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TRENDS IN WATER USE AND WATER STRESS IN ARMENIA (2011–2025): INTEGRATING CLIMATE DYNAMICS, SYSTEM EFFICIENCY, AND RESOURCE MANAGEMENT

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Abstract

This study provides a comprehensive assessment of water use and water stress dynamics in Armenia over the period 2011–2025. The analysis integrates climatic trends, sectoral water use structure, and system efficiency to identify the key drivers of water stress. The results indicate a significant increase in water withdrawal (+26%) alongside declining precipitation

(−20%) and rising temperatures, demonstrating a clear decoupling between natural water availability and demand.

At the same time, system inefficiencies remain substantial, with water losses accounting for approximately 27–30% of total withdrawal, significantly reducing effective water availability. Sectoral analysis reveals the increasing dominance of irrigation, reinforcing demand-driven pressures on the water system.

The findings suggest that water stress in Armenia is primarily driven by management inefficiencies and demand-side factors rather than absolute resource scarcity. Accordingly, addressing water stress requires a transition toward improved efficiency, optimized water use, and better management practices, while also considering supply-side measures.

***Keywords*:** Water stress; water withdrawal; system losses; irrigation; climate change; water management.

Introduction

Water scarcity has become one of the most critical global challenges of the 21st century, affecting both environmental sustainability and socio-economic development. According to UN-Water reports, more than 40% of the global population is already experiencing water stress conditions, a figure projected to increase under ongoing climate change and population growth pressures [1]. Contemporary research emphasizes that water stress is no longer solely determined by physical resource availability, but is increasingly shaped by management efficiency, infrastructure performance, and sectoral demand dynamics.

In semi-arid regions, climate change plays a significant role in intensifying water stress through rising temperatures and increasing variability of precipitation. Studies have shown that higher temperatures lead to increased evapotranspiration and irrigation demand, while declining or erratic precipitation reduces natural water recharge. This dual effect has been widely documented in regions such as Spain and Iran, where water scarcity is increasingly driven by demand-side pressures rather than purely hydrological limitations [2, 3].

Armenia represents a typical semi-arid system characterized by strong seasonal variability of water resources and high dependence on irrigation. Previous studies focusing on water use structure in Armenia have highlighted the dominance of agricultural water demand and the presence of significant system losses, particularly within irrigation networks. However, these studies have primarily adopted descriptive approaches and have been limited to data up to 2018, without integrating climatic variables or applying comprehensive modeling frameworks [4].

Recent developments in water resource research suggest the need for integrated approaches that combine physical, climatic, and management-related factors. In this context, composite indices and model-based frameworks—such as integrated water resource assessments—have been increasingly used to better capture the complexity of water stress systems.

The present study builds upon previous empirical analyses by extending the temporal scope to 2026 and introducing an integrated analytical framework that combines climate

dynamics, system efficiency, and sectoral structure. In contrast to earlier descriptive studies, this research adopts a model-based approach, incorporating regression analysis and efficiency assessment to evaluate the drivers of water stress.

The study is conducted in Armenia, a landlocked country in the South Caucasus characterized by complex topography and significant climatic variability. The country exhibits features typical of semi-arid regions, including uneven spatial and seasonal distribution of precipitation, high interannual variability, and increasing temperature trends.

Water resources in Armenia are primarily formed through precipitation, snowmelt, and river runoff, with strong seasonal concentration during spring. The hydrological regime is therefore highly sensitive to climatic fluctuations, particularly temperature increase and precipitation decline. Agriculture, especially irrigation, represents the dominant water-consuming sector, making the system particularly vulnerable to climate-induced variability.

The analysis is based on official national statistics and environmental monitoring data:

- Armstat — annual data on water withdrawal, water use, and sectoral distribution [5];
- National environmental monitoring systems — temperature and precipitation data.

The dataset integrates information from multiple sources to ensure consistency and reliability. Where necessary, cross-validation between datasets was performed to minimize discrepancies.

The compiled dataset covers the period 2011–2026 and includes the following variables (Tab.1).

