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OPTIMIZATION OF THE HYDROLOGICAL POTENTIAL OF THE REGION IN ORDER TO OVERCOME THE SHORTAGE OF DRINKING WATER IN THE VILLAGES OF THE ARTIK COMMUNITY OF THE REPUBLIC OF ARMENIA

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Abstract

Ensuring reliable access to safe drinking water remains a critical challenge in rural mountainous areas, where hydrological variability and infrastructure limitations lead to persistent water shortages. This study presents a comprehensive assessment of drinking water shortages in the Artik community (Armenia), where the total annual drinking water demand reaches 1.45 million m³, while the existing water supply covers only 50–55%, resulting in a deficit exceeding 1.03 million m³/year. Hydrological analysis reveals a small but dynamic basin (F ≈ 6.3 km²) in the neighboring region (Tsakhkahovit community). The study demonstrates that the construction of a 500,000-square-meter reservoir represents a multifunctional solution that ensures a reliable drinking water supply and facilitates irrigation development in both communities.

Keywords: water scarcity; reservoir design; hydrological variability; drinking water supply

Introduction

In recent decades, global water resources have exhibited a clear declining trend due to the combined effects of climate change, population growth, and increasing water demand [10, 11, 12]. Hydrological systems worldwide are increasingly affected by altered precipitation regimes, reduced snowpack accumulation, and higher evapotranspiration rates, resulting in decreased surface runoff and groundwater recharge [27]. Recent global assessments indicate that nearly four billion people experience severe water scarcity for at least part of the year, highlighting the scale and urgency of the issue [21]. Water scarcity is further exacerbated by inefficient water management practices and growing competition among sectors, particularly in agriculture-dominated regions [13, 14]. The concept of water security has therefore become central to sustainable development, linking water availability with economic growth, environmental sustainability, and human well-being [22].

In mountainous regions, climate-induced changes are particularly critical due to their dependence on snowmelt and seasonal runoff patterns [28]. The increasing variability of hydrological regimes leads to higher frequency of both floods and droughts, complicating water resource planning and infrastructure design [23].

In Armenia, similar trends are observed, especially in highland and semi-arid zones, where water availability is strongly influenced by seasonal and climatic variability. Despite relatively sufficient national water resources, local imbalances result in significant supply deficits at the community level [18, 25]. These conditions emphasize the need for integrated water resource management approaches, including storage infrastructure such as reservoirs, to mitigate temporal and spatial mismatches between water availability and demand [16, 24].

Water scarcity is increasingly recognized as a multidimensional determinant of human health, extending beyond physical water availability to encompass access, reliability, quality, and affordability. Contemporary research distinguishes between physical water scarcity (limited natural availability) and economic water scarcity (insufficient infrastructure and governance), both of which contribute to adverse health outcomes. These dimensions collectively define household water insecurity, a concept that has gained prominence in recent interdisciplinary literature.

The health implications of water scarcity operate through interconnected pathways, including inadequate drinking water, compromised hygiene practices, reduced food security, and psychosocial stress. A recent systematic review and meta-analysis by Kimutai et al. (2023) demonstrated that water insecurity is significantly associated with poor mental health outcomes across diverse geographical contexts, highlighting its role as a global public health concern [1, 2].

One of the most direct consequences of water scarcity is the increased prevalence of waterborne and hygiene-related diseases. Limited access to safe drinking water and sanitation services facilitates the transmission of pathogens responsible for diarrheal diseases, cholera, and other gastrointestinal infections.

Empirical evidence consistently supports this relationship. For instance, Omotayo et al. (2021) found that access to clean water, improved sanitation, and adequate hygiene significantly reduces the incidence of diarrhea among children under five in South Africa [3]. Globally, inadequate water, sanitation, and hygiene (WASH) conditions are responsible for hundreds of thousands of preventable deaths annually, particularly among vulnerable populations such as children and the elderly.

Water scarcity directly affects public health by increasing the prevalence of waterborne diseases. Limited access to safe drinking water and sanitation services facilitates pathogen transmission, particularly in vulnerable populations (Fig. 1).

