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STRATEGIC MANAGEMENT OF DRINKING WATER RESOURCES IN ARMENIA: BALANCING CLIMATE CHANGE, BOTTLED WATER PRODUCTION, AND LONG-TERM WATER SECURITY

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Abstract

Armenia possesses substantial drinking water resources, including high-quality groundwater, springs, and mineral water reserves, which constitute an important component of the country's environmental, economic, and strategic assets. At the same time, increasing bottled water production, climate change, growing water demand, and the need to ensure long-term water security are creating new challenges for the sustainable management of these resources. Although Armenia is generally considered a water-rich country, the long-term availability of drinking water cannot be assessed solely on the basis of current resource

abundance. Strategic management requires the integration of climatic, environmental, economic, and institutional factors that influence both water availability and resource sustainability.

This study presents a comprehensive assessment of Armenia's drinking water resources and evaluates the interactions between climate change, bottled water production, and long-term water security. The analysis is based on official statistical data, hydrological information, climate indicators, and institutional documents describing water resource management and bottled water production trends. The study examines recent changes in water abstraction, production dynamics, resource utilization, and the potential impacts of climate variability on drinking water resources.

Based on the identified challenges, the paper proposes an integrated strategic management framework aimed at balancing economic development with long-term resource conservation. The framework emphasizes sustainable groundwater management, climate adaptation, protection of drinking water sources, improved monitoring systems, efficient allocation of water resources, and evidence-based decision-making. The proposed approach demonstrates that effective drinking water resource management should move beyond traditional resource accounting and incorporate long-term resilience, ecosystem protection, and adaptive governance.

The findings contribute to the development of sustainable water resource management policies and provide practical recommendations for balancing bottled water production with the preservation of Armenia's strategic drinking water resources under changing climatic conditions.

***Keywords*:** drinking water resources; strategic water management; bottled water production; climate change; groundwater; water security; sustainable resource management; Armenia.

Introduction

Freshwater resources are among the most valuable strategic assets for ensuring sustainable development, protecting public health, supporting economic growth, and maintaining ecosystem integrity. Although approximately 71% of the Earth's surface is covered by water, less than 1% of global water resources is readily available as accessible freshwater for human use. Rapid population growth, urbanization, industrial expansion, agricultural intensification, and climate change are increasing pressure on freshwater resources worldwide, making their sustainable management one of the most important global environmental challenges of the twenty-first century.

Access to safe drinking water is internationally recognized as a fundamental human right and constitutes a key component of the 2030 Agenda for Sustainable Development, particularly Sustainable Development Goal 6, which calls for universal and equitable access to safe and affordable drinking water. Nevertheless, ensuring long-term drinking water security extends beyond guaranteeing present-day access. It also requires protecting water sources, maintaining groundwater recharge, adapting to climate change, improving governance, and balancing environmental, economic, and social interests over extended planning horizons.

During the last decade, scientific attention has increasingly shifted from conventional water resource development toward integrated strategic water resource management. This transition reflects the growing recognition that countries possessing relatively abundant freshwater resources are not immune to water-related risks. Climate variability, changing precipitation regimes, increasing evaporation, groundwater depletion, pollution, and competing water demands may gradually reduce the reliability of drinking water supplies even where current resource availability appears sufficient. Consequently, modern water management strategies increasingly emphasize long-term resilience, adaptive governance, and sustainable resource management rather than the continuous expansion of water abstraction.

Armenia is among the countries endowed with substantial high-quality drinking water resources, primarily supplied by groundwater aquifers, mountain springs, and mineral water sources. These resources form the foundation of the country's drinking water supply system and support a steadily expanding bottled water industry that contributes significantly to national economic development and export growth. However, increasing water demand, climate-induced hydrological changes, and the continued expansion of bottled water production are creating new challenges for the long-term sustainability and strategic management of these valuable resources.

Although numerous scientific studies have addressed Armenia's drinking water resources, most have focused on individual aspects such as hydrogeological conditions, water quality, water balance, water supply systems, or statistical assessments of bottled water production. Comparatively few studies have comprehensively examined the interrelationships among climate change, drinking water resource utilization, the expansion of bottled water production, and long-term water security within a unified strategic management perspective. Consequently, there is a clear need for an integrated strategic approach to the management of Armenia's drinking water resources that extends beyond conventional resource assessment and incorporates long-term resource conservation, climate resilience, sustainable economic development, and the safeguarding of water security.

Global Approaches to Drinking Water Resource Management

The management of drinking water resources has evolved considerably over the past several decades in response to growing environmental, socio-economic, and climatic challenges. Traditionally, water management policies primarily focused on expanding water supply through the construction of reservoirs, groundwater abstraction systems, inter-basin water transfers, and centralized distribution infrastructure. This engineering-oriented approach was largely driven by the objective of meeting increasing water demand and supporting economic development. However, the accelerating impacts of climate change, rapid urbanization, population growth, environmental degradation, and increasing competition among water users have demonstrated that expanding water supply alone is insufficient to ensure long-term drinking water security [1,5,7].

These challenges have led to a gradual transition from conventional water resource development toward integrated and strategic management approaches. One of the most influential concepts introduced during this transition is Integrated Water Resources Management (IWRM), which promotes the coordinated management of water, land, and related natural resources to maximize economic and social benefits while preserving ecosystem

sustainability. Since its introduction by the Global Water Partnership, the IWRM framework has become one of the fundamental principles guiding national water policies and international water governance. Complementary governance frameworks developed by the Organisation for Economic Co-operation and Development have further emphasized transparency, institutional coordination, stakeholder participation, accountability, and evidence-based decision-making as essential elements of effective water governance [7–10].

In recent years, scientific and policy attention has increasingly shifted toward the broader concept of water security, which extends beyond ensuring adequate water quantity and quality. Contemporary approaches recognize that long-term drinking water security depends on the resilience of water resources to climate change, the sustainability of groundwater recharge, ecosystem protection, effective governance, adaptive management, and the capacity of institutions to respond to emerging environmental risks. This transition is reflected in the United Nations World Water Development Reports and the Sustainable Development Goal 6 framework, which advocate integrated management strategies capable of balancing environmental sustainability, economic development, and social equity while strengthening resilience to climate-related pressures [1–6,12–14].

Despite the substantial progress achieved in strategic water resource management during the past two decades, existing international approaches primarily focus on integrated governance, water-use efficiency, climate adaptation, and ecosystem protection at the general water-resource level. Comparatively less attention has been devoted to the strategic management of drinking water resources as a distinct category of national natural assets, particularly in countries possessing abundant high-quality groundwater reserves and rapidly expanding bottled water industries. Furthermore, limited emphasis has been placed on balancing long-term drinking water security with the increasing economic utilization of potable water resources. These knowledge gaps indicate the need for more specialized strategic management approaches capable of integrating climate resilience, groundwater sustainability, economic development, and long-term protection of drinking water resources within a unified management framework.

Despite the significant progress achieved in strategic water resource management, increasing scientific attention is now focused on understanding how climate change influences the long-term sustainability of drinking water resources, thereby necessitating a more detailed examination of climate-related impacts on water availability and security.

Climate Change and Drinking Water Resources

Climate change has emerged as one of the most significant challenges affecting the sustainability of drinking water resources worldwide. Rising air temperatures, changing precipitation patterns, increasing evapotranspiration, more frequent droughts, and the growing occurrence of extreme hydrological events are altering the natural processes that regulate water availability and groundwater recharge. These changes directly influence both the quantity and quality of drinking water resources and increase uncertainty regarding their long-term availability [1–6,12–14].

Numerous studies have demonstrated that groundwater systems, traditionally considered more resilient than surface water resources, are also becoming increasingly vulnerable to climate variability. Reduced recharge rates, prolonged dry periods, changing

snow accumulation and snowmelt dynamics, and increasing abstraction pressures may gradually diminish groundwater reserves and alter spring discharge regimes. Since groundwater constitutes the principal source of drinking water in many countries, including Armenia, these processes have become a major concern for long-term water resource planning and sustainable management [3,11–14].