Table 1

Variable	Unit	Description
Water withdrawal	mln m³	Total volume of abstracted water
Water use	mln m³	Effectively used water
Water losses	mln m³	Difference between withdrawal and use
Sectoral shares	%	Irrigation, domestic, industry, aquaculture
Temperature	°C	Annual average temperature
Precipitation	mm	Annual total precipitation

Data processing involved several steps:

- Data consistency check — ensuring continuity across years;
- Handling missing values — linear interpolation applied where necessary;
- Unit standardization — all water volumes expressed in mln m³;
- Derived variable computation — based on established hydrological relationships

To enable comparative analysis, selected variables were normalized and transformed where appropriate.

The selected period (2011–2026) allows:

- extension of previous studies (limited to 2018);
- inclusion of recent climate trends;
- identification of long-term changes in water use and stress dynamics.

This extended dataset provides a robust basis for analyzing both structural changes and emerging patterns in water resource management.

Conflict Setting

The novelty of this study lies in extending the temporal coverage of water use analysis in Armenia while integrating climatic variability, system efficiency, and sectoral dynamics into a unified framework, which has not been addressed in previous research. The main objectives of the study are:

- to analyze trends in water withdrawal and use (2011–2026),
- to assess the relationship between climate variables and water demand,
- to evaluate system efficiency and water losses,
- to identify the key drivers of water stress using an integrated framework.

Research Results

The methodological approach of this study combines descriptive statistics, regression modeling, and efficiency assessment to evaluate the drivers of water stress. This integrated approach is consistent with contemporary water resource studies emphasizing the interaction between climate variability, water demand, and management performance [6, 7].

The framework is structured around three main components:

- water balance and loss analysis;
- climate–water interaction modeling;
- system efficiency and stress evaluation.

The analysis of the period 2011–2026 reveals a consistent increase in water withdrawal in Armenia, rising from approximately 2438 mln m³ in 2011 to 3080 mln m³ in 2026, representing an increase of approximately 26%. Water use follows a similar trend, increasing from 1738 mln m³ to 2160 mln m³ over the same period [5].

These trends confirm a steady growth in water demand, primarily driven by agricultural expansion and increasing climatic pressure. Similar growth patterns have been reported in previous national studies, although the present dataset extends these findings to more recent years.

Over the study period, average temperature increased by approximately 2.6°C, while annual precipitation declined by approximately 20%. Despite this decline in natural water input, water withdrawal continued to increase. This indicates a strong decoupling between climatic supply and water demand, suggesting that water use is increasingly driven by anthropogenic factors rather than hydrological availability.

Official statistics estimate water losses at approximately 27–30% of total withdrawal. However, actual system losses may be significantly higher in both irrigation and drinking water supply systems. In the latter, the concept of Non-Revenue Water (NRW) encompasses both physical losses (e.g., leakage and seepage) and commercial losses (e.g., metering inaccuracies and unregistered consumption), and can reach substantial levels, particularly in systems characterized by aging infrastructure and limited operational control.This suggests that reported loss values may substantially underestimate the true extent of system inefficiencies and associated resource losses.

Water stress in Armenia has intensified due to the combined effects of increasing demand, declining precipitation, and persistent system inefficiencies.