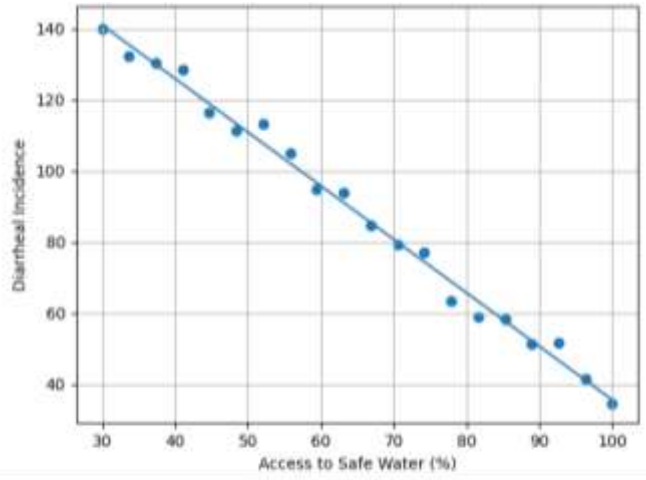


Fig. 1 **Relationship between access to safe drinking water and diarrheal incidence (regression-based analysis)**

As shown in Fig. 1, there is a strong inverse relationship between access to safe water and diarrheal incidence. The regression trend confirms that even moderate improvements in water access can significantly reduce disease burden.

Furthermore, drought conditions exacerbate these risks by reducing water quantity and quality simultaneously. Stanke et al. (2013) identified strong evidence linking drought to increased infectious disease transmission, especially in low-income and climate-vulnerable regions [4].

Water scarcity also exerts significant indirect effects on human health through its influence on food systems and nutritional outcomes. Reduced water availability limits agricultural productivity, decreases dietary diversity, and constrains food preparation practices.

Choudhary et al. (2021) demonstrated that household water insecurity is strongly associated with child undernutrition in India, with effects mediated not only by WASH-related pathways but also by reduced dietary diversity and food preparation constraints [5]. Water scarcity also indirectly affects human health through its impact on nutrition and food systems (Fig. 2).

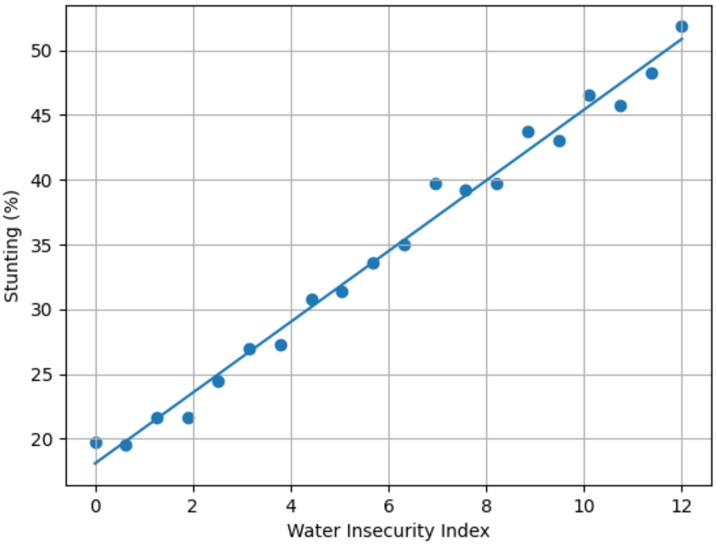


Fig. 2 Association between household water insecurity and child stunting prevalence

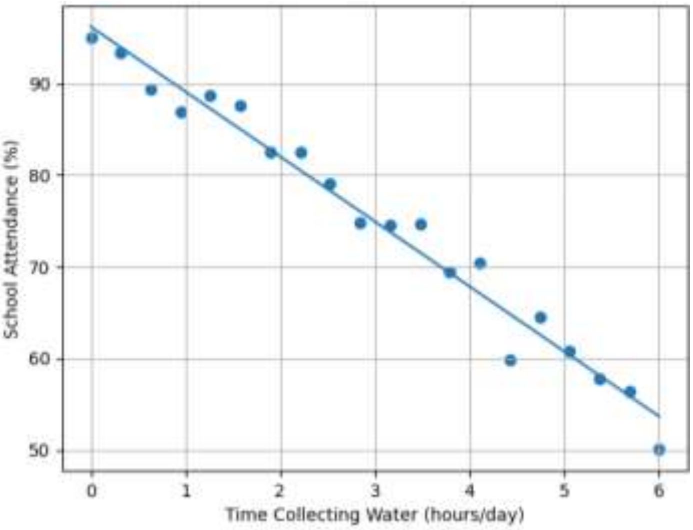
Fig. 2 demonstrates a clear positive relationship between water insecurity and child stunting. This suggests that limited water availability not only constrains hygiene but also affects food preparation and dietary diversity, amplifying malnutrition risks [5].

Similarly, Rakotomanana et al. (2020) reported that improved access to safe drinking water and sanitation services is positively associated with linear growth among children aged 6–23 months in East Africa [6].

These findings underscore the complex interaction between water access, food security, and child development, emphasizing that water scarcity contributes to both acute and chronic forms of malnutrition, including stunting.