Beyond physical impacts on water availability, climate change also affects drinking water quality through increased sediment transport, higher concentrations of dissolved pollutants, changing hydrochemical conditions, and greater risks of contamination during extreme hydrological events. Consequently, ensuring drinking water security increasingly requires integrated monitoring systems capable of simultaneously evaluating hydrological, hydrogeological, climatic, and water-quality indicators rather than relying on individual environmental parameters [1–6,12–14].

Recent international research emphasizes that adaptation to climate change should become an integral component of strategic drinking water resource management. Modern adaptation measures include the protection of groundwater recharge areas, enhancement of monitoring systems, improvement of water-use efficiency, diversification of drinking water sources, development of climate-resilient infrastructure, and the incorporation of climate projections into long-term water resource planning. These approaches contribute not only to reducing climate-related risks but also to strengthening the resilience and sustainability of national drinking water systems [1–6,9,12–14].

Despite considerable progress in understanding climate-related impacts on water resources, most existing studies primarily assess the physical consequences of climate change on hydrological systems. Comparatively limited attention has been devoted to evaluating how climate change interacts with the expanding economic utilization of drinking water resources, particularly bottled water production, and how these combined pressures influence long-term strategic management and national water security. This issue is particularly relevant for countries where drinking water resources represent both an essential public resource and a growing economic asset.

Bottled Water Production, Groundwater Sustainability, and Research Progress in Armenia

The global bottled water industry has experienced remarkable growth during the past two decades, driven by increasing consumer demand for safe drinking water, urbanization, changing lifestyles, and concerns regarding the quality of public water supplies. In many countries, bottled water production has become an important economic sector, contributing to employment, regional development, and export revenues. However, this rapid expansion has also intensified scientific discussions regarding the long-term sustainability of groundwater abstraction, protection of drinking water sources, and the need to balance economic development with the conservation of strategic water resources [1–6].

Groundwater represents the principal source of bottled drinking water in most producing countries. Although groundwater generally provides high-quality drinking water with relatively limited treatment requirements, excessive abstraction may gradually exceed natural recharge rates, resulting in declining groundwater levels, reduced spring discharge, ecosystem degradation, and increasing vulnerability to climate variability. Consequently, international

studies increasingly emphasize that bottled water production should be managed within the broader framework of sustainable groundwater management and long-term water security rather than solely through economic considerations [3,5,9,11–14].

Armenia possesses abundant high-quality groundwater resources and numerous natural springs, creating favorable conditions for the development of bottled drinking water and mineral water production. During recent decades, this sector has become an important component of the national economy and has strengthened its position in international markets. At the same time, the sustainable utilization of these resources has become an increasingly important issue as climate change, growing water demand, and expanding economic activities continue to increase pressure on strategic drinking water reserves.

Among the studies devoted to Armenia's drinking water resources, the work of Markosyan et al. (2018) represents one of the first comprehensive assessments integrating information on national drinking water resources with the country's bottled water production and export potential [15]. The study demonstrated the significant availability of high-quality drinking water resources in Armenia and highlighted their economic importance as a strategic natural asset. It also emphasized the country's considerable opportunities for expanding bottled water exports based on its favorable hydrogeological conditions.

Since the publication of that study, however, substantial changes have occurred. New statistical data, advances in scientific understanding of climate change, evolving international approaches to water security, growing bottled water production, and increasing attention to sustainable groundwater management have considerably altered the context within which Armenia's drinking water resources should be evaluated. These developments indicate that previous assessments require further expansion toward integrated strategic management approaches capable of simultaneously addressing climate resilience, groundwater sustainability, economic development, and long-term drinking water security.

Conflict Setting

Despite the significant progress achieved in drinking water resource management during recent decades, an important scientific contradiction remains unresolved. On the one hand, countries possessing abundant high-quality drinking water resources are generally considered to have a favorable long-term water security outlook. On the other hand, climate change, increasing groundwater abstraction, expanding bottled water production, and growing socio-economic demand are progressively altering the conditions under which these resources are utilized and conserved. Consequently, resource abundance alone can no longer be regarded as a sufficient indicator of long-term drinking water security.

This contradiction is particularly evident in Armenia. The country possesses substantial reserves of high-quality groundwater and spring water, while bottled water production has become an increasingly important economic sector. Simultaneously, climate change, changing hydrological conditions, and increasing pressure on groundwater resources introduce new uncertainties regarding the long-term sustainability of drinking water resources. These interacting processes require a management approach that extends beyond conventional resource inventories and production statistics.

The analysis of the available scientific literature indicates that existing studies generally examine hydrogeological conditions, water quality, climate impacts, groundwater utilization, or bottled water production as separate research topics. Comparatively few studies have attempted to integrate these components within a unified strategic management framework capable of simultaneously evaluating climate resilience, groundwater sustainability, economic development, and long-term drinking water security.

Accordingly, there is a need to develop a comprehensive strategic management approach that considers drinking water resources not only as environmental assets but also as strategic national resources requiring long-term protection, adaptive management, and evidence-based policy development.

The objective of this study is to comprehensively assess the current status and development trends of Armenia's drinking water resources, evaluate the potential impacts of climate change and bottled water production, and develop an integrated strategic management framework that supports balanced decision-making between economic development, conservation of drinking water resources, and long-term water security. The proposed framework represents the principal scientific contribution of this study and is intended to provide methodological support for strategic drinking water resource management in Armenia and in other countries facing similar environmental and socio-economic challenges.

Materials and Methods

Study Area

The Republic of Armenia was selected as the study area because of its considerable reserves of high-quality drinking water resources, extensive groundwater systems, numerous mountain springs, and well-developed bottled water industry. These characteristics make Armenia an appropriate case for evaluating the interactions among climate change, drinking water resource utilization, economic development, and long-term water security. Particular attention was given to groundwater resources, which constitute the principal source of drinking water for both public supply and bottled water production.

Data Sources

The study was based on the integration of multiple data sources, including official statistical publications of the Statistical Committee of the Republic of Armenia (ArmStat), reports of the Ministry of Environment, national water cadastre information, hydrogeological and climatic datasets, and international publications issued by UNESCO, UN-Water, the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC), the Organisation for Economic Co-operation and Development (OECD), and the World Bank. Data covering the period 2018–2025 were used to evaluate recent developments in drinking water resources, bottled water production, groundwater utilization, and climate-related indicators.

Research Methodology

The research employed an integrated methodological approach combining literature review, statistical analysis, comparative assessment, trend analysis, hydrogeological evaluation, climate assessment, and policy analysis. Temporal trends in drinking water resource utilization and bottled water production were analyzed using official statistical data. Climate-related

influences were evaluated through the assessment of temperature and precipitation trends together with internationally recognized climate reports. Comparative analysis was applied to identify relationships among climate change, groundwater sustainability, bottled water production, and long-term drinking water security. The results of these analyses were synthesized to identify the principal strategic challenges affecting drinking water resource management in Armenia.

Development of the Strategic Drinking Water Resource Management Framework

Based on the identified scientific gaps, literature review, statistical evaluation, climate assessment, and policy analysis, a Strategic Drinking Water Resource Management Framework (SDWRMF) was developed. The framework integrates four interrelated components: (i) assessment of drinking water resource availability and sustainability; (ii) evaluation of climate-related pressures and groundwater resilience; (iii) assessment of economic utilization, including bottled water production; and (iv) strategic management and policy decision-making. The proposed framework provides a systematic methodology for evaluating drinking water resources as strategic national assets while simultaneously considering environmental sustainability, economic development, and long-term water security. The practical application and validation of the framework are presented in the subsequent Results and Discussion section.

