

Water Conservation Methods: A Comprehensive Review of Residential, Agricultural, and Industrial Applications

Metoder för vattenbesparing: En utförlig översikt över tillämpningar inom hushåll, jordbruk och industri



Mohammad AlJaradin¹, Kenneth M Persson²,

¹Hamdan Bin Mohammed Smart University, Dubai, UAE.

²Water Resources Engineering, Lund University, Sweden

Abstract

Water scarcity has emerged as one of the most pressing global challenges of the 21st century, affecting approximately 2 billion people worldwide. This comprehensive review examines water conservation methods across three critical sectors: residential, agricultural, and industrial applications. Through analysis of current technologies, implementation strategies, and case studies, this paper identifies key water-saving techniques that can reduce consumption by 20–40% in residential settings, 30–50% in agricultural operations, and up to 60% in industrial processes. The review highlights the economic and environmental benefits of water conservation while addressing implementation challenges including initial costs, technological barriers, and behavioral resistance. Findings suggest that integrated approaches combining technological solutions with policy interventions and public awareness campaigns yield the most significant water savings. A theoretical yet possible development leading to 20% water conservation measures in agriculture, 30% in the domestic sector and 40% in industry would free around $1 \times 10^{12} \text{ m}^3$ (one trillion cubic metres) of freshwater for nature and ecosystem services outside the anthropogenic sector, resulting in lessening of the water stress to the situation as it was in 1980. The paper concludes with recommendations for stakeholders to accelerate adoption of water conservation methods through incentive programs, regulatory frameworks, and educational initiatives.

Keywords: Water Conservation, water efficiency, water reuse, Residential water saving, water scarcity.

Sammanfattning

Vattenbrist har framträtt som en av 2000-talets mest angelägna globala utmaningar och påverkar cirka 2 miljarder människor världen över. Denna omfattande översikt går igenom metoder för vattenbesparing inom tre dominerande sektorer: hushåll, jordbruk och industri. Genom analys av nuvarande teknologier, implementeringsstrategier och fallstudier identifierar denna studie viktiga vattenbesparande tekniker som kan minska vattenförbrukningen med 20–40 % i hushåll, 30–50 % inom jordbruket och upp till 60 % i industriella processer.

Översikten belyser de ekonomiska och miljömässiga fördelarna med vattenbesparing samtidigt som den behandlar utmaningar vid implementering, inklusive initiala kostnader, teknologiska hinder och beteendemässigt motstånd. Resultaten tyder på att integrerade tillvägagångssätt som kombinerar tekniska lösningar med politiska åtgärder och informationskampanjer ger de mest betydande vattenbesparingarna. En teoretisk men möjlig utveckling som leder till 20 % vattenbesparing inom jordbruket, 30 % inom hushållssektorn och 40 % inom industrin skulle frigöra omkring $1 \times 10^{12} \text{ m}^3$ (en biljon kubikmeter) sötvatten för naturen och ekosystemtjänster utanför den antropogena sektorn, vilket skulle minska vattenstress till en nivå motsvarande situationen år 1980. Artikeln avslutas med rekommendationer till berörda aktörer om att påskynda införandet av vattenbesparingsmetoder genom incitamentsprogram, regulatoriska ramverk och utbildningsinsatser.

Introduction

The global water crisis represents one of the most significant challenges facing humanity in the 21st century. According to the United Nations World Water Development Report 2023, approximately 2 billion people lack access to safely managed drinking water at home, while 3.6 billion people lack access to safely managed sanitation (UN Water, 2023). The situation is expected to deteriorate further due to population growth, urbanization, climate change, and increasing industrial demands. By 2050, global water demand is projected to increase by 20-30%, with some regions experiencing water stress levels exceeding 40% (World Resources Institute, 2023).

Water scarcity affects every continent and is not merely an issue for developing nations. California's ongoing drought challenges, Cape Town's near "Day Zero" water crisis in 2018, and Australia's millennium drought demonstrate that water security concerns transcend geographical and economic boundaries. The economic impact of water scarcity is substantial, with the World Bank estimating that water-related losses could reach 6% of GDP in some regions by 2050 if current trends continue (World Bank, 2022).