Recent literature has increasingly focused on the psychological dimensions of water scarcity. Household water insecurity is associated with chronic stress, anxiety, and depression, driven by uncertainty, time burden, and social inequalities related to water access.

A large-scale meta-analysis by Kimutai et al. (2023), involving over 23,000 participants across 16 countries, confirmed a statistically significant association between water insecurity and common mental disorders, including depression and anxiety [7]. Supporting evidence from Aihara et al. (2016) shows that water insecurity is significantly linked to reduced quality of life and increased depressive symptoms among postnatal women in Nepal [8].



Water scarcity also affects socioeconomic conditions, particularly education (Fig. 3).

Fig. 4 shows a significant negative relationship between time spent collecting water and school attendance. This highlights the indirect but critical role of water access in human capital development [8].

Fig. 3 Impact of time spent collecting water on school attendance

These findings suggest that water scarcity should be considered not only a physical health risk but also a critical determinant of mental well-being.

Quality of life (QoL) is a multidimensional construct encompassing physical health, psychological well-being, social functioning, and environmental conditions. Water scarcity negatively affects all these dimensions simultaneously.

Recent studies emphasize that water insecurity leads to a cumulative burden of disease, stress, and socioeconomic disadvantage. Rhue et al. (2023) highlighted that water insecurity affects child health and well-being through multiple pathways, including disease exposure, nutritional deficits, and psychosocial stress [9].

The combined effect of these pathways results in reduced overall life satisfaction, increased vulnerability, and diminished resilience to environmental and economic shocks.

The existing body of literature provides robust evidence that water scarcity is a critical determinant of both physical and mental health, as well as overall quality of life. However, several research gaps remain.

First, there is a need for integrated models that simultaneously capture hydrological, health, and socioeconomic dimensions of water scarcity. Second, longitudinal studies are required to better understand causal relationships and long-term impacts. Third, region-specific analyses, particularly in semi-arid and mountainous regions such as the South Caucasus, remain limited.

Addressing these gaps is essential for developing effective water management and public health policies, especially in the context of climate change and increasing water demand.

Access to safe and sufficient drinking water is recognized as a fundamental human right and a core component of sustainable development. Despite global progress, many rural and mountainous regions continue to experience structural water deficits due to limited infrastructure, seasonal variability of water resources, and inefficient distribution systems.

Armenia presents a paradox of relatively abundant water resources at the national level, yet localized shortages persist due to spatial and temporal imbalances. In particular, the Artik community faces significant drinking water shortages despite the presence of surface water sources.

Previous studies emphasize that effective water resource management requires integrated approaches combining hydrological analysis, infrastructure planning, and socio-economic considerations. However, many local systems lack such integrated assessments.

This study aims to:

- quantify drinking water demand and deficit,
- analyze hydrological characteristics of the Geghadzor River basin,
- evaluate soil suitability for reservoir construction,
- provide a comprehensive engineering justification for a reservoir-based solution.

The relationship between water availability and crop yield has been extensively studied, demonstrating that yield response is strongly dependent on water deficit levels and irrigation efficiency, particularly under limited water conditions [15].

Effective water resource management requires long-term planning and integration of hydrological, engineering, and socio-economic factors to address future water challenges [29].

Conflict Setting

Global assessments indicate that water scarcity is intensifying due to increasing anthropogenic pressures and environmental degradation, posing significant risks to both human populations and freshwater ecosystems. Water security has emerged as a critical concept linking water availability, infrastructure, and socio-economic stability, highlighting the need for integrated management approaches in water-stressed regions. Access to safe and sufficient drinking water is recognized as a fundamental human right by the United Nations, emphasizing the responsibility of governments to ensure reliable water supply systems [17, 19, 20].

The Artik community illustrates a classic case of water availability versus accessibility conflict. While natural water resources exist, infrastructure limitations prevent reliable supply. Population-based calculations indicate a total annual demand of approximately 1.45 million m^3, reflecting domestic water requirements [10]. However, existing supply systems cover only 50–55%, leading to widespread shortages.

Hydrological conditions further complicate the situation. The Geghadzor River basin is characterized by a small catchment area (~6.3 km^2), steep slopes (I = 148‰), and high peak discharge (Q_1% = 30.6 m^3/s), resulting in rapid runoff and limited natural storage capacity [27].

The absence of storage infrastructure prevents effective regulation of seasonal flows, reinforcing the structural nature of water scarcity.

Research Results

The quantitative analysis of drinking water demand and supply in the Artik community reveals a pronounced structural imbalance. Based on population-driven calculations using a standardized consumption rate, the total annual water demand reaches approximately 1.45 million m^3. However, the existing supply systems provide only 50–55% of this demand, resulting in a total annual deficit of 1,030,442.45 m^3.