Research Results

Drinking Water Resources of Armenia

Armenia possesses substantial high-quality drinking water resources that constitute one of the country's most valuable strategic natural assets. Drinking water is supplied predominantly from groundwater aquifers and natural springs, which are characterized by favorable hydrogeological conditions and generally high water quality. These resources satisfy the majority of the country's public drinking water demand while simultaneously supporting the production of bottled drinking and mineral water. Owing to their strategic importance for public health, socio-economic development, and environmental sustainability, the long-term protection and rational management of these resources have become fundamental priorities of national water policy. Consequently, the assessment of drinking water resources should extend beyond conventional quantitative inventories and incorporate considerations of sustainability, resilience, and long-term water security.

The hydrogeological structure of Armenia plays a decisive role in the formation and long-term availability of drinking water resources. The country's mountainous terrain, complex geological setting, and diverse aquifer systems provide favorable conditions for the accumulation, natural filtration, and continuous recharge of groundwater. As a result, groundwater constitutes the primary source of drinking water for most settlements and represents the principal resource supporting bottled water production. Compared with surface water resources, groundwater generally exhibits greater stability in both quantity and quality, making it particularly valuable under conditions of increasing climatic variability. Nevertheless, the sustainability of groundwater resources depends on maintaining a balance between natural recharge and water abstraction, emphasizing the importance of continuous monitoring and scientifically based resource management.

Table 1

General Characteristics of Armenia's Water Resources

Indicator	Value	Unit
Average annual river runoff	7.2–7.7	billion m³/year
Renewable internal freshwater resources	6.85–7.0	billion m³/year
Number of rivers	~9,480	—
Number of reservoirs	74	—
Total reservoir storage capacity	0.988	billion m³
Lake Sevan water volume	~38.0	billion m³
Official strategic national water reserve	39.3	billion m³

Note: The value of **39.3 billion m³** is adopted in this study as the official indicator of Armenia's strategic national water reserve in accordance with the Law of the Republic of Armenia *"On the National Water Program of the Republic of Armenia"* (Law No. HO-232-N, adopted on 27 November 2006). This value represents the legally recognized strategic water reserve ensuring the country's long-term water and environmental security. Values such as **45.5 billion m³**, occasionally reported in the literature, refer to the gross national water resource potential and are therefore not used as the official strategic water reserve indicator in the present study.

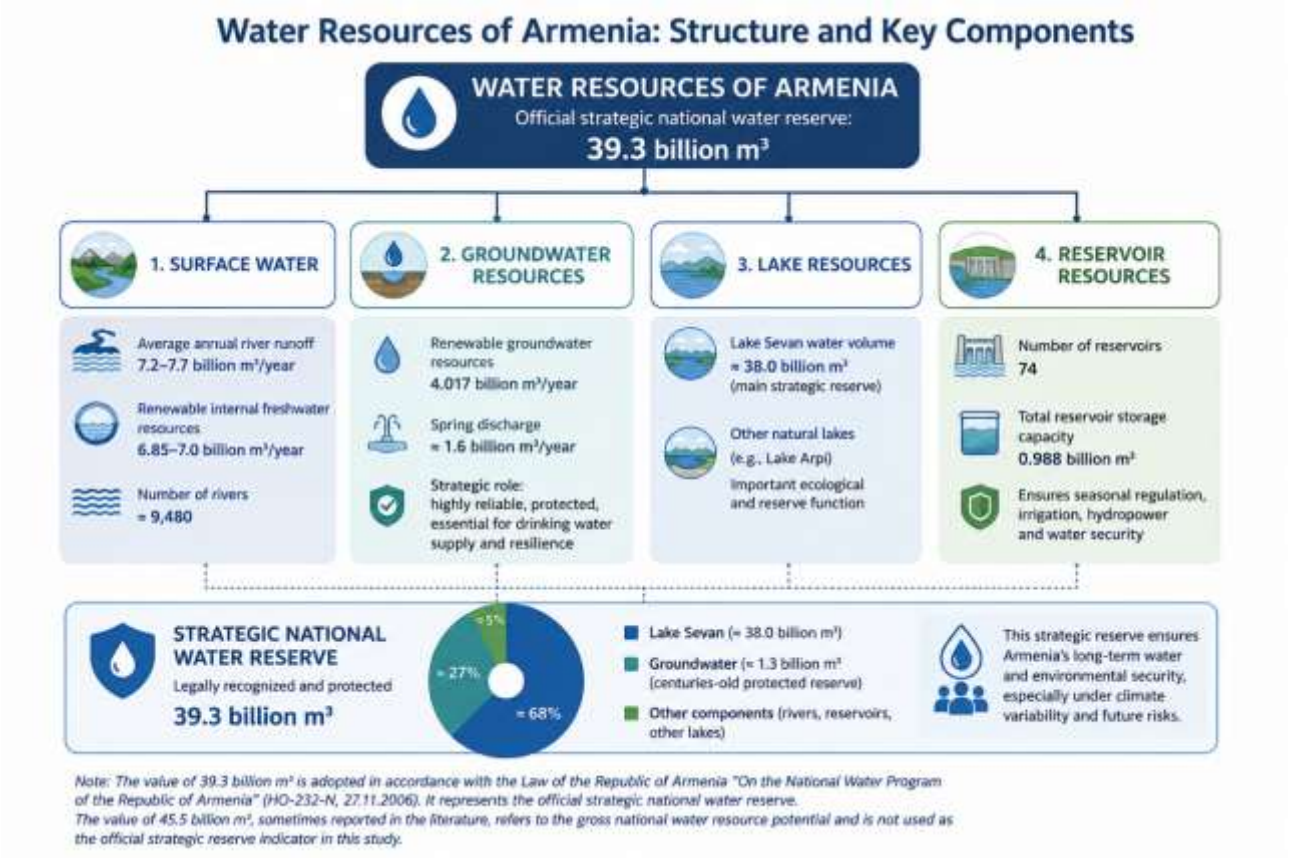

Fig. 1 General Structure of Armenia's Water Resources

Fig. 1 illustrates the general structure of Armenia's water resources, including surface water, groundwater, lake resources, and reservoirs, together with their principal quantitative characteristics. The figure highlights the central role of Lake Sevan and groundwater resources in ensuring the country's long-term water security and provides the conceptual basis for the subsequent assessment of strategic drinking water resources using the Strategic Drinking Water Resource Management Framework (SDWRMF).

The analysis of Armenia's water resources demonstrates that the country possesses considerable freshwater potential, forming a strong basis for long-term water security. As summarized in Tab.1 and illustrated in Fig.1, Armenia's water resources comprise surface waters, groundwater, lake resources, and reservoirs, which together constitute an integrated national water system. Surface water resources are represented by an average annual river runoff of approximately 7.2–7.7 billion m³ and an extensive hydrographic network of nearly 9,480 rivers. Lake Sevan, with an estimated water volume of approximately 38 billion m³, constitutes the country's principal strategic freshwater reserve, while the existing network of 74 reservoirs provides a total storage capacity of approximately 0.988 billion m³, contributing to seasonal flow regulation and water supply reliability. According to the National Water Program of the Republic of Armenia, the officially recognized strategic national water reserve amounts to 39.3 billion m³, representing the legally protected long-term freshwater reserve that underpins the country's water and environmental security.

Table 2

Characteristics of Armenia's Strategic Groundwater Resources

Indicator	Value	Unit
Total renewable groundwater resources	4.017	billion m³/year
Spring discharge	1.595	billion m³/year
Drainage discharge	1.419	billion m³/year
Deep groundwater discharge	1.003	billion m³/year
Potential exploitable groundwater resources	>3.0	billion m³/year
Officially approved exploitable groundwater reserves	1.215	billion m³/year
Drinking water supplied from groundwater	96	%
Official strategic groundwater reserve	1.3	billion m³
Principal strategic hydrogeological basin	Ararat Artesian Basin	—
Contribution of the Ararat Artesian Basin to national groundwater resources	45–50	%

Note: Renewable groundwater resources represent the annually replenished groundwater potential of the country. Potential exploitable groundwater resources (>3.0 billion m³/year) refer to the estimated maximum volume that could theoretically be abstracted under favorable hydrogeological and engineering conditions without causing irreversible depletion. In contrast, the officially approved exploitable groundwater reserves (1.215 billion m³/year) represent the legally verified and technically proven portion of groundwater resources approved for sustainable use through the state hydrogeological assessment system. In accordance with the objectives of this study, both indicators are presented because they characterize different dimensions of Armenia's strategic groundwater potential and its currently approved sustainable utilization capacity.

