CPU-i9, RAM 32Gb

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This setup allowed simulation of the worst-case scheduling scenario, *where the master node significantly lags behind in event processing compared to the compute nodes*, leading to queues, deadlocks, and increased response times.

The following measurements were conducted during the research:

- Average and maximum process execution quantum - using built-in OS profiling tools (Linux: *perf sched, cat /proc/sched_debug* [14]. Windows: Performance Monitor and PowerShell commands *Get-ScheduledTask, Get-Counter*) [15].
- Average task response time - calculated as the average duration of jobs sent from the master node, including initialization, queuing, and completion times. Measurements were performed using *time, systemd-analyze*, and Python scripts with the *time* module (Linux), as well as PowerShell scripts (Windows).
- p95 and p99 values - calculated using Python scripts with *numpy.percentile*.

The accuracy of the neural network outputs was verified by comparing them with known reference outputs from a pre-trained neural network studied in [16] (reference network). *TensorFlow* [17] was used as the machine learning framework.

Research Results

The research results for different CPU time quantum values are presented in Tab.1. Graphs illustrating the relationship between computation latency and the length of the CPU time quantum, as well as the p95 and p99 parameters, are shown in Fig. 1–3. The average execution time by task type is presented in Fig. 4.

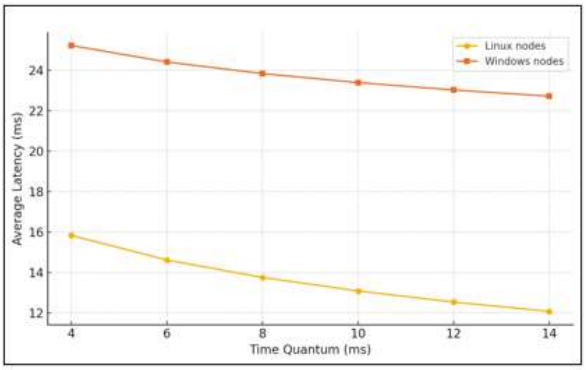

Fig. 1 Dependence of average execution latency on the length of the CPU time quantum

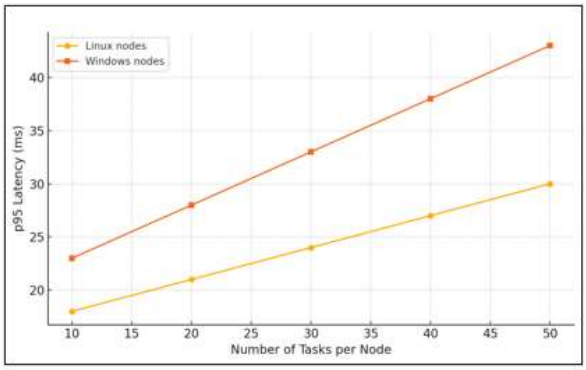

Fig. 2 Dependence of p95 on the number of tasks per single node

When managing Linux nodes with a Windows master node, spikes in p99 latency are observed, while stable p95 values indicate overall system resilience. In the opposite configuration (Linux master node, Windows compute nodes), the p95 value shows greater

The p95 metric is more representative for assessing user experience and production readiness of heterogeneous computing environments compared to simple averages. On Linux nodes, the CFS scheduler demonstrates high resilience to overload by smoothly redistributing time quanta among tasks. In Windows nodes, high load can cause performance degradation, especially with fixed time quanta that do not adapt to task behavior.