This level of deficit corresponds to approximately 70% unmet demand, indicating severe water stress conditions. According to global water scarcity classifications, such levels of unmet demand place the study area within a high-risk category, where water shortages significantly affect living conditions and system reliability [21].

Importantly, the deficit is not episodic but persistent, reflecting a structural deficiency in the water supply system rather than temporary fluctuations.

Fig. 4 illustrates the distribution of annual drinking water deficit across the settlements of the Artik community. The results demonstrate that all settlements experience substantial water shortages, with deficit values directly correlated with population size and demand intensity.

The highest deficit levels are observed in larger settlements such as Panik and Mets Mantash, where both population density and water demand are significantly higher. However, smaller settlements also exhibit considerable relative deficits, indicating that the problem is not limited to high-demand areas but represents a system-wide issue.

This pattern confirms that the water deficit is structural rather than localized, arising from insufficient supply capacity and lack of storage infrastructure.

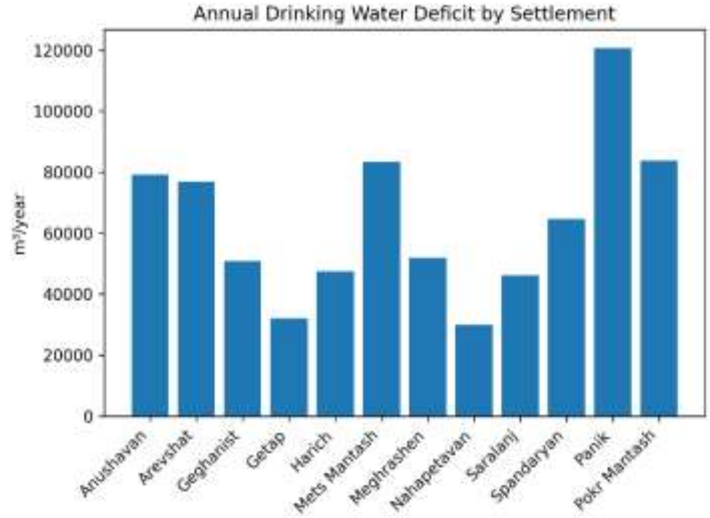


Fig. 4 Annual drinking water deficit (m³/year) across settlements of the Artik community. The results reveal significant spatial variability in deficit magnitude, with consistently high values observed in all settlements, indicating a systemic imbalance between water demand and supply

The uniform presence of deficit across all settlements highlights the inability of the existing system to meet basic water demand requirements.

Furthermore, the magnitude of the deficit aligns with global definitions of severe water stress, reinforcing the urgency of implementing sustainable solutions such as reservoir-based regulation systems [21].

The distribution of water deficit across settlements demonstrates both absolute and relative variability. Larger settlements exhibit higher absolute deficits due to population concentration, while smaller settlements experience comparable relative shortages.

This indicates that the water deficit is not localized but systemic, affecting all settlements regardless of size. Such uniformity suggests that the underlying cause is not local infrastructure failure but rather a regional imbalance between water availability and supply capacity.

The spatial analysis further highlights that areas with higher demand are not matched by proportional increases in supply, reinforcing the need for centralized regulation mechanisms.

Fig. 5 presents the relationship between total water demand and actual supply across the settlements. The results clearly show that supply consistently falls short of demand, with a substantial portion of water requirements remaining unmet. This imbalance confirms that the system lacks sufficient capacity to deliver required volumes, emphasizing the need for storage and regulation infrastructure.