Water conservation has emerged as a critical strategy to address these challenges, offering a cost-effective alternative to developing new water sources. Conservation methods can be broadly categorized into technological solutions, behavioral modifications, and policy interventions. Technological approaches include efficiency improvements in fixtures, irrigation systems, and industrial processes. Behavioral modifications focus on changing consumption

patterns through education and incentives. Policy interventions encompass regulatory frameworks, pricing mechanisms, and conservation mandates.

The effectiveness of water conservation varies significantly across sectors. According to the latest data from FAO AQUASTAT 2025 Water Data Snapshot, which compiles the most recent global figures through the 2022 collection cycle, agriculture accounts for approximately 71-72% of global freshwater withdrawals (the total volume of water extracted from surface water, groundwater, or desalinated water), industry accounts for approximately 15-16%, and the domestic/municipal sector accounts for approximately 12-13% (FAO, 2025). These figures represent a notable update from earlier estimates commonly cited from around 2015, which indicated a distribution of approximately 70% agriculture, 18% industry, and 12% residential. Recent data from the UN-Water SDG 6.4.1 indicator shows that global water use efficiency has improved by approximately 23% since 2015, rising from 17.47 USD/m³ to 21.50 USD/m³ in 2022 (UN-Water, 2024). Agricultural water use efficiency improved by 38% over the same period, although it remains the least efficient sector at 0.69 USD/m³. Notably, while total global freshwater withdrawals have remained essentially flat since 2015 (approximately 4,000 km³ per year), per-capita renewable freshwater availability has declined by 7%, from 5,719 m³ per person in 2015 to 5,326 m³ per person in 2022, primarily due to population growth (FAO, 2025). Each sector presents unique opportunities and challenges for water conservation. Residential conservation often focuses on fixture efficiency and

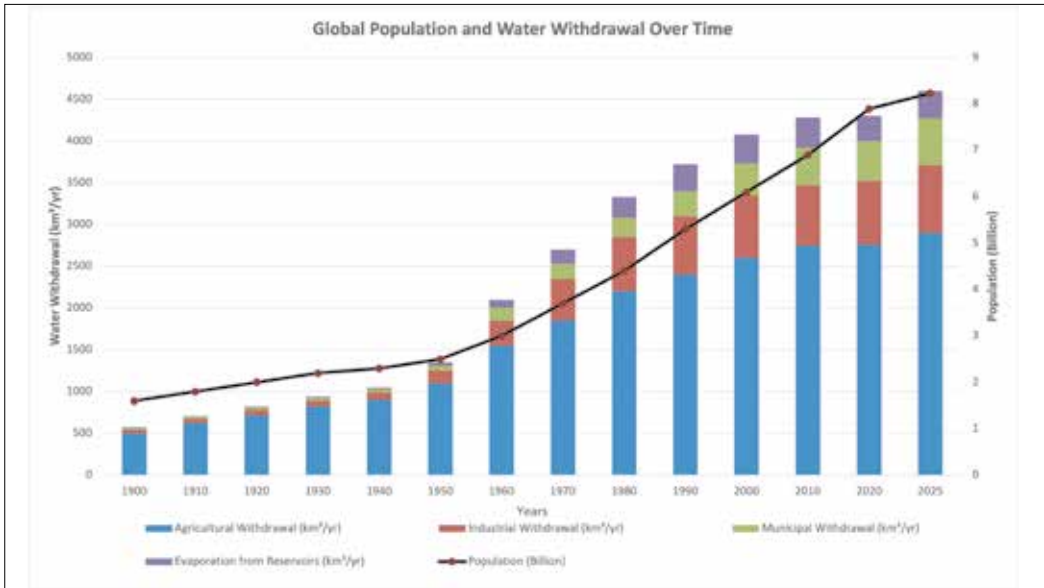


Figure 1. Global accumulated freshwater consumption (m³) and world population growth. Data sources: FAO AQUASTAT [2025]; UN Population Division.

behavioral changes, agricultural conservation emphasizes irrigation efficiency and crop selection, while industrial conservation targets process optimization and water recycling. These trends underscore both the urgency and the opportunity for enhanced water conservation efforts worldwide.