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Table 1

Cluster Parameter Values for Different Configurations

Metric	**Windows → Linux**	**Linux → Windows**
Average execution quantum (ms)	7.3	12.1
Average task start latency (ms)	18.6	26.7
p95	24.1	39.5
p99	17.3	28.4
Percentage of threads that switched prematurely	12%	28%

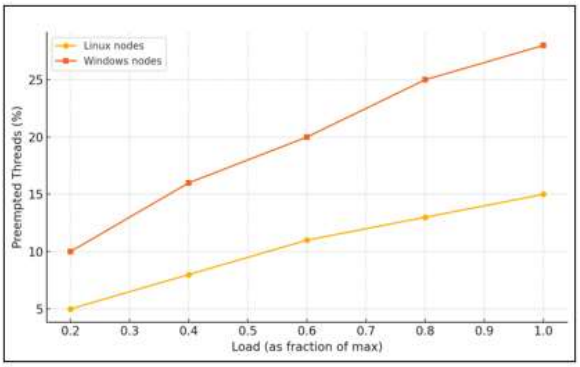

Fig. 3 Percentage of premature thread switches with increasing load

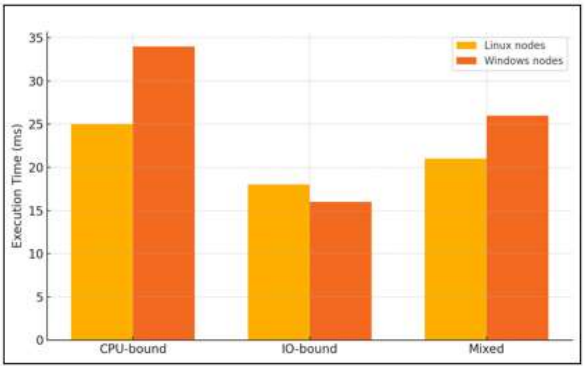

Fig. 4 Average execution time by task type

The optimal p95 and p99 values are achieved with a Linux master node in a heterogeneous cluster.

Conclusion

The configuration with a Linux master node and Windows compute nodes demonstrates more stable behavior on the nodes, especially under peak loads. Differences in system time and timing mechanisms can cause drift in task distribution; therefore, it is recommended to set the system time to Coordinated Universal Time (UTC) during initial setup.

It is also important to note the limited flexibility in configuring the CPU time quantum on Windows nodes: even with administrator access, it is not possible to achieve the level of configuration precision comparable to Linux. When designing heterogeneous systems, it is recommended to use Linux as the master server, especially when flexible coordination and monitoring are required, and to limit Windows nodes to tasks with predictable workloads.

The results obtained can be used to develop cross-platform task scheduling tools optimized for the conditions of heterogeneous computing infrastructures.

References

1. Akinshin A., «*Professional Benchmarking*»: *The Art of Measuring Performance,* Apress, Piter, 2022, Saint Petersburg-Moscow-Minsk, pp. 576.
2. Bertsimas D., et al, «Deep Trees for (Un)structured Data: Tractability, Performance, and Interpetability». https://doi.org/10.48550/arXiv.2410.21595