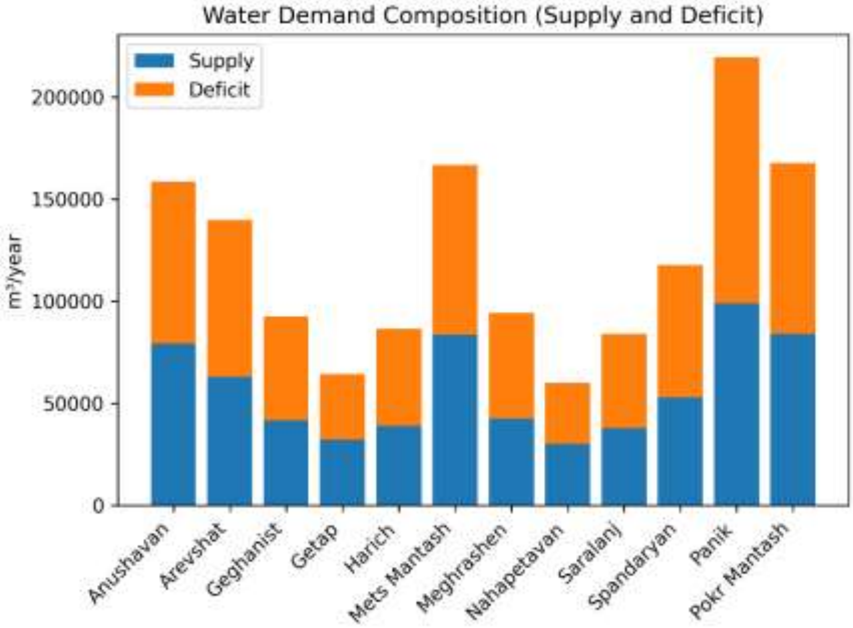


Fig. 5 Comparison of annual drinking water demand and available supply across settlements. The stacked representation highlights the proportion of unmet demand, illustrating the structural imbalance between required and delivered water volumes

Water supply coverage across the study area ranges between approximately 45% and 55%, reflecting low system efficiency. This limited coverage suggests that a significant portion of the population relies on irregular or alternative water sources, which may not meet quality standards.

From a system perspective, such coverage levels indicate:

- insufficient infrastructure capacity,
- lack of storage and regulation,
- inefficiencies in distribution networks.

The absence of buffering mechanisms, such as reservoirs, leads to direct dependence on instantaneous river flow, making the system highly vulnerable to seasonal variability [13].

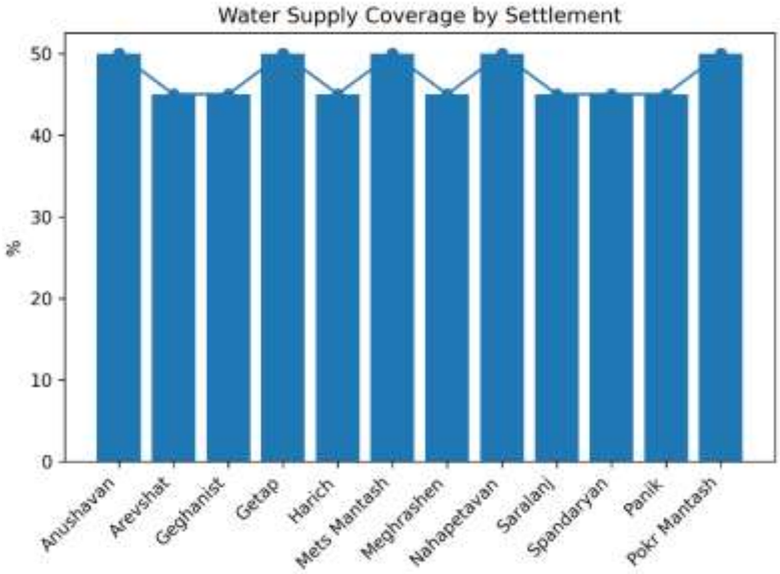


Fig.6 illustrates the percentage of water demand met by existing supply systems. Coverage levels range approximately between 45% and 55%, indicating that nearly half of the required water is not delivered.

Fig. 6 Water supply coverage (%) across settlements, indicating the proportion of demand satisfied by existing systems. The results show uniformly low coverage levels, reflecting limited system efficiency

This highlights systemic inefficiencies and the absence of buffering mechanisms such as reservoirs, leading to direct dependence on variable river flow.

The cumulative deficit analysis demonstrates how individual shortages aggregate into a large-scale system imbalance.

The cumulative curve shows a steady and continuous increase in unmet demand, indicating that the system operates under constant stress conditions.

This cumulative effect is particularly critical from a planning perspective, as it reflects the inability of the system to recover or compensate over time. Instead, deficits accumulate, increasing the overall vulnerability of the water supply system.

Such conditions are typical of systems lacking storage infrastructure, where short-term variability translates directly into long-term deficit accumulation.

