ECONOSCITECH INTEGRATION

ISSUE 7

INTERNATIONAL SCIENTIFIC ELECTRONIC JOURNAL

TASHKENT STATE UNIVERSITY OF ECONOMICS

American University of Technology
Powered by Arizona State University®

ISSN: 3060-5075

Acceptance of articles
PUBLISHED EVERY MONTHLY

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2026

THE SCIENTIFIC-POPULAR ELECTRONIC JOURNAL **"ECONOSCITECH-INTEGRATION"** HAS BEEN REGISTERED UNDER THE NUMBER C-5669651 BY THE AGENCY FOR INFORMATION AND MASS COMMUNICATIONS (AOKA) OF THE REPUBLIC OF UZBEKISTAN, EFFECTIVE FROM OCTOBER 9, 2024.

In accordance with Resolution No. 384/6 dated April 10, 2026, issued by the Presidium of the Supreme Attestation Commission under the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan, this journal is included in the list of recommended international scientific publications for publishing the primary research findings of doctoral dissertations in the field of Economic Sciences.

Partners: Tashkent State University of Economics / American University of Technology in Tashkent (AUT)

Electronic publication. Issue 7. 374 pages.
Approved for publication in July 2026.

Editorial Board Members:

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SECTORAL ANALYSIS OF WATER RESOURCE USE EFFICIENCY UNDER CIRCULAR ECONOMY PRINCIPLES: EVIDENCE FROM UZBEKISTAN

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Abstract. Efficient water resource management is essential for achieving sustainable economic development, particularly in water-scarce countries such as Uzbekistan. Agriculture, the energy sector, the chemical industry, and metallurgy are among the country's major water-consuming sectors. Therefore, improving water use efficiency is a strategic priority in the transition to a circular economy. This study aims to assess water use efficiency across these sectors based on circular economy principles. The research employs comparative, statistical, descriptive, and systems analysis methods using national statistical data and international reports. The findings reveal significant differences among the selected sectors in terms of water consumption intensity, water use efficiency, and water reuse potential. The scientific novelty of the study lies in the development of the Sectoral Water Circularity Assessment Matrix (SWCAM), which provides a practical framework for evaluating sectoral performance and identifying management priorities for sustainable water resource utilization. The proposed approach contributes to improving organizational and management mechanisms for water resource use and supports evidence-based policy decisions aimed at strengthening circular water management in Uzbekistan.

Keywords: circular economy, water resource management, water use efficiency, sectoral analysis, agriculture, energy sector, chemical industry, metallurgy, Uzbekistan, sustainable development.

Аннотация. Эффективное управление водными ресурсами является одним из ключевых условий обеспечения устойчивого экономического развития, особенно для стран с ограниченными водными ресурсами, таких как Узбекистан. Сельское хозяйство, энергетика, химическая промышленность и металлургия относятся к числу наиболее водоёмких отраслей национальной экономики. В этой связи повышение эффективности использования водных ресурсов на основе принципов циркулярной экономики приобретает стратегическое значение. Целью исследования является оценка эффективности использования водных ресурсов в указанных отраслях с позиций принципов циркулярной экономики. В работе применены сравнительный, статистический, описательный и системный методы анализа с использованием официальных национальных статистических данных и материалов международных организаций. Результаты исследования свидетельствуют о существенных различиях между анализируемыми отраслями по уровню водоёмкости, эффективности использования воды и потенциалу повторного использования водных ресурсов. Научная новизна исследования заключается в разработке матрицы Sectoral Water Circularity Assessment Matrix (SWCAM), предназначенной для комплексной оценки эффективности использования водных ресурсов по отраслям экономики и определения приоритетных направлений совершенствования системы управления. Предложенный подход способствует развитию организационно-управленческих механизмов рационального использования водных ресурсов и формированию научно обоснованных управленческих решений, направленных на развитие циркулярного водопользования в Республике Узбекистан.

Ключевые слова: циркулярная экономика, управление водными ресурсами, эффективность использования воды, отраслевой анализ, сельское хозяйство, энергетика, химическая промышленность, металлургия, Узбекистан, устойчивое развитие.