3. Hazem T., Abdelhadi A., «Hardware Proximal Policy Optimization – A Universal Pipelined Architecture for Generalized Advantage Estimation». https://doi.org/10.48550/arXiv.2501.12703
4. Ryu M., Byeon G., Kim K., «A GPU-Accelerated Distributed Algorithm for Optimal Power Flow in Distribution Systems». https://doi.org/10.48550/arXiv.2501.08293
5. Ryu M., Byeon G., Kim K., «A GPU-Accelerated Distributed Algorithm for Optimal Power Flow in Distribution Systems». https://doi.org/10.48550/arXiv.2501.08293
6. Jamgharyan T., «Research of Model for Increase Learning Speed of a Neural Network in the Linux Operating System», *Bulletin Of High Technology*, N 2 (34) 2025, pp. 99-108. https://doi.org/10.56243/18294898-2025.2-99
7. Jamgharyan T., «Research of Model for Increase Learning Speed of a Neural Network in the Windows Operating System», *Bulletin Of High Technology*, N 4 (36) 2025, pp. 116-123. https://doi.org/10.56243/18294898-2025.4-116
8. Both David, Using and Administering Linux:Volume 1: Zero to SysAdmin:Getting Started, Second Edition, APRESS, 2023, pp. 667
9. Both David, Using and Administering Linux:Volume 3, Second Edition, APRESS, 2023, pp. 536
10. Russinovich M., Margosis A., Windows Sysintenals Administrator's Reference, Microsoft Press, 2012, pp. 478
11. Russinovich M., Yosifofovich P., et al., Windows Internals, Part 1: System architecture, processes, threads, memory management, and more, 7th Edition., The Microsoft Press, 2018, pp. 945
12. Official download page for various versions of the Windows operating system, https://www.microsoft.com/en-us/evalcenter , the resource is available on 25.01.2026
13. Microsoft Learn. Failover Clustering in Windows Server and Azure Local description page https://learn.microsoft.com/en-us/windows-server/failover-clustering/failover-clustering-overview , the resource is available on 25.01.2026
14. Nemeth E., Snyder G., Hein T., Whaley B., Unix and Linux Administration Handbook, Prentice Hall, 2012, pp. 1303
15. Windows operating systems testing tools official download page, https://learn.microsoft.com/en-us/sysinternals/ , the resource is available on 25.01.2026
16. Jamgharyan T., Iskandaryan V., Khemchyan A., (2024). Obfuscated Malware Detection Model. *Mathematical Problems of Computer Science*, *62*, 72–81. https://doi.org/10.51408/1963-0122
17. Tensor Flow software download official page. https://www.tensorflow.org/install?hl=ru , the resource is available on 17.03.2026

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RESEARCH OF A MODEL COMPUTATION SYNCHRONIZATION IN A HETEROGENEOUS CLUSTER

ՏԱՐԱՍԵՌ ԿԼԱՍՏԵՐՈՒՄ ՀԱՇՎԱՐԿՆԵՐԻ ՀԱՄԱԺԱՄԵՑՄԱՆ ՄՈԴԵԼԻ ՀԵՏԱԶՈՏՈՒՄ

Ջամղարյան Թ. Վ.
Հայաստանի ազգային պոլիտեխնիկական համալսարան

Հոդվածում ներկայացված են պրոցեսորի ժամանակի քվանտի տարբեր արժեքների ազդեցությունը տարասեռ հաշվարկային կլաստերի աշխատանքի վրա հետազոտության արդյունքները: Դիտարկվել են հաշվարկային կլաստերի երկու կոնֆիգուրացիաներ՝ (1) կառավարիչ հանգույցը՝ Windows օպերացիոն համակարգով, հաշվարկային հանգույցները՝ Linux օպերացիոն համակարգով, և (2) կառավարիչ հանգույցը՝ Linux օպերացիոն համակարգով, հաշվարկային հանգույցները՝ Windows օպերացիոն համակարգով: Խնդիրների պլանավորման պարամետրերի անհամապատասխանությունը հանգեցնում է ուշացման ավելացման, արձագանքի ժամանակի անկայունության և արտադրողականության վատթարացման՝ տվյալների զուգահեռ մշակման ժամանակ:

Բանալի բառեր. պրոցեսորի ժամանակի քվանտ, հետերոգեն կլաստեր, փոխազդեցության մոդել, կլաստերի հանգույց, p95, p99, CFS.

ИССЛЕДОВАНИЕ МОДЕЛИ СИНХРОНИЗАЦИИ ВЫЧИСЛЕНИЙ В ГЕТЕРОГЕННОМ КЛАСТЕРЕ

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В статье представлены результаты исследования влияние разных значений кванта процессорного времени на поведение гетерогенного вычислительного кластера. Рассмотрены две конфигурации вычислительного кластера: (1) управляющая нода на базе операционной системы Windows вычислительные ноды под управлением Linux, (2) управляющая нода на базе операционной системы Linux вычислительные ноды под управлением Windows.

Показано, что несогласованность параметров планирования задач приводит к росту латентности, нестабильности времени отклика и деградации производительности при параллельной обработке данных.

Ключевые слова: квант процессорного времени, гетерогенный кластер, модель взаимодействия, нода кластера, p95, p99, CFS.

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