A strategic approach to increase water efficiency would decrease freshwater consumption with significant importance for water safety locally as well as globally. In figure 1 data is presented for the accumulated water consumption globally since 1900. The figure also presents world population showing how economic growth and population increase both lead to an increase in freshwater consumption. Since the amount of freshwater available for use depends on the hydrology in an area, only increased precipitation can increase the total amount of freshwater, if desalination is not considered, as has been the case for water scarce areas like the Gulf countries. An increase in measures for water saving, reuse and recycling can contribute substantially to lowering the freshwater demands. A logical conclusion is that the present linear correlation between population and freshwater needs need to be changed towards higher water efficiency. This paper aims to explore pathways for achieving a signifi-

cant reduction in global water use by identifying how a break in the water demand curve can be realized through improved waster-use efficiency. It examines the potential contributions of technological innovations, policy interventions, and behavioral changes across residential, agricultural, and industrial sectors, and evaluates the broader societal and environmental implications of enhanced water efficiency, particularly in reducing water stress and restoring freshwater availability for ecosystems.

Residential Water Saving Methods

Residential water conservation encompasses a wide range of technologies and practices that can significantly reduce household water consumption. The average American household uses approximately 1 100 liters of water daily, with indoor use accounting for 70% and outdoor use representing 30% (EPA, 2023). Toilets consume the largest portion of indoor water use at 24%, followed by washing machines (20%), showers (17%), and faucets (12%).

Low-flow fixtures represent one of the most effective residential conservation measures. Modern low-flow toilets use 4,8 liters per flush compared to older models that consume 12-25 liters per flush,

achieving water savings of 60-80% (EPA, 2023). High-efficiency washing machines reduce water consumption by 40-50% compared to conventional models, using 50-90 liters per load versus 150 liters for standard machines. Low-flow showerheads and faucet aerators can reduce water flow by 30-50% while maintaining user satisfaction through improved design and pressure optimization.

Rainwater harvesting systems offer significant potential for outdoor water use reduction. A typical residential rainwater harvesting system can collect 1 l/m² of roof area per mm of rainfall (American Rainwater Catchment Systems Association, 2023). For a 180 m² home in an area receiving 700 mm of annual rainfall, this translates to approximately 126 000 liters of harvestable water annually. When properly designed and maintained, rainwater harvesting systems can meet 50-100% of outdoor irrigation needs while reducing stormwater runoff and erosion.

Greywater systems represent an advanced conservation strategy that reuses water from sinks, showers, and washing machines for landscape irrigation. Simple laundry-to-landscape systems can divert 50-150 liters per load directly to irrigation zones, while complex whole-house systems can treat and redistribute all greywater sources. Studies indicate that greywater systems can reduce overall household water consumption by 30-50% when properly implemented (Greywater Action, 2023). A study of 66 households in California with 83 residential greywater irrigation systems found that properly designed and maintained systems provided significant outdoor water savings with minimal health risks when basic precautions were followed (Greywater Action, 2014). However, implementation requires careful attention to water quality, soil conditions, and local regulations.

Smart irrigation technologies optimize outdoor water use through weather-based controllers, soil moisture sensors, and drip irrigation systems. Weather-based irrigation controllers use local meteorological data to adjust watering schedules, reducing outdoor water use by 15-30% compared to conventional timer-based systems (Irrigation Association, 2023). Soil moisture sensors provide real-time feedback on plant water needs, preventing overwatering and reducing consumption by an additional 20-40%.

Drip irrigation systems deliver water directly to plant root zones with 85-95% efficiency compared to 60-75% for conventional sprinkler systems.