INTRODUCTION

Water is a strategic economic and natural resource that forms the foundation of sustainable economic growth, food security, industrial production, energy generation, environmental sustainability, and human well-being [1].

As freshwater demand continues to increase due to rapid population growth, urbanization, industrialization, and climate change, pressure on available water resources has intensified worldwide [2]. According to international assessments, nearly all sectors of the economy increasingly depend on reliable water supplies, while growing water scarcity threatens productivity, economic resilience, and sustainable development [3]. Consequently, improving water use efficiency and strengthening integrated water resource management have become global priorities for achieving long-term environmental and economic sustainability [4].

The increasing pressure on global freshwater resources is driven by several interconnected factors, including population growth, urbanization, industrialization, and climate change. These drivers collectively increase water demand, intensify water scarcity, and emphasize the need to adopt more efficient and sustainable water management approaches. The conceptual relationship among these factors is illustrated in Figure 1.

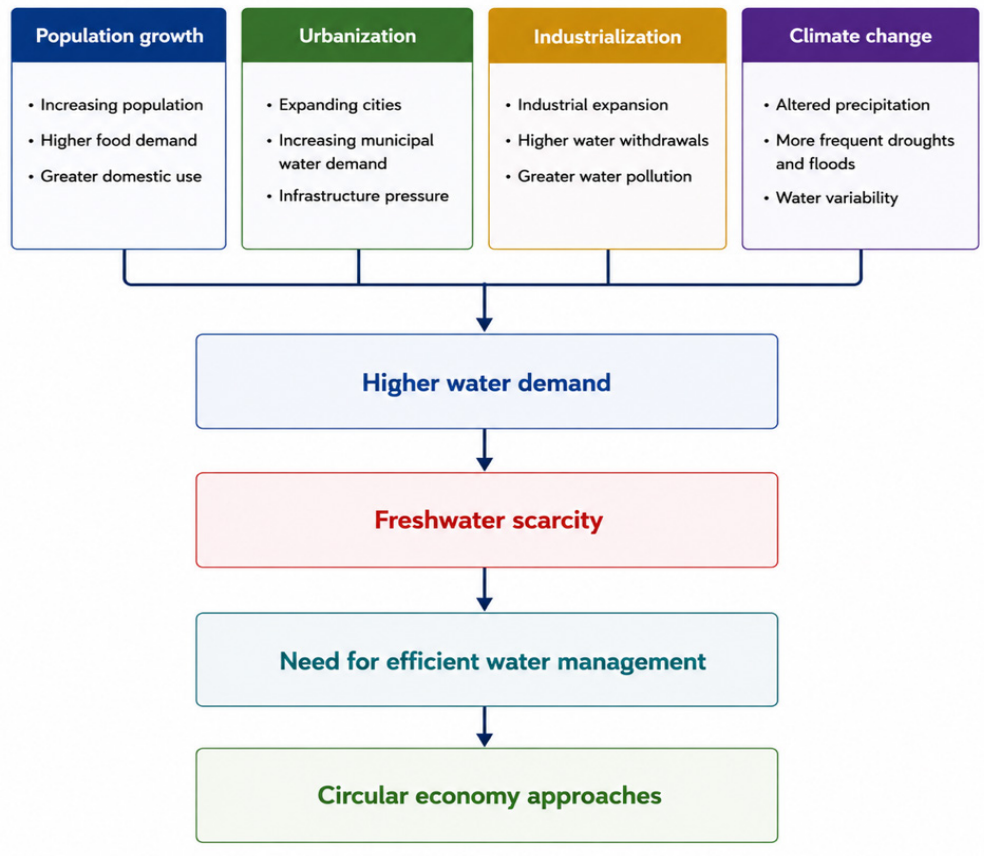

Figure 1. Conceptual framework of global drivers influencing water demand and the transition toward circular water management

In response to growing water-related challenges, the circular economy has emerged as a strategic approach to improving resource efficiency and promoting sustainable development [5]. Unlike the traditional linear model of resource consumption based on the “take–make–dispose” principle, the circular economy emphasizes reducing resource use, extending resource life cycles, reusing materials, and recovering valuable resources [6]. In the context of water resource management, circular economy principles encourage water conservation, wastewater reuse, resource recovery, and the adoption of innovative technologies that improve water productivity while minimizing environmental impacts [5]. Consequently, the transition toward circular water management has become an important component of sustainable economic development and integrated water resource management strategies worldwide.