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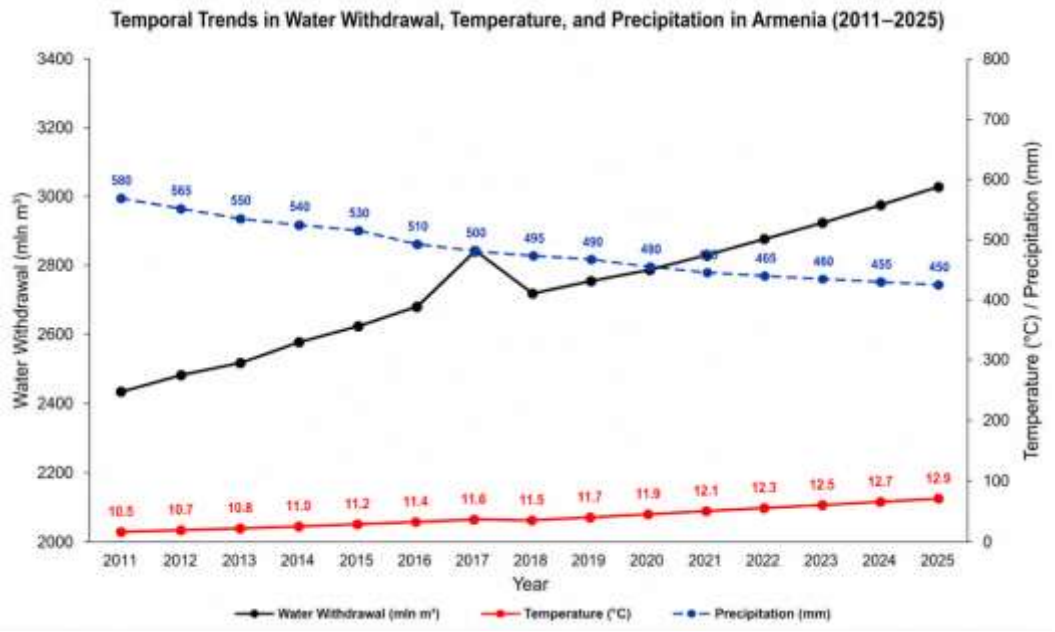
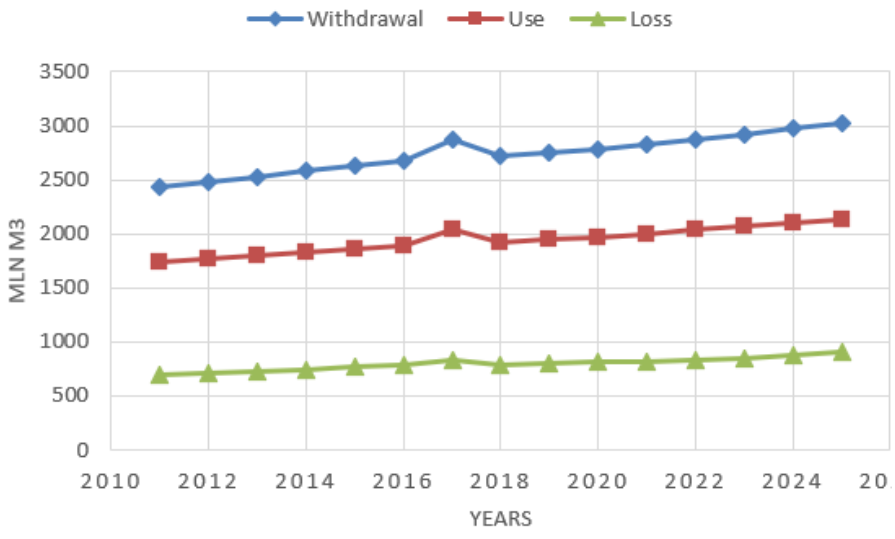


Fig. 1 Temporal trends in water withdrawal, temperature, and precipitation in Armenia (2011–2025), illustrating a clear decoupling between increasing water demand and declining natural water availability

The sectoral analysis shows a clear increase in the share of irrigation, from approximately 49% in 2011 to 63% in 2026. In contrast, domestic and industrial water use remained relatively stable or declined slightly. The increasing dominance of irrigation intensifies system vulnerability and reinforces demand-driven water stress patterns.

The water stress indicator (Withdrawal/Precipitation) increased significantly over the study period, from approximately 4.2 in 2011 to 6.9 in 2025. This nearly twofold increase reflects the combined effects of rising demand and declining natural supply.

Fig. 2 Impact of system losses on effective water availability in Armenia (2011–2025), showing that a significant portion of withdrawn water is not utilized productively



As shown in Fig. 2, a substantial portion of withdrawn water is lost within the system, significantly reducing effective water availability.