Fig. 2 presents the structure of Armenia's renewable groundwater resources and their role in national drinking water supply. The figure illustrates the distribution of renewable groundwater into spring, drainage, and deep groundwater flow components, together with the relationship between renewable resources, potential exploitable resources, officially approved exploitable groundwater reserves, and the strategic groundwater reserve. It also highlights the

dominant contribution of the Ararat Artesian Basin to the country's groundwater resources and the fundamental role of groundwater in providing centralized drinking water supply.

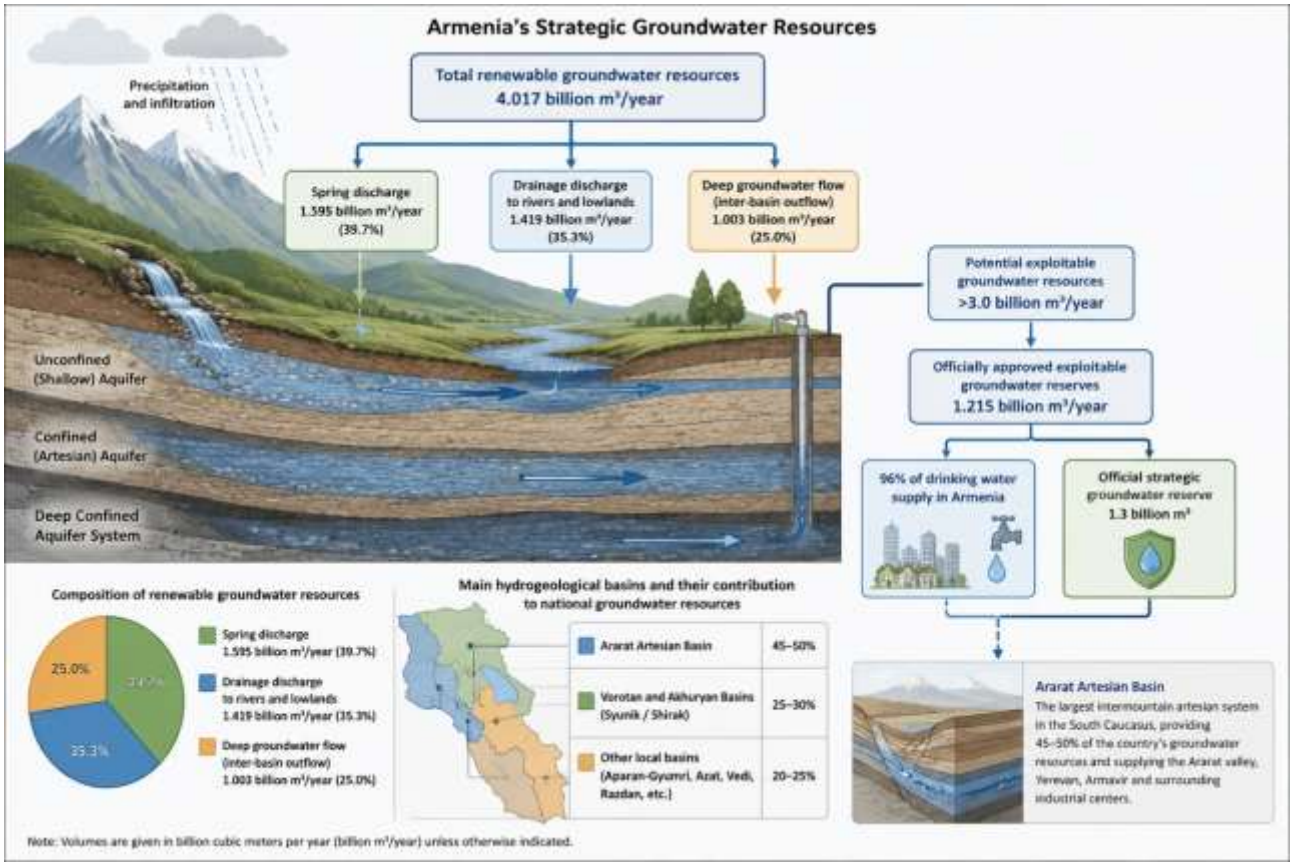

Fig. 2 Structure and Utilization of Armenia's Strategic Groundwater Resources

The characteristics of Armenia's strategic groundwater resources are presented in Table 2 and illustrated in Figure 2. The country possesses approximately 4.017 billion m³/year of renewable groundwater resources, which are replenished through natural hydrological processes and constitute the principal source of drinking water. Renewable groundwater consists of three major components: spring discharge (1.595 billion m³/year), drainage discharge (1.419 billion m³/year), and deep groundwater flow (1.003 billion m³/year), indicating a well-balanced hydrogeological system. Although the country's potential exploitable groundwater resources exceed 3.0 billion m³/year, the officially approved exploitable groundwater reserves amount to 1.215 billion m³/year, reflecting the volume that has been hydrogeologically verified and authorized for environmentally sustainable abstraction. Groundwater supplies approximately 96% of Armenia's centralized drinking water, highlighting its critical importance for national water security. Furthermore, the officially recognized strategic groundwater reserve of 1.3 billion m³, together with the dominant contribution of the Ararat Artesian Basin, demonstrates the strategic significance of groundwater resources for ensuring long-term drinking water security under increasing climatic and socio-economic pressures.

Table 3

Climate Change Indicators Affecting Drinking Water Resources in Armenia (2018–2025)

Year	Mean Annual Temperature (°C)	Temperature Anomaly (°C)	Annual Precipitation (mm)	Precipitation Relative to Climate Normal (%)
2018	9.1	+1.5	480–520	80–87
2019	8.5	+0.7	480–520	80–87
2020	9.0	+1.2	480–520	80–87
2021	8.9	+1.1	550	92
2022	8.2	+0.3	570	96
2023	9.02	+1.2	510	86
2024	8.87	+1.0	740.98	125
2025*	8.9–9.0	~+1.0	~490**	82–84

Preliminary estimates based on official hydrometeorological observations.

Climate normal (1991–2020): Mean annual precipitation: 592 mm. Temperature anomalies are calculated relative to the official climatic normal (1991–2020).