Agricultural Water Saving Methods

Agriculture represents the largest consumer of global freshwater resources, utilizing approximately 71-72% of available supplies worldwide (FAO, 2025). With growing populations and changing dietary preferences increasing food demand, improving agricultural water efficiency has become paramount for global water security. Traditional flood irrigation methods achieve only 40-60% efficiency, losing substantial water to evaporation, runoff, and deep percolation. Modern conservation techniques can improve efficiency to 80-95% while maintaining or increasing crop yields.

Drip irrigation stands as one of the most effective agricultural water conservation technologies, delivering water directly to plant root zones through networks of tubes, pipes, and emitters. This method reduces water consumption by 30-50% compared to flood irrigation while often increasing crop yields by 20-90% (International Commission on Irrigation and Drainage, 2023). Israel's widespread adoption of drip irrigation has enabled the country to achieve water self-sufficiency despite arid conditions, demonstrating the technology's potential. Micro-sprinkler systems offer similar benefits for tree crops and larger plants, providing targeted water application with 80-90% efficiency.

Precision agriculture integrates GPS technology, sensors, and data analytics to optimize water application based on field variability and real-time conditions. Variable rate irrigation systems can adjust water application rates within individual fields based on soil type, topography, and crop needs, reducing water use by 15-30% while improving yield uniformity (Precision Agriculture Association, 2023). Satellite imagery and drone technology enable farmers to monitor crop stress and soil moisture across large areas, facilitating timely irrigation decisions and preventing water waste.

Crop selection and breeding programs focus on developing drought-tolerant varieties that maintain productivity under reduced water conditions. Traditional breeding and genetic modification have produced



Agriculture represents the largest consumer of global freshwater resources

ced crops with 20-40% improved water use efficiency compared to conventional varieties (International Rice Research Institute, 2023). Deficit irrigation strategies deliberately apply less water than crop requirements during specific growth stages, reducing total water use by 10-30% with minimal yield impacts when properly managed. Alternative crops such as quinoa, amaranth, and drought-tolerant legumes can replace water-intensive crops in suitable climates.

Soil management practices enhance water retention and reduce irrigation requirements through improved soil structure and organic matter content. Conservation tillage methods, including no-till and reduced-till practices, can increase soil water storage capacity by 10-25% while reducing evaporation losses (Soil Science Society of America, 2023). Cover crops and mulching further reduce evaporation while improving soil health and water infiltration. Organic matter additions through compost and biochar can increase soil water-holding capacity by 20-200% depending on soil type and application rates.

Water recycling and treatment technologies enable agricultural reuse of municipal wastewater, drainage water, and tailwater. Constructed wetlands and advanced treatment systems can produce irrigation-quality water from various sources, expanding available water supplies while reducing environmental impacts. In California, recycled water provi-

des approximately 2700 million cubic meters annually for agricultural use, representing 7% of total agricultural water consumption (California Department of Water Resources, 2023). Drainage water reuse systems capture and treat agricultural runoff, preventing pollution while recovering valuable water resources.

Industrial Water Saving Methods

Industrial water consumption accounts for approximately 15-16% of global freshwater use, with significant variation among industries and geographical regions (United Nations Industrial Development Organization, 2023). Manufacturing processes, cooling systems, and cleaning operations represent the primary industrial water uses. Water-intensive industries including pulp and paper, steel production, chemical manufacturing, and food processing face increasing pressure to reduce consumption due to rising costs, regulatory requirements, and sustainability commitments. Industrial water conservation offers substantial potential for water savings, often achieving 30-60% reductions through comprehensive efficiency programs.

Process optimization represents the most cost-effective approach to industrial water conservation, focusing on eliminating waste and improving operational efficiency. Water audits identify consumption patterns, losses, and conservation opportunities

throughout industrial facilities. Leak detection and repair programs can reduce water losses by 10-20% through systematic identification and correction of distribution system failures (American Water Works Association, 2023). Process modifications such as counter-current flow systems, closed-loop operations, and dry processing alternatives can dramatically reduce water requirements while maintaining product quality and production rates.