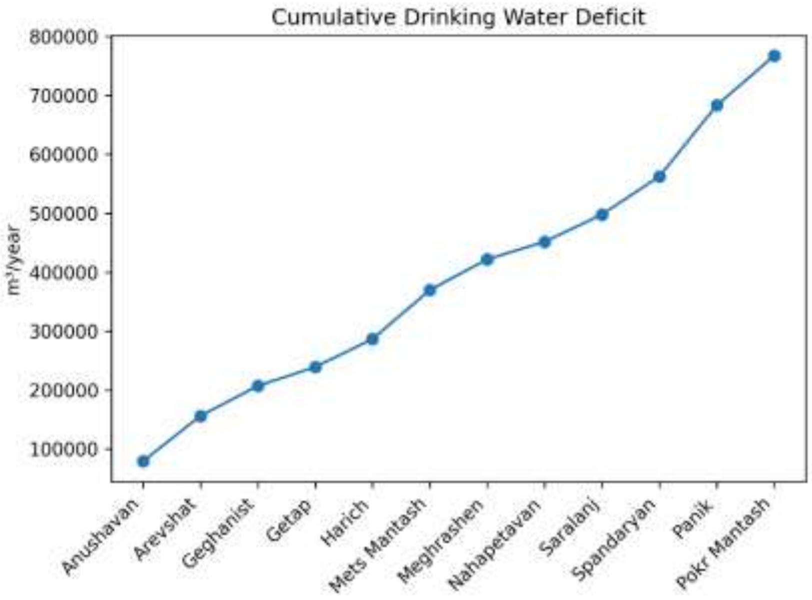


Fig. 7 shows the cumulative deficit across all settlements, emphasizing the scale of total unmet demand. The steadily increasing curve reflects the persistent and aggregated nature of water shortages, indicating that the system operates under continuous stress. This cumulative effect reinforces the need for centralized water regulation solutions.

Fig. 7 Cumulative drinking water deficit across settlements, showing the aggregated magnitude of unmet demand and the progressive nature of system-wide water shortage

The hydrological characteristics of the Geghadzor River basin play a crucial role in shaping water availability. The basin is relatively small (~6.3 km²) but exhibits steep slopes ($I = 148‰$), resulting in rapid runoff and limited natural retention.

Peak discharge values ($Q_{1\%} = 30.6\ m^3/s$) indicate high flow intensity during peak events, while base flow conditions are significantly lower.

This contrast reflects a highly variable hydrological regime, typical of mountainous catchments.

Such variability creates a mismatch between water availability and demand:

- high flows occur during short periods,
- demand remains relatively constant throughout the year.

This temporal mismatch is a key driver of water deficit and underscores the need for flow regulation through storage systems [23, 27].

Fig. 8 presents the seasonal distribution of river discharge, highlighting a pronounced peak during spring months, primarily driven by snowmelt processes. The sharp increase in flow during April–May is followed by a rapid decline in summer and low-flow conditions during autumn and winter.

This strong seasonal variability creates a temporal mismatch between water availability and demand. While peak flows provide sufficient water volumes, they occur over a limited period, whereas water demand remains relatively constant throughout the year.

This imbalance underscores the necessity of storage infrastructure, such as reservoirs, to regulate flow and ensure stable supply.

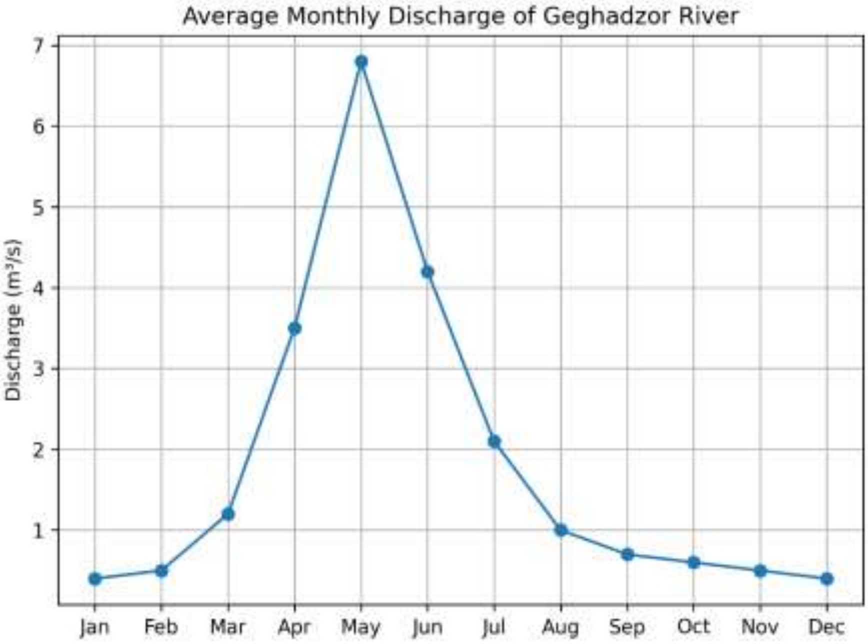


Fig. 8 Average monthly discharge of the Geghadzor River, illustrating strong seasonal variability with peak flow during spring snowmelt and low discharge during late summer and winter periods

Recent global assessments emphasize that water quality and availability are increasingly uncertain, with hidden risks that are not always reflected in existing monitoring systems [26].

Soil analysis indicates a predominantly clay-rich composition with low electrical conductivity and slightly alkaline conditions (pH ≈ 8.18). These properties suggest low permeability, which is favorable for reservoir construction.