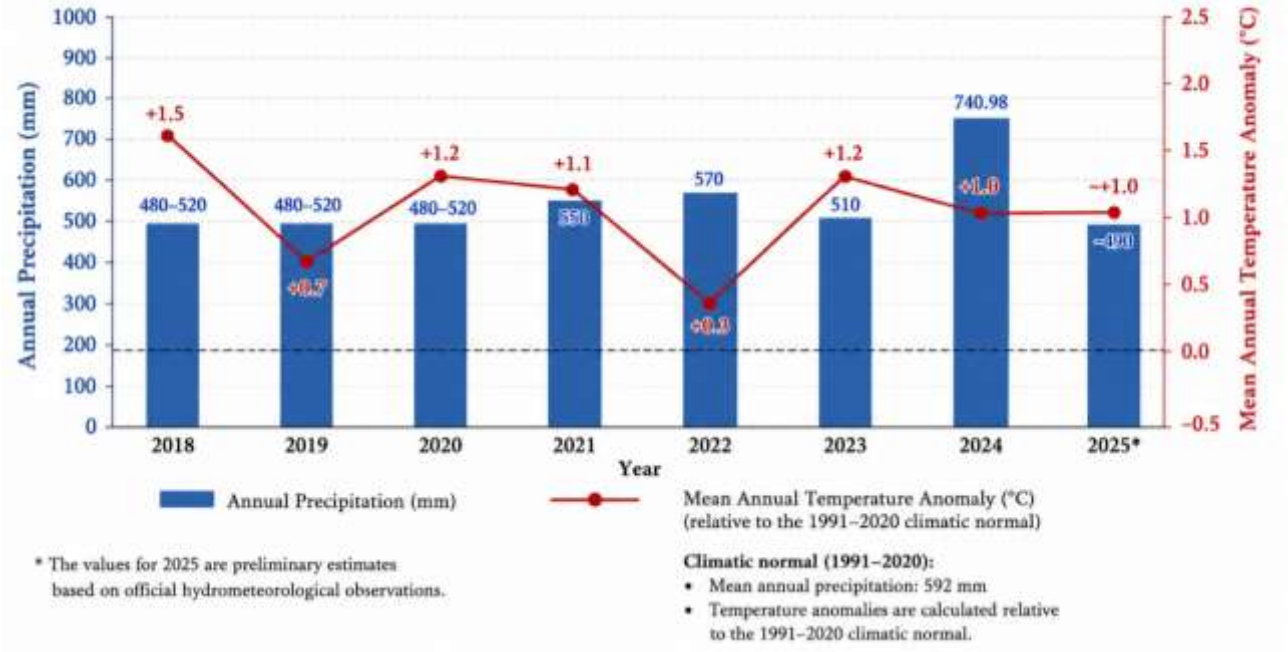

Fig. 3. Trends in Mean Annual Temperature Anomalies and Annual Precipitation in Armenia (2018–2025)

The Fig. 3 illustrates the temporal variation of two principal climatic indicators affecting drinking water resources in Armenia during 2018–2025. Annual precipitation is presented as bars, while mean annual temperature anomalies relative to the 1991–2020 climatic normal are shown as a line. The combined presentation highlights the persistent warming trend together with pronounced interannual precipitation variability, emphasizing the increasing climatic uncertainty influencing the long-term sustainability of drinking water resources.

Climate data presented in Table 3 and Figure 3 demonstrate a clear warming trend and increasing climatic variability in Armenia during the period 2018–2025. Mean annual air temperature remained consistently above the climatic normal throughout the study period, with positive anomalies ranging from +0.3°C to +1.5°C, confirming the ongoing warming observed

across the country. At the same time, annual precipitation exhibited pronounced interannual variability, ranging from prolonged drought conditions during 2018–2020 and again in 2025 to exceptionally wet conditions in 2024. Such fluctuations indicate increasing climatic instability rather than a simple linear change in precipitation patterns.

These climatic changes have direct implications for the long-term sustainability of drinking water resources. Reduced snow accumulation, earlier snowmelt, and increasing evapotranspiration decrease groundwater recharge, while declining spring discharge and increasing dependence on groundwater abstraction place additional pressure on strategic drinking water reserves. According to national assessments, climate change has already contributed to measurable reductions in the discharge of mountain springs and has intensified pressure on the Ararat Artesian Basin. Climate projections indicate that by 2050, renewable groundwater resources may decline by approximately 8–10%, emphasizing the necessity of integrating climate adaptation measures into the strategic management of drinking water resources.

Table 4

Bottled Water Production and Groundwater Utilization in Armenia (2018–2025)

Indicator	Value	Unit
Bottled drinking and natural mineral water production (2024–2025)	145–155	million liters/year
Groundwater abstraction for bottled water production	0.145–0.155	million m^3/year
Share of officially approved exploitable groundwater reserves	~0.013	%
Bottled water export (2024)	30.9	million liters
Planned annual export growth	5–8	%
Principal export markets	Russia, USA, UAE, Kazakhstan, Ukraine	—
Main strategic groundwater pressure identified at the national level	Aquaculture and agricultural irrigation	—
Strategic environmental requirement for the bottled water industry	Continuous hydrogeological monitoring of mineral water sources	—

Note: Current official assessments indicate that bottled water production utilizes only a very small fraction of Armenia's officially approved exploitable groundwater reserves and therefore does not presently constitute a significant threat to national strategic drinking water resources. Nevertheless, continued industry expansion, combined with climate change and increasing groundwater demand, underscores the importance of preventive strategic groundwater management and continuous hydrogeological monitoring.

Fig. 4 illustrates the relative position of bottled water production within the overall structure of groundwater utilization in Armenia. The figure demonstrates that, although the bottled water industry has experienced continuous production and export growth, its current groundwater abstraction represents only a negligible proportion of the officially approved exploitable groundwater reserves. In contrast, aquaculture and agricultural irrigation constitute the principal anthropogenic pressures on groundwater resources. Nevertheless, considering projected climate change, increasing water demand, and the expected expansion of bottled water production, preventive strategic management and continuous hydrogeological monitoring remain essential to ensure the long-term sustainability of Armenia's strategic drinking water resources.

Figure 4. Strategic Position of Bottled Water Production within Armenia's Groundwater Use Framework (2024–2025)
Based on official data of RA Statistical Committee and RA Ministry of Environment

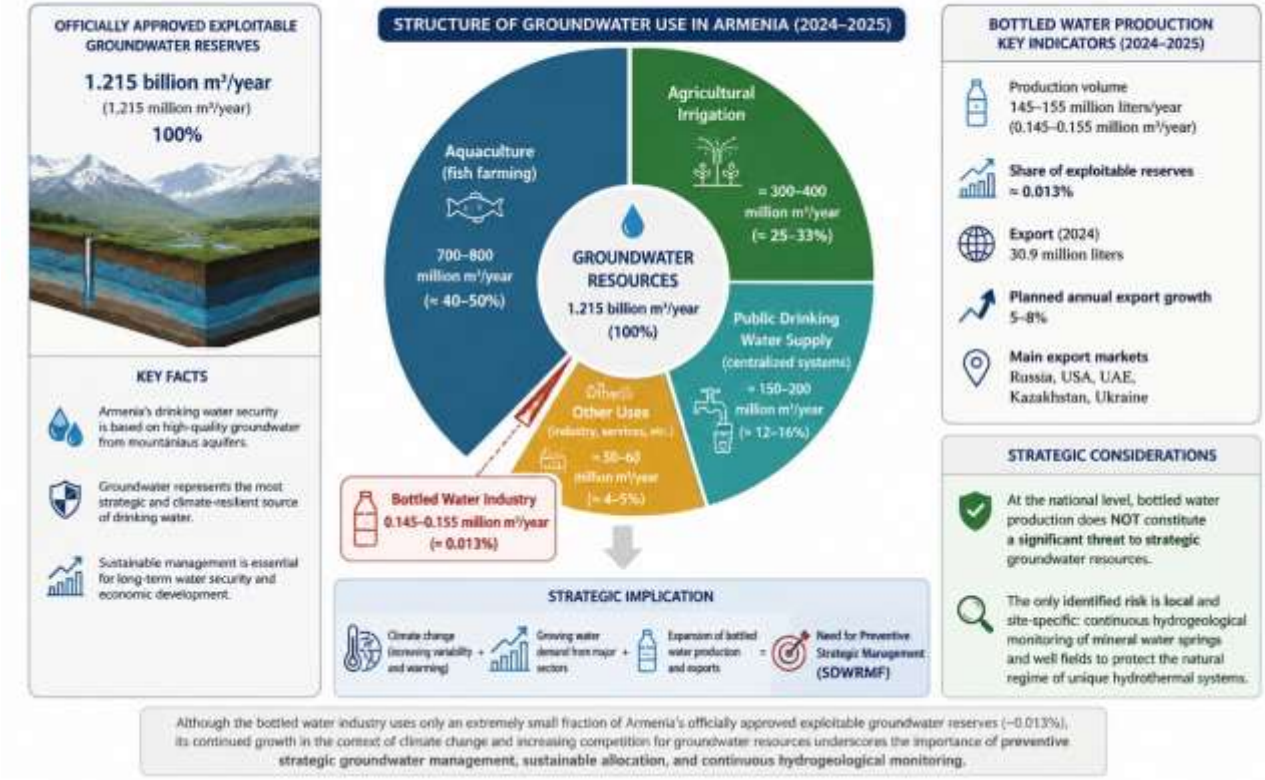

Fig. 4 Groundwater Utilization Structure and the Position of Bottled Water Production within Armenia's Strategic Water Resources Management Framework

The results presented in the preceding sections demonstrate that Armenia currently possesses sufficient strategic drinking water resources to ensure long-term national water security. However, the analysis also reveals that future sustainability cannot be evaluated solely on the basis of resource availability. Climate change is gradually reducing groundwater recharge, increasing climatic variability and uncertainty, while socio-economic development is expected to increase future water demand. At the same time, the bottled water industry continues to expand and contributes to economic growth and export development, although its current groundwater abstraction remains negligible in comparison with the officially approved exploitable groundwater reserves.