Uzbekistan is experiencing increasing pressure on water resources due to its arid climate, population growth, and the high dependence of the national economy on irrigated agriculture. Agriculture remains the dominant water-consuming sector, while the energy, chemical, and metallurgical industries also require substantial water resources for production processes [7]. Although various studies have examined water management and circular economy issues separately, comprehensive sectoral assessments that integrate water use efficiency with circular economy principles remain limited, particularly in the context of Uzbekistan.

Therefore, this study aims to evaluate water use efficiency across the major water-consuming sectors of the economy and proposes the Sectoral Water Circularity Assessment Matrix (SWCAM) as a conceptual framework for assessing sectoral performance and supporting evidence-based management decisions for sustainable water resource utilization.

LITERATURE REVIEW

Water scarcity and the increasing demand for freshwater have accelerated the transition from conventional linear water management to circular water management approaches. Recent studies emphasize that circular economy principles, including water reuse, recycling, and resource recovery, have become essential for improving water security and ensuring sustainable development. A systematic review by Fernandes et al. (2023) [8] demonstrates that research on circular economy implementation in the water sector has expanded rapidly over the last decade, with particular attention given to wastewater reuse, resource recovery, and institutional governance.

In addition to technological innovations, effective governance and integrated management play a crucial role in achieving circular water systems. Morseletto et al. (2022) [9] argue that the circular economy of water should not be limited to wastewater recycling, but should also include water efficiency, resource recovery, and long-term sustainability through coordinated institutional and policy frameworks. Their study highlights that successful implementation requires technological, economic, and governance integration rather than isolated technical solutions.

Despite these advances, limited research has comparatively assessed water use efficiency across major water-consuming sectors within a single analytical framework, particularly in developing countries such as Uzbekistan. Most previous studies have focused either on municipal wastewater reuse or industrial water recycling, while comparative assessments covering agriculture, energy, the chemical industry, and metallurgy remain scarce [10]. Therefore, this study addresses this gap by evaluating sectoral water use efficiency under circular economy principles and proposing the Sectoral Water Circularity Assessment Matrix (SWCAM) as a practical framework for supporting sector-specific water management decisions.

RESEARCH METHODOLOGY

This study employs a mixed qualitative and quantitative research design to evaluate water resource use efficiency across the major water-consuming sectors of Uzbekistan within the framework of circular economy principles. A sectoral comparative approach was adopted to examine differences in water consumption patterns, water productivity, and opportunities for water reuse in agriculture, the energy sector, the chemical industry, and metallurgy. The research combines descriptive, comparative, and analytical methods to identify sector-specific challenges and management priorities for improving sustainable water resource utilization.

The analysis is based on secondary data obtained from national and international sources. National statistical information was collected from the Statistics Agency under the President of the Republic of Uzbekistan and the Ministry of Water Resources. International datasets and reports were obtained from the Food and Agriculture Organization of the United Nations (FAO AQUASTAT), the World Bank, the OECD, and UNESCO. These sources provide comprehensive information on water withdrawals, sectoral water use, irrigation, industrial water consumption, and water resource management policies. Data published between 2020 and 2025 were primarily used to ensure the relevance and comparability of the analysis.

To achieve the research objectives, several analytical methods were applied. Comparative analysis was used to evaluate differences in water consumption among the selected economic sectors. Statistical analysis was employed to examine sectoral indicators and identify trends in water use efficiency. Descriptive analysis supported the interpretation of water resource management practices and sectoral characteristics. In addition, a systems approach was adopted to examine the interrelationships between circular economy principles and water resource management. These methods enabled a comprehensive assessment of sectoral water use efficiency and management performance.

The study evaluates four major water-consuming sectors: agriculture, the energy sector, the chemical industry, and metallurgy. Sectoral performance is assessed using four analytical dimensions: (i) water consumption intensity, (ii) water use efficiency, (iii) water reuse potential, and (iv) circular economy readiness. Based on these dimensions, the study develops the Sectoral Water Circularity Assessment Matrix (SWCAM), which provides a conceptual framework for comparing sectoral performance and identifying priority areas for improving organizational and management mechanisms in water resource management.