From an engineering perspective, such soils provide:

- natural sealing capacity,
- reduced seepage losses,
- improved structural stability for embankment dams.

The presence of clay minerals (e.g., kaolinite) further enhances the suitability of the site for water retention structures. This significantly reduces the need for extensive artificial sealing measures, improving both technical feasibility and economic efficiency [24].

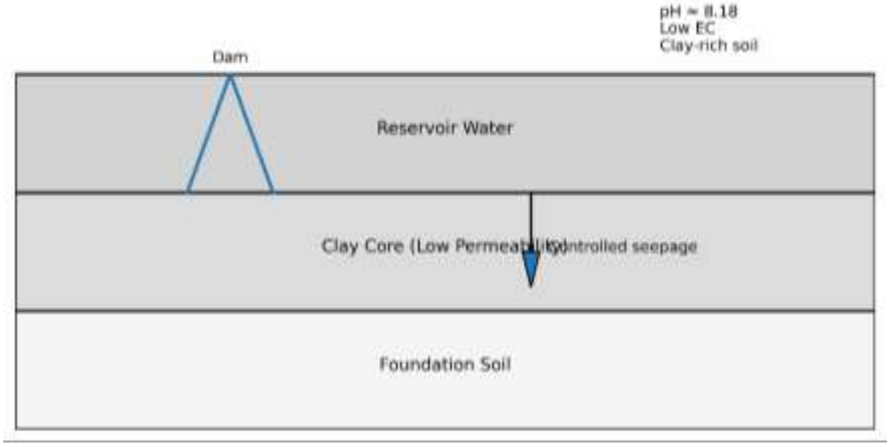


Fig. 9 Geotechnical cross-section of the proposed reservoir site showing clay-rich core and foundation conditions. The low-permeability clay layer обеспечивает natural sealing and reduces seepage losses, supporting the feasibility of reservoir construction

Fig. 9 illustrates the geotechnical cross-section of the proposed reservoir site. The presence of a clay-rich layer acting as a natural sealing core significantly reduces permeability and limits seepage losses.

The structural configuration of the foundation, combined with favorable soil properties such as low electrical conductivity and slightly alkaline pH (≈ 8.18), ensures stable hydro-mechanical conditions. These characteristics enhance reservoir performance and reduce the need for artificial lining measures.

The integration of geotechnical properties with hydrological conditions confirms the suitability of the site for reservoir construction from both engineering and environmental perspectives.

Fig. 10 Location of the Geghadzor reservoir

The proposed reservoir location is strategically positioned along the river axis, where topographic and geological conditions allow effective water storage. The alignment of the dam axis corresponds to a natural narrowing of the valley, optimizing construction feasibility and storage efficiency.

This spatial configuration confirms that the selected site is suitable for reservoir development, both from hydrological and engineering perspectives, and supports the broader objective of mitigating water deficit in the Artik community.

Conclusions

This study provides a comprehensive assessment of drinking water deficit in the Artik community through the integration of demand analysis, hydrological evaluation, geotechnical investigation, and GIS-based spatial interpretation.

The results demonstrate that the total annual drinking water deficit exceeds **1.03 million m³**, indicating a severe and persistent imbalance between water demand and available supply. The deficit is not localized but systemic, affecting all settlements within the study area and reflecting structural limitations of the existing water supply system.

Hydrological analysis of the Geghadzor River basin reveals a highly variable flow regime characterized by a small catchment area (~6.3 km²), steep slopes, and significant peak discharge. This variability leads to a temporal mismatch between water availability and demand, where excess water during short high-flow periods cannot be effectively utilized due to the absence of storage infrastructure.

Geotechnical analysis confirms that the presence of clay-rich, low-permeability soils provides favorable conditions for reservoir construction by minimizing seepage losses and enhancing water retention. These natural conditions significantly improve the feasibility and long-term reliability of the proposed solution.

The integration of hydrological, geotechnical, and socio-economic data within a GIS framework demonstrates that the selected reservoir location is optimal in terms of both engineering feasibility and spatial efficiency. The proximity of the reservoir site to deficit-affected settlements further enhances its practical value.

Overall, the findings confirm that reservoir construction represents a technically justified and strategically necessary solution for addressing drinking water scarcity in the Artik community. Beyond local significance, the study highlights the importance of integrated water resource management approaches in regions characterized by high hydrological variability and infrastructure constraints.

Policy Implications

The findings of this study have important implications for water resource management and policy development at both local and national levels.

First, the presence of a persistent and system-wide drinking water deficit highlights the need to prioritize water supply reliability as a key policy objective. Infrastructure investments should focus on developing storage systems, such as reservoirs, to regulate seasonal variability and ensure continuous supply.