These findings indicate that strategic drinking water management should move beyond the traditional assessment of available water resources toward an integrated preventive management approach capable of simultaneously considering natural resource availability, climate-related risks, economic utilization, environmental sustainability, and long-term national water security. To address these challenges, this study proposes the Strategic Drinking Water Resource Management Framework (SDWRMF) as an integrated decision-support framework for balancing resource conservation, economic development, and sustainable groundwater utilization under changing climatic conditions.

The Strategic Drinking Water Resource Management Framework (SDWRMF) is designed to support long-term decision-making by integrating the principal factors affecting

drinking water resource sustainability into a unified management system. Unlike conventional approaches that primarily focus on the availability of water resources, the proposed framework simultaneously considers the quantity and quality of drinking water resources, climate-related pressures, groundwater utilization, economic development, environmental protection, and institutional governance. This integrated perspective enables strategic decisions to be based not only on current resource availability but also on future risks and sustainability objectives, thereby strengthening the resilience of national drinking water resource management.

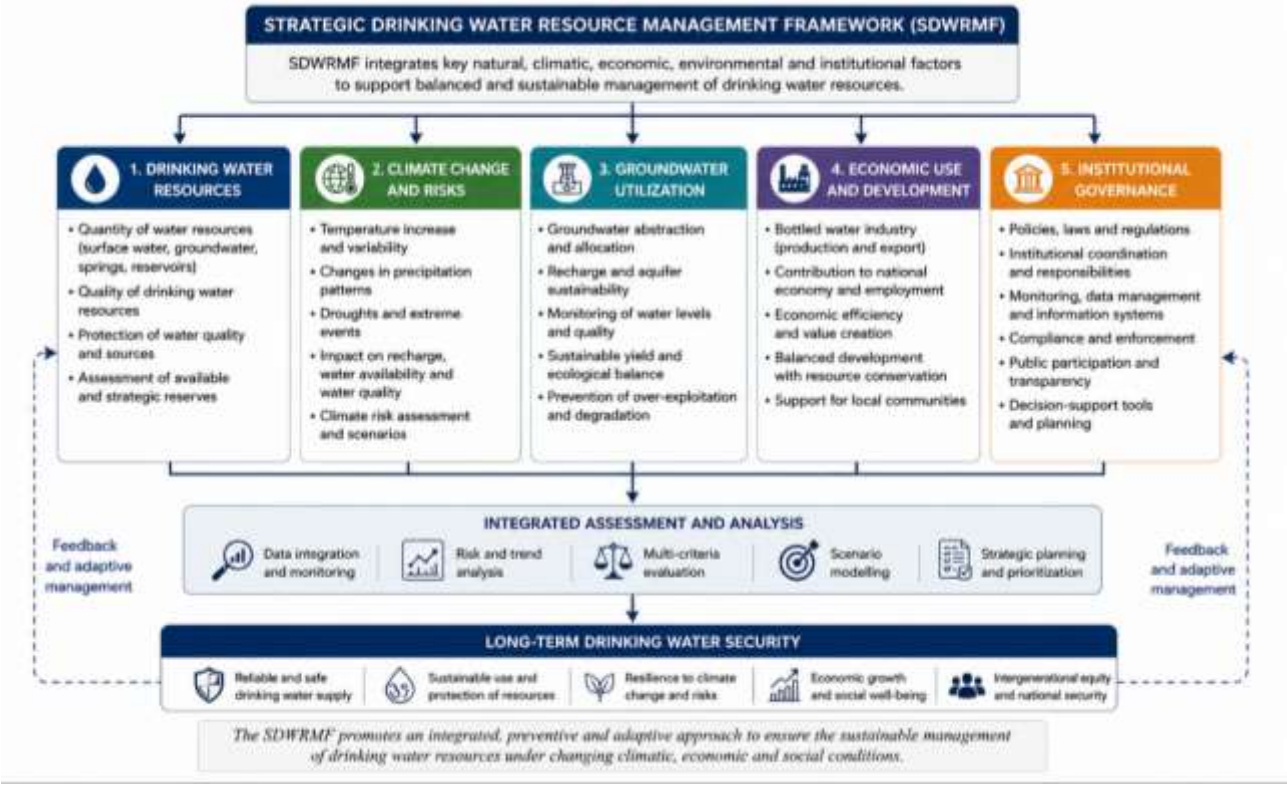

Fig. 5 Strategic Drinking Water Resource Management Framework (SDWRMF)

Fig. 5 presents the Strategic Drinking Water Resource Management Framework (SDWRMF) proposed in this study. The framework integrates five interrelated management dimensions: drinking water resources, climate change and associated risks, groundwater utilization, economic use and development, and institutional governance. These components are linked through an integrated assessment and decision-support process that enables comprehensive evaluation of resource conditions, climate-related pressures, groundwater sustainability, economic development, and governance effectiveness. The framework supports adaptive and preventive decision-making aimed at balancing resource conservation, sustainable economic development, and the long-term security of Armenia's strategic drinking water resources under changing climatic conditions.

Drinking Water Resources

The first component of the Strategic Drinking Water Resource Management Framework (SDWRMF) is based on the comprehensive assessment of drinking water resources. It encompasses not only the quantitative evaluation of available water resources but also the

assessment of their quality, natural recharge capacity, strategic importance, and long-term sustainability. Particular attention is given to the interrelationship between surface water and groundwater resources, the protection of strategic water reserves, continuous monitoring of drinking water quality, and the maintenance of sustainable abstraction limits. This component forms the foundation of the SDWRMF, as all subsequent management decisions should be based on an objective assessment of the current condition of the country's drinking water resources and their capacity to ensure long-term water security.

Climate Change and Risk Assessment

The second component of the Strategic Drinking Water Resource Management Framework (SDWRMF) focuses on the assessment of climate change and its implications for the long-term sustainability of drinking water resources. This component evaluates trends in air temperature, precipitation, drought frequency, extreme hydrological events, and their influence on groundwater recharge, spring discharge, and drinking water availability. It also incorporates climate projections, vulnerability assessment, and scenario analysis to identify potential future risks affecting strategic water resources. By integrating climate-related information into the decision-making process, the framework supports adaptive management strategies that enhance the resilience of drinking water resources under changing environmental conditions and reduce the long-term risks associated with climate uncertainty.

Sustainable Groundwater Utilization

The third component of the Strategic Drinking Water Resource Management Framework (SDWRMF) focuses on ensuring the sustainable utilization of groundwater resources, which constitute the principal source of drinking water in Armenia. This component emphasizes maintaining a balance between groundwater abstraction and natural recharge while preserving groundwater quality and the long-term functionality of aquifer systems. It includes continuous hydrogeological monitoring, assessment of groundwater abstraction rates, protection of strategic groundwater reserves, regulation of groundwater use by different economic sectors, and prevention of localized overexploitation. Particular attention is given to preserving the hydrogeological stability of strategically important groundwater basins, especially the Ararat Artesian Basin, through science-based management, regular monitoring, and adaptive regulatory measures. This component ensures that groundwater utilization remains environmentally sustainable while supporting national drinking water security and socio-economic development.