Cooling system improvements offer significant water saving potential for thermoelectric power plants, refineries, and manufacturing facilities. Traditional once-through cooling systems consume vast quantities of water, with a typical 500-MW power plant using 900-1800 thousand cubic meters daily (U.S. Geological Survey, 2023). Closed-loop cooling systems reduce water consumption by 95-98% compared to once-through systems, while air-cooled condensers eliminate cooling water requirements entirely.

Advanced cooling tower technologies including drift eliminators, efficient fill materials, and automated chemical treatment systems can reduce cooling water consumption by an additional 20-40%.

Water recycling and reuse systems treat and recover industrial wastewater for subsequent use in manufacturing processes, cooling systems, or cleaning operations. Membrane technologies including reverse osmosis, ultrafiltration, and nanofiltration can produce high-quality recycled water suitable for demanding industrial applications. Biological treatment systems effectively remove organic contaminants from food processing and chemical manufacturing wastewater. Advanced oxidation processes can eliminate persistent organic compounds and enable water reuse in pharmaceutical and electronics manufacturing. Comprehensive water recycling programs can achieve 70-90% water reuse rates while reducing wastewater discharge volumes and treatment costs.

Water treatment and purification technologies enable industries to utilize alternative water sources including brackish groundwater, municipal wastewater, and stormwater. Desalination systems powered by renewable energy provide reliable water supplies for coastal industrial facilities, while advanced treatment technologies can upgrade impaired water sources to industrial quality standards. Zero liquid discharge

systems eliminate industrial wastewater through comprehensive treatment and recovery processes, achieving complete water recycling while producing solid waste for disposal or beneficial use (Water Environment Federation, 2023).

Economic and Environmental Benefits

Water conservation delivers substantial economic benefits across residential, agricultural, and industrial sectors through reduced water costs, deferred infrastructure investments, and improved operational efficiency. Residential water conservation can reduce household water bills by 20-40% through fixture upgrades and behavioral modifications, with typical payback periods of 2-5 years for efficiency investments (EPA, 2023). Agricultural water conservation improves crop yields and quality while reducing irrigation costs, with economic returns of \$2-6 for every dollar invested in efficient irrigation systems (World Bank, 2023). Industrial water conservation reduces operating costs while improving competitiveness and regulatory compliance, often achieving payback periods of 1-3 years for conservation investments.

Deferred infrastructure benefits represent significant economic advantages of water conservation programs. Every litre of water conserved reduces demands on water supply, treatment, and distribution systems, delaying expensive capacity expansions. The Metropolitan Water District of Southern California estimates that conservation programs have deferred \$2.5 billion in infrastructure investments over the past decade (Metropolitan Water District, 2023). Similarly, wastewater reduction through conservation decreases treatment costs and delays expansion requirements, providing additional economic benefits.

Environmental benefits of water conservation include reduced pressure on freshwater ecosystems, decreased energy consumption, and lower greenhouse gas emissions. Water conservation helps maintain environmental flows in rivers and streams, supporting aquatic habitats and biodiversity. Energy savings from reduced water pumping, treatment, and heating can decrease greenhouse gas emissions by 0.3-0.8 grams of CO₂ per liter of water saved (California Energy Commission, 2023). Conservation also reduces wastewater generation, decreasing pollution loads and

treatment energy requirements.

Job creation and economic development opportunities arise from water conservation investments in manufacturing, installation, and maintenance of efficient technologies. The water efficiency industry employs thousands of workers in manufacturing, engineering, installation, and service sectors. Green building programs incorporating water efficiency features attract businesses and residents, stimulating local economic development while reducing environmental impacts.

Challenges and Barriers to Implementation

Despite proven benefits, water conservation faces numerous implementation challenges including economic barriers, technical limitations, institutional constraints, and behavioral resistance. Initial capital costs represent the primary economic barrier, particularly for advanced technologies such as rainwater harvesting systems, greywater treatment, and industrial recycling equipment. Residential conservation measures may require upfront investments of \$500-5,000 per household, while industrial water recycling systems can cost millions of dollars (Water Research Foundation, 2023).