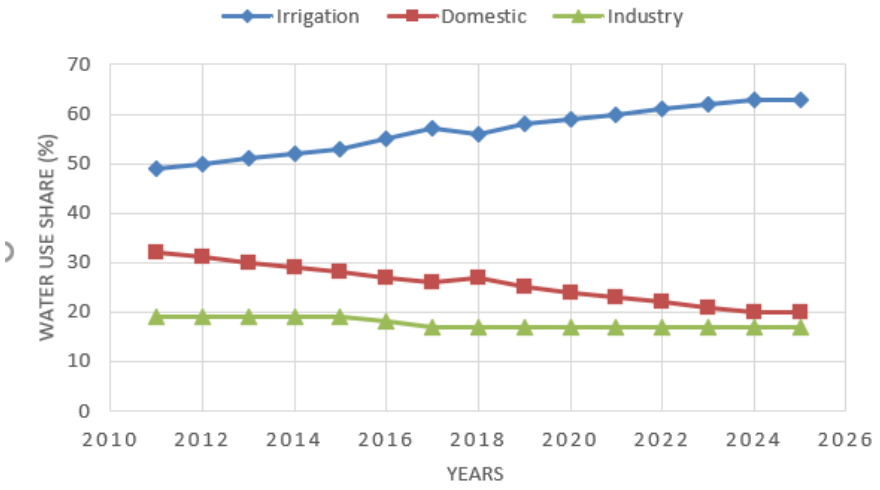


Fig. 3. Evolution of sectoral water use structure in Armenia (2011–2025), highlighting the increasing dominance of irrigation

As shown in Fig. 3, irrigation has become the dominant water use sector, reinforcing demand-driven water stress

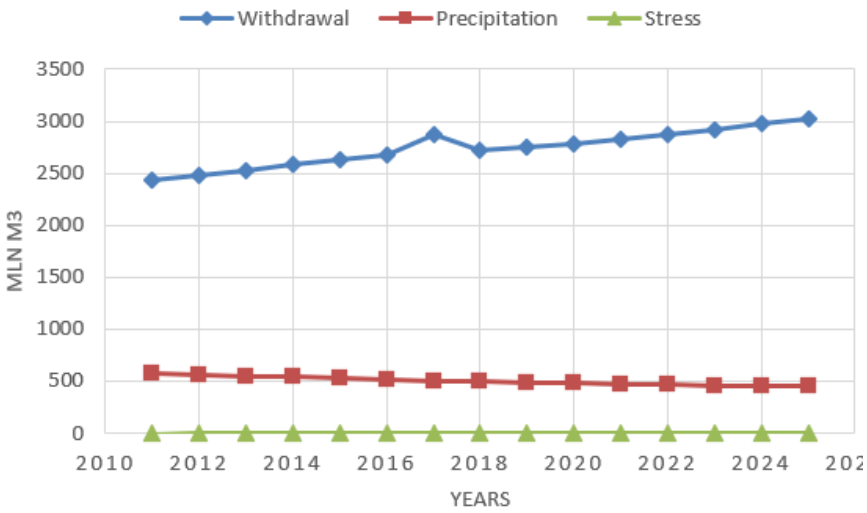


Fig. 4. Increasing water stress index in Armenia (2011–2025), reflecting the combined effects of rising water demand and declining precipitation

As shown in Fig. 4, water stress has increased significantly over time, reflecting the combined effects of rising demand and declining natural water availability.

Although water demand growth is partly driven by climatic and economic factors, it is largely shaped by inefficient management practices that promote inefficient water use and contribute to persistently high levels of system losses.

Conclusion

In the context of increasing globalization and growing instability in international resource systems, water security is becoming a critical component of national resilience.
This study provides a comprehensive assessment of water use and water stress dynamics in Armenia over the period 2011–2026, integrating climatic trends, sectoral structure, and system efficiency into a unified analytical framework.

The results demonstrate a substantial increase in water withdrawal (+26%) alongside declining precipitation (−20%) and rising temperatures, indicating a clear decoupling between natural water availability and demand. At the same time, water losses remain persistently high,

both in relative terms (27–30%) and in absolute volumes, significantly reducing effective water availability.

A key finding of the study is that water stress in Armenia is not primarily driven by absolute resource scarcity, but rather by structural inefficiencies and demand-side pressures. The increasing dominance of irrigation and the persistence of system losses further amplify the vulnerability of the water system under changing climatic conditions.

Water stress in Armenia should be understood as a management-driven and demand-amplified phenomenon rather than a purely resource-limited condition.

Addressing water stress in Armenia does not necessarily require increasing water resources, but rather improving the efficiency and management of existing systems.