Economic Development and Bottled Water Production

The fourth component of the Strategic Drinking Water Resource Management Framework (SDWRMF) addresses the relationship between economic development and the sustainable utilization of drinking water resources. The framework recognizes bottled drinking and natural mineral water production as an important contributor to national economic growth, employment, and export development. At the same time, it emphasizes that economic activities relying on strategic groundwater resources should be managed within scientifically justified and environmentally sustainable limits. This component promotes the integration of economic planning with groundwater resource protection through regular assessment of groundwater abstraction, continuous hydrogeological monitoring, environmental impact evaluation, and adaptive management mechanisms. Such an approach ensures that economic development can

continue without compromising the long-term sustainability and strategic security of Armenia's drinking water resources.

Institutional Governance and Decision Support

The fifth component of the Strategic Drinking Water Resource Management Framework (SDWRMF) focuses on institutional governance and evidence-based decision support. It provides the organizational and regulatory foundation necessary for implementing integrated drinking water resource management at the national level. This component promotes coordination among governmental institutions, scientific organizations, water utilities, environmental authorities, and other stakeholders involved in water resource management. It also emphasizes continuous data collection, monitoring, information exchange, and periodic reassessment of management decisions based on updated scientific evidence and changing environmental conditions. By integrating reliable scientific information with adaptive governance mechanisms, this component enhances the effectiveness, transparency, and long-term resilience of strategic drinking water resource management while supporting informed policy development and sustainable decision-making.

Expected Benefits of Implementing the Strategic Drinking Water Resource Management Framework (SDWRMF)

The implementation of the Strategic Drinking Water Resource Management Framework (SDWRMF) is expected to strengthen the long-term sustainability, resilience, and efficiency of drinking water resource management in Armenia. By integrating hydrological, climatic, environmental, economic, and institutional information into a unified decision-support framework, SDWRMF enables a comprehensive assessment of both current conditions and future risks.

The proposed framework supports early identification of emerging threats to strategic drinking water resources, improves coordination among responsible institutions, promotes evidence-based policy development, and facilitates adaptive management under changing climatic and socio-economic conditions. Furthermore, SDWRMF provides a balanced approach that simultaneously supports groundwater conservation, sustainable economic development, and the protection of national drinking water security.

Beyond its application in Armenia, the conceptual structure of SDWRMF may also serve as a transferable decision-support framework for other countries facing similar challenges related to climate change, increasing groundwater demand, and the need to balance economic development with the long-term protection of strategic drinking water resources.

Discussion

Principal Scientific Findings

The present study demonstrates that Armenia possesses substantial strategic drinking water resources, primarily supplied by high-quality groundwater, which currently provide approximately 96% of the country's centralized drinking water supply. The assessment confirmed that the existing groundwater resources and officially approved exploitable reserves remain sufficient to support both domestic water supply and the continuing development of the bottled water industry. Nevertheless, the analysis indicates that the long-term sustainability of these resources cannot be evaluated solely on the basis of their current availability.

The results further demonstrate that climate change has become one of the principal long-term drivers influencing the sustainability of drinking water resources in Armenia. Persistent positive temperature anomalies, increasing climatic variability, changes in precipitation patterns, and projected reductions in groundwater recharge collectively increase uncertainty regarding future drinking water availability. These findings support the growing international consensus that strategic water management should increasingly focus on resilience and adaptive capacity rather than solely on resource abundance.

The study also demonstrates that the current scale of bottled drinking and mineral water production does not constitute a significant pressure on Armenia's strategic groundwater resources. According to the available official data, groundwater abstraction for bottled water production represents only a negligible proportion of the officially approved exploitable groundwater reserves. The principal anthropogenic pressures continue to originate from other sectors, particularly aquaculture and agricultural irrigation. However, the combination of climate change, increasing groundwater demand, and the expected long-term expansion of water-dependent economic activities justifies the adoption of preventive strategic management approaches.

The principal scientific contribution of this research is the development of the Strategic Drinking Water Resource Management Framework (SDWRMF), which integrates hydrological, climatic, environmental, economic, and institutional factors within a unified decision-support framework. Unlike conventional approaches that evaluate these factors separately, SDWRMF provides an integrated methodology for balancing drinking water resource conservation, sustainable economic development, and long-term national water security under changing climatic conditions.

Comparison with Previous Studies

Previous studies on Armenia's drinking water resources have primarily focused on individual aspects of water resource management, including hydrogeological characteristics, groundwater resources, drinking water quality, water supply systems, climate change impacts, or bottled water production. These studies have made important contributions to understanding the country's water resources and have provided valuable scientific and technical information for sectoral planning and resource management.

The findings of the present study are generally consistent with previous research regarding the strategic importance of groundwater resources, the increasing influence of climate change, and the growing economic significance of bottled water production. However, unlike earlier studies, which have largely examined these issues independently, the present research integrates them within a single strategic management perspective.

The principal distinction of the proposed Strategic Drinking Water Resource Management Framework (SDWRMF) lies in its ability to simultaneously consider resource availability, groundwater sustainability, climate-related risks, economic utilization, environmental protection, and institutional governance within a unified decision-support framework. This integrated approach provides a broader basis for strategic planning and policy development than conventional resource assessment methodologies.

Furthermore, although the framework was developed using Armenia as a case study, its conceptual structure is sufficiently flexible to be adapted for application in other countries

facing similar challenges associated with climate change, increasing groundwater demand, and the need to balance economic development with long-term drinking water security.

Practical Implications of the Strategic Drinking Water Resource Management Framework (SDWRMF)

The proposed Strategic Drinking Water Resource Management Framework (SDWRMF) has important practical implications for the sustainable management of drinking water resources in Armenia. By integrating hydrological, climatic, environmental, economic, and institutional information into a unified decision-support framework, SDWRMF provides a systematic basis for strategic planning and evidence-based policy development.

The framework can support governmental institutions in evaluating alternative management scenarios, identifying emerging risks, prioritizing investments, and developing adaptive measures aimed at protecting strategic drinking water resources. It also facilitates coordination among institutions responsible for water management, environmental protection, climate adaptation, and economic development, thereby improving the overall effectiveness of water governance.

From an operational perspective, SDWRMF may be applied as a planning and assessment tool for groundwater monitoring programs, abstraction licensing, climate adaptation strategies, and long-term water resource planning. Its flexible conceptual structure allows periodic updating as new scientific information, monitoring data, and policy priorities become available, ensuring that management decisions remain responsive to changing environmental and socio-economic conditions.

The practical implementation of SDWRMF therefore represents not only a scientific contribution but also a potential management instrument for strengthening national drinking water security and supporting sustainable development under increasing climatic uncertainty.

Study Limitations and Future Research

Although the proposed Strategic Drinking Water Resource Management Framework (SDWRMF) provides an integrated approach to strategic drinking water resource management, several limitations should be acknowledged. First, the framework was developed using Armenia as the primary case study, and its application in other geographical and institutional settings will require adaptation to local hydrological, climatic, and governance conditions. Second, the present study is based primarily on officially available statistical, hydrological, and environmental data, which may be refined as new monitoring results and updated national databases become available.

Future research should focus on the practical implementation and validation of SDWRMF through detailed regional case studies, quantitative performance indicators, and scenario-based modelling under different climate and socio-economic development pathways. Additional research may also investigate the integration of remote sensing, geographic information systems, artificial intelligence, and real-time monitoring technologies into the framework to further improve decision support and adaptive water resource management.

Despite these limitations, the proposed framework establishes a comprehensive scientific foundation for strategic drinking water resource management and provides a flexible basis for future methodological development and international application.