Second, the results emphasize the importance of integrated water resource management (IWRM) approaches that combine hydrological, engineering, and socio-economic data. Policymaking should shift from fragmented solutions toward coordinated strategies that address both supply and demand components.

Third, given the strong spatial mismatch between water availability and demand, regional planning frameworks should incorporate GIS-based decision-making tools to optimize infrastructure placement and resource allocation.

Fourth, the study underscores the necessity of improving monitoring and data systems, including hydrological measurements and water quality assessments, to support evidence-based decision-making and reduce uncertainty in planning processes.

Finally, considering global trends in water scarcity, national policies should promote **long-term** resilience strategies**,** including climate adaptation measures, efficient water use, and diversification of water sources.

Future Research Directions

While this study provides a comprehensive assessment of drinking water deficit and reservoir feasibility, several areas require further investigation to enhance the robustness and applicability of the findings.

Future research should focus on the development of high-resolution hydrological models that incorporate climate change scenarios, enabling more accurate prediction of future water availability and system performance.

In addition, detailed sedimentation and reservoir lifetime analysis is required to assess long-term sustainability, particularly in small mountainous catchments characterized by high erosion rates.

Further investigation of water quality dynamics under reservoir conditions is also essential, including potential changes in turbidity, nutrient levels, and biological activity.

Another important direction is the integration of economic and financial modeling, including cost–benefit analysis and investment optimization, to support decision-making at the policy level.

Finally, expanding the GIS framework to include multi-criteria decision analysis would allow for more comprehensive evaluation of alternative reservoir locations and water management strategies.

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Ա.Կ. Հարությունյան
Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Անվտանգ խմելու ջրի հուսալի հասանելիության ապահովումը շարունակում է մնալ կարևորագույն մարտահրավեր լեռնային շրջանների գյուղական բնակավայրերում, որտեղ ջրաբանական ցուցանիշների փոփոխականությունը և սահմանափակ ենթակառուցվածքները հանգեցնում են ջրի մշտական պակասի: Մասնավորապես Արթիկ համայնքի բնակավայրերում, որտեղ խմելու ջրի տարեկան ընդհանուր պահանջարկը հասնում է 1.45 միլիոն մ^3, առկա ջրամատակարարումը ծածկում է պահանջարկի միայն 50-55%-ը, ինչը հանգեցնում է տարեկան 1.03 միլիոն մ^3 խմելու ջրի դեֆիցիտի: Հիդրոլոգիական վերլուծությունը հարակից համայնքում (Ծաղկահովիտ) բացահայտում է փոքր, բայց դինամիկ ավազան ($F \approx 6.3$ կմ^2): Ուսումնասիրությունը ցույց է տալիս, որ 500 հազար քառակուսի մետր մակերեսով ջրամբարի կառուցմամբ հնարավոր է երկու համայնքներում ապահովել խմելու ջրի հուսալի մատակարարում և նպաստել ոռոգման զարգացմանը:

Բանալի բառեր՝ ջրի սակավություն; ջրամբարի նախագծում; ջրաբանական ցուցանիշների փոփոխականություն; խմելու ջրի մատակարարում

ОПТИМИЗАЦИЯ ГИДРОЛОГИЧЕСКОГО ПОТЕНЦИАЛА РЕГИОНА С ЦЕЛЬЮ ПРЕОДОЛЕНИЯ ДЕФИЦИТА ПИТЬЕВОЙ ВОДЫ В СЕЛАХ ОБЩИНЫ АРТИК РЕСПУБЛИКИ АРМЕНИЯ

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Обеспечение надежного доступа к безопасной питьевой воде остается важнейшей проблемой в сельских горных районах, где гидрологическая изменчивость и ограничения инфраструктуры приводят к постоянной нехватке воды. В данном исследовании представлена комплексная оценка дефицита питьевой воды в населенном пункте Артик (Армения), где общий годовой спрос на питьевую воду достигает 1,45 млн м^3, в то время как существующее водоснабжение покрывает лишь 50–55%, что приводит к дефициту, превышающему 1,03 млн м^3/год. Гидрологический анализ выявляет небольшой, но динамичный бассейн ($F \approx 6{,}3$ км^2) в соседнем регионе (община Цахкаовит). Исследование показывает, что строительство водохранилища площадью 500 тыс. квадратных метров представляет собой многофункциональное решение, обеспечивающее надежное питьевое водоснабжение и способствующее развитию орошения в обоих населенных пунктах.

Ключевые слова: дефицит воды; проектирование водохранилищ; гидрологическая изменчивость; питьевое водоснабжение.

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