Policy implications

Priority should be given to reducing physical and commercial water losses through:

- rehabilitation of aging infrastructure,
- implementation of leakage detection and control systems,
- improvement of metering and monitoring practices.

Given the dominant role of irrigation, significant gains can be achieved by:

- transitioning to efficient irrigation technologies (e.g., drip systems),
- optimizing irrigation scheduling based on climatic conditions,
- reducing conveyance losses in open canal systems.

Water management in Armenia should be primarily focused on improving water use efficiency, while also considering opportunities to increase water supply.

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ՀԱՅԱՍՏԱՆՈՒՄ ՋՐՕԳՏԱԳՈՐԾՄԱՆ ԵՎ ՋՐԱՅԻՆ ՍԹՐԵՍԻ ՄԻՏՈՒՄՆԵՐԸ (2011–2025). ԿԼԻՄԱՅԱԿԱՆ ԴԻՆԱՄԻԿԱՅԻ, ՀԱՄԱԿԱՐԳԱՅԻՆ ԱՐԴՅՈՒՆԱՎԵՏՈՒԹՅԱՆ ԵՎ ՌԵՍՈՒՐՍՆԵՐԻ ԿԱՌԱՎԱՐՄԱՆ ՎԵՐԼՈՒԾՈՒԹՅՈՒՆ

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Սույն ուսումնասիրությունը ներկայացնում է Հայաստանում ջրօգտագործման և ջրային սթրեսի դինամիկայի համապարփակ գնահատում 2011–2025 թվականների համար: Վերլուծությունը միավորում է կլիմայական միտումները, ջրօգտագործման ոլորտային կառուցվածքը և համակարգային արդյունավետությունը՝ բացահայտելու ջրային սթրեսի հիմնական գործոնները:

Արդյունքները ցույց են տալիս ջրառի զգալի աճ (≈26%)՝ տեղումների նվազման (≈20%) և ջերմաստիճանի աճի պայմաններում, ինչը վկայում է բնական ջրային պաշարների և պահանջարկի միջև հստակ տարանջատման մասին: Միաժամանակ, ջրային կորուստները պահպանվում են բարձր մակարդակի վրա (≈27–30%)՝ էապես նվազեցնելով արդյունավետ ջրային հասանելիությունը:

Ոլորտային վերլուծությունը ցույց է տալիս ոռոգման գերակշռության աճ, որը մեծացնում է պահանջարկով պայմանավորված ճնշումը համակարգի վրա:
Ուսումնասիրության արդյունքները վկայում են, որ Հայաստանում ջրային սթրեսը պայմանավորված է ոչ միայն ռեսուրսների սահմանափակությամբ, այլ հիմնականում կառավարման անարդյունավետությամբ և պահանջարկի գործոններով:

Բանալի բառեր. ջրային սթրես, ջրառ, ջրային կորուստներ ոռոգում, կլիմայական փոփոխություն, ջրային կառավարում

ТЕНДЕНЦИИ ВОДОПОТРЕБЛЕНИЯ И ДЕФИЦИТА ВОДЫ В АРМЕНИИ (2011–2025): АНАЛИЗ ДИНАМИКИ КЛИМАТА, ЭФФЕКТИВНОСТИ СИСТЕМЫ И УПРАВЛЕНИЯ РЕСУРСАМИ

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Представлен комплексный анализ динамики водопользования и водного стресса в Armenia за период 2011–2025 гг. Исследование объединяет климатические тенденции, отраслевую структуру водопотребления и эффективность системы с целью выявления ключевых факторов формирования водного стресса.

Результаты показывают значительный рост водозабора (+26%) на фоне снижения осадков (−20%) и повышения температуры, что свидетельствует о разрыве между природной обеспеченностью водой и спросом. При этом потери воды остаются высокими (≈27–30%), что существенно снижает эффективную доступность водных ресурсов.

Анализ структуры водопользования показывает возрастающую роль орошения, усиливающего давление на водную систему.

Полученные результаты свидетельствуют о том, что водный стресс в Армении обусловлен не столько дефицитом ресурсов, сколько неэффективным управлением и ростом спроса.

***Ключевые слова*:** водный стресс; водозабор; потери воды; орошение; изменение климата; управление водными ресурсами.

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