Technical challenges include system complexity, maintenance requirements, and performance reliability concerns. Greywater systems require careful design and ongoing maintenance to prevent health risks and system failures. Industrial water recycling systems must meet strict quality standards while operating reliably under varying conditions. Technology integration challenges arise when retrofitting conservation equipment into existing facilities, particularly in older buildings and industrial plants with outdated infrastructure.

Institutional barriers include regulatory restrictions, utility rate structures, and lack of supporting policies. Many jurisdictions prohibit greywater systems or impose complex permitting requirements that discourage adoption. Utility rate structures that charge lower rates for higher consumption discourage conservation efforts. Limited building codes and standards for water efficiency slow market adoption of conservation technologies.

Behavioral and social barriers significantly impact conservation program success. Consumer resistance

to low-flow fixtures persists due to perceived performance concerns, despite technological improvements. Agricultural producers may resist conservation technologies due to unfamiliarity, perceived complexity, or concerns about crop impacts. Cultural attitudes toward water abundance in some regions create resistance to conservation measures even during drought conditions.

Looking at the water needs globally, the link between population increase, economic growth and water consumption increase must be removed. The freshwater availability may seem sufficient, but it is unevenly distributed. Regions like North Africa and the Middle East face severe water stress, with demand often exceeding renewable supply. Water scarcity, however, is best understood across scales.

At the global level, averages can hide local problems. At the river basin level, scarcity depends on the balance between local supply and total demand, meaning shortages can occur even in water-rich countries. At the local level, impacts are direct, affecting households, farmers, and daily water access.

These scales are connected, small-scale actions, such as efficient irrigation or water-saving at home, can reduce basin-level demand and help ease broader water stress. The present freshwater use of 4×10^{12} m³ (four trillion cubic metres) per year must decrease. A development where smart water use in domestic, industrial and agricultural sectors is supported by innovative solutions and conscious water use by all actors could lead to significant water savings and substantial reduction of freshwater needs. Using the previous reported potential for water savings and efficiency, theoretical freshwater use could decrease to the water needs of 1980, see table 1.

Estimated use per category in cubic metres / year			
Sector	Present use	Potential savings	Remaining yearly consumption
Agriculture	28E+11	5,6E+11	22,4E+11
Residential	4E+11	1,2E+11	2,8E+11
Industry	8E+11	3,2E+11	4,8E+11
Sum	40E+11	10E+11	30 E+11

Table 1. Estimated global freshwater withdrawals by sector (2022 AQUASTAT data), theoretical conservation potential, and projected remaining consumption. Freshwater volumes are expressed in cubic metres per year.

A decrease from 4×10^{12} m³ (four trillion cubic metres) to 3×10^{12} m³ (three trillion cubic metres) would move the freshwater status to how water was used around 1980, effectively reversing four decades of growth in freshwater demand while accommodating continued population growth through efficiency gains rather than expanded supply.

Conclusion and Recommendations

Water conservation represents an essential strategy for addressing global water security challenges through proven technologies and practices across residential, agricultural, and industrial sectors. Comprehensive implementation of conservation measures can reduce water consumption by 20-40% in residential settings, 30-50% in agricultural operations, and up to 60% in industrial processes while delivering substantial economic and environmental benefits. Success requires integrated approaches combining technological solutions, policy interventions, and behavioral modifications tailored to local conditions and constraints.

Key recommendations for accelerating water conservation adoption include implementing tiered utility rate structures that reward conservation, establishing building codes and standards requiring water efficiency, providing financial incentives for conservation investments, and conducting public education campaigns promoting conservation awareness. Government agencies should streamline permitting processes for conservation technologies while ensuring health and safety protection. Research and development investments should focus on reducing costs and improving performance of advanced conservation technologies.

Future research priorities include developing low-cost sensor technologies for monitoring water use, improving treatment technologies for water reuse applications, and advancing drought-tolerant crop varieties. Long-term success requires sustained commitment from governments, utilities, industries, and individuals to prioritize water conservation as an essential element of sustainable water management. The economic, environmental, and social benefits of water conservation justify immediate action to implement comprehensive conservation programs worldwide.

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