Conclusions

1. The present study confirms that Armenia possesses substantial strategic drinking water resources, with groundwater constituting the principal source of the country's centralized drinking water supply. The current resource base remains sufficient to support both domestic water demand and the continued development of the bottled water industry.
2. Climate change represents one of the most significant long-term challenges for the sustainable management of Armenia's drinking water resources. Persistent warming, increasing climatic variability, and projected reductions in groundwater recharge highlight the necessity of integrating climate adaptation into strategic water resource management.
3. The analysis demonstrates that bottled drinking and natural mineral water production currently utilizes only a negligible proportion of the officially approved exploitable groundwater reserves. At present, the principal anthropogenic pressures on groundwater resources originate primarily from aquaculture and agricultural irrigation rather than from the bottled water industry.
4. The findings indicate that the long-term sustainability of strategic drinking water resources should be evaluated through an integrated perspective that simultaneously considers hydrological, climatic, environmental, economic, and institutional factors instead of relying solely on resource availability.
5. The Strategic Drinking Water Resource Management Framework (SDWRMF) proposed in this study provides an integrated decision-support framework capable of balancing drinking water resource conservation, sustainable groundwater utilization, economic development, and long-term national water security under changing climatic conditions.
6. The proposed framework offers practical opportunities for improving strategic planning, adaptive management, institutional coordination, and evidence-based policy development related to drinking water resource management in Armenia.
7. Although developed using Armenia as a case study, the conceptual structure of SDWRMF may also be adapted for application in other countries facing similar challenges associated with climate change, increasing groundwater demand, and the long-term protection of strategic drinking water resources.

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STRATEGIC MANAGEMENT OF DRINKING WATER RESOURCES IN ARMENIA: BALANCING CLIMATE CHANGE, BOTTLED WATER PRODUCTION, AND LONG-TERM WATER SECURITY

ՀԱՅԱՍՏԱՆԻ ԽՄԵԼՈՒ ՋՐԱՅԻՆ ՌԵՍՈՒՐՍՆԵՐԻ ՌԱԶՄԱՎԱՐԱԿԱՆ ԿԱՌԱՎԱՐՈՒՄԸ. ՀԱՎԱՍԱՐԱԿՇՌԵԼՈՎ ԿԼԻՄԱՅԱԿԱՆ ՓՈՓՈԽՈՒԹՅՈՒՆՆԵՐԸ, ՇՇԱԼԳՎԱԾ ՋՐԻ ԱՐՏԱԴՐՈՒԹՅՈՒՆԸ և ԵՐԿԱՐԱԺԱՄԿԵՏ ՋՐԱՅԻՆ ԱՆՎՏԱՆԳՈՒԹՅՈՒՆԸ

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Հայաստանը հարուստ է բարձրորակ խմելու ջրային ռեսուրսներով, ներառյալ ստորերկրյա ջրերը, աղբյուրները և հանքային ջրերը, որոնք հանդիսանում են երկրի բնապահպանական, տնտեսական և ռազմավարական կարևորագույն բնական պաշարներից մեկը: Միաժամանակ շշալցված ջրի արտադրության աճը, կլիմայական փոփոխությունները, ջրի պահանջարկի ավելացումը և երկարաժամկետ ջրային անվտանգության ապահովման անհրաժեշտությունը ձևավորում են նոր մարտահրավերներ այդ ռեսուրսների կայուն կառավարման համար: Չնայած Հայաստանը համարվում է համեմատաբար ջրառատ երկիր, խմելու ջրային ռեսուրսների երկարաժամկետ ապահովվածությունը չի կարող գնահատվել միայն դրանց առկա քանակական պաշարների հիման վրա: Ռազմավարական կառավարումը պահանջում է կլիմայական, բնապահպանական, տնտեսական և ինստիտուցիոնալ գործոնների համակցված գնահատում, որոնք ազդում են ինչպես ջրային ռեսուրսների հասանելիության, այնպես էլ դրանց կայունության վրա:

Սույն հետազոտությունը ներկայացնում է Հայաստանի խմելու ջրային ռեսուրսների համալիր գնահատում՝ վերլուծելով կլիմայական փոփոխությունների, շշալցված ջրի արտադրության և երկարաժամկետ ջրային անվտանգության միջև առկա փոխազդեցությունները: Վերլուծությունը հիմնված է պաշտոնական վիճակագրական տվյալների, հիդրոլոգիական տեղեկատվության, կլիմայական ցուցանիշների և ջրային ռեսուրսների կառավարման ու շշալցված ջրի արտադրության ոլորտը կարգավորող փաստաթղթերի ուսումնասիրության վրա: Հոդվածում գնահատվում են ջրառի, շշալցված ջրի արտադրության, ջրային ռեսուրսների օգտագործման դինամիկան և կլիմայական փոփոխությունների հնարավոր ազդեցությունները խմելու ջրի պաշարների վրա:

Բացահայտված հիմնախնդիրների հիման վրա առաջարկվում է խմելու ջրային ռեսուրսների ռազմավարական կառավարման ինտեգրված շրջանակ, որի նպատակն է ապահովել տնտեսական զարգացման և ջրային ռեսուրսների երկարաժամկետ պահպանության միջև հավասարակշռություն: Առաջարկվող մոտեցումը հիմնված է ստորերկրյա ջրերի կայուն կառավարման, կլիմայական փոփոխություններին հարմարվողականության, խմելու ջրի աղբյուրների պահպանության, մոնիթորինգի համակարգերի կատարելագործման, ջրային ռեսուրսների արդյունավետ բաշխման և գիտականորեն հիմնավորված որոշումների ընդունման սկզբունքների վրա: Հետազոտության արդյունքները կարող են նպաստել Հայաստանի ջրային

քաղաքականության կատարելագործմանը և երկարաժամկետ ջրային անվտանգության ապահովմանն ուղղված ռազմավարությունների մշակմանը:

Բանալի բառեր՝ խմելու ջրային ռեսուրսներ, ռազմավարական կառավարում, շշալցված ջրի արտադրություն, կլիմայական փոփոխություններ, ստորերկրյա ջրեր, ջրային անվտանգություն, կայուն զարգացում, Հայաստան:

СТРАТЕГИЧЕСКОЕ УПРАВЛЕНИЕ РЕСУРСАМИ ПИТЬЕВОЙ ВОДЫ АРМЕНИИ: БАЛАНС МЕЖДУ ИЗМЕНЕНИЕМ КЛИМАТА, ПРОИЗВОДСТВОМ БУТИЛИРОВАННОЙ ВОДЫ И ДОЛГОСРОЧНОЙ ВОДНОЙ БЕЗОПАСНОСТЬЮ

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Армения располагает значительными запасами высококачественных ресурсов питьевой воды, включая подземные воды, родники и минеральные воды, которые являются одним из важнейших природных, экологических, экономических и стратегических ресурсов страны. Вместе с тем рост производства бутилированной воды, изменение климата, увеличение потребности в водных ресурсах и необходимость обеспечения долгосрочной водной безопасности формируют новые вызовы для устойчивого управления этими ресурсами. Несмотря на то что Армения традиционно считается страной, богатой водными ресурсами, долгосрочная обеспеченность питьевой водой не может оцениваться исключительно по объему существующих запасов. Стратегическое управление требует комплексного учета климатических, экологических, экономических и институциональных факторов, влияющих как на доступность, так и на устойчивость водных ресурсов.

В настоящем исследовании представлена комплексная оценка ресурсов питьевой воды Армении с анализом взаимосвязей между изменением климата, производством бутилированной воды и долгосрочной водной безопасностью. Исследование основано на официальных статистических данных, гидрологической информации, климатических показателях и нормативно-институциональных материалах, характеризующих управление водными ресурсами и развитие производства бутилированной воды. Выполнен анализ динамики водозабора, производства бутилированной воды, использования водных ресурсов, а также потенциального воздействия климатических изменений на ресурсы питьевой воды.

На основе выявленных проблем предложена интегрированная система стратегического управления ресурсами питьевой воды, направленная на обеспечение баланса между экономическим развитием и долгосрочным сохранением водных ресурсов. Предлагаемый подход основан на принципах устойчивого управления подземными водами, адаптации к изменению климата, охраны источников питьевой

воды, совершенствования систем мониторинга, эффективного распределения водных ресурсов и принятия научно обоснованных управленческих решений. Полученные результаты могут способствовать совершенствованию водной политики Армении и разработке долгосрочных стратегий обеспечения водной безопасности.

***Ключевые слова*:** ресурсы питьевой воды, стратегическое управление, производство бутилированной воды, изменение климата, подземные воды, водная безопасность, устойчивое управление, Армения.

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