ANALYSIS AND RESULTS

Water resources play a crucial role in supporting Uzbekistan's economic development, particularly in sectors that heavily depend on reliable water supplies. Although agriculture remains the largest consumer of freshwater, other sectors, including energy, the chemical industry, and metallurgy, also require substantial water resources for production processes and technological operations.

However, the intensity of water use, the level of water productivity, and opportunities for water reuse differ considerably across these sectors. Therefore, a sectoral assessment is essential for identifying priority areas to improve water use efficiency and promote the implementation of circular economy principles (Table 1).

Table 1
Characteristics of major water-consuming sectors in Uzbekistan[1]

Sector	Primary water use	Water demand	Circular economy potential
Agriculture	Irrigation	Very High	High
Energy	Cooling systems, hydropower	Medium	Medium–High
Chemical industry	Technological processes	High	High
Metallurgy	Cooling and processing	High	High

As shown in Table 1, agriculture is the dominant water-consuming sector in Uzbekistan, primarily due to the country's extensive irrigated farming system. Industrial sectors, particularly the chemical industry and metallurgy, also require significant volumes of water, mainly for cooling and technological processes. The energy sector demonstrates relatively lower direct water consumption; however, water remains an essential resource for hydropower generation and cooling systems at thermal power plants. These sectoral differences indicate that improving water use efficiency requires differentiated management approaches tailored to the specific characteristics of each sector.

Agriculture is the largest consumer of water resources in Uzbekistan, accounting for approximately 90% of the country's total freshwater withdrawals. This high level of water consumption is mainly associated with irrigated crop production, particularly cotton, wheat, fruits, and vegetables. Irrigation plays a crucial role in ensuring agricultural productivity; however, inefficient irrigation methods, aging infrastructure, and considerable water losses reduce overall water use efficiency. As a result, improving irrigation technologies, promoting water-saving practices, and expanding the reuse of treated wastewater have become key priorities for enhancing agricultural sustainability within the framework of the circular economy.

The energy sector is another important water user, primarily through hydropower generation and cooling systems at thermal power plants. Although its total water consumption is considerably lower than that of agriculture, water remains indispensable for maintaining energy production and operational efficiency. The introduction of closed-loop cooling systems, water recycling technologies, and improved operational management can significantly reduce freshwater withdrawals while supporting the transition toward more sustainable energy production.

Water plays a vital role in the chemical industry, where it is extensively used in technological processes, cooling operations, cleaning, and the transportation of raw materials. Increasing industrial production has led to growing pressure on water resources, emphasizing the need for more efficient water management. The implementation of water recycling systems, wastewater treatment technologies, and cleaner production practices can substantially improve water productivity and reduce environmental impacts.

Metallurgical enterprises consume considerable amounts of water for cooling equipment, processing raw materials, and maintaining production systems. Modern metallurgical plants increasingly adopt closed-cycle water supply systems that reduce freshwater abstraction and improve resource efficiency. Further investment in advanced water treatment technologies and circular water management practices would strengthen environmental performance while reducing production costs.

Overall, the analysis demonstrates significant differences in water consumption patterns, water use efficiency, and opportunities for water reuse among the major water-consuming sectors of Uzbekistan. While agriculture remains the largest water consumer, industrial sectors possess greater potential for implementing circular water management practices through technological modernization and water recycling. These findings provide the basis for developing the proposed Sectoral Water Circularity Assessment Matrix (SWCAM), which is presented in the following section.

1 author's development

To facilitate a systematic comparison of water resource use across the major water-consuming sectors, this study proposes the Sectoral Water Circularity Assessment Matrix (SWCAM). The matrix is designed to evaluate sectoral performance based on four key dimensions: water consumption intensity, water use efficiency, water reuse potential, and circular economy readiness. These dimensions provide a practical framework for identifying sector-specific strengths, weaknesses, and priority areas for improving sustainable water resource management (Table 2).

Table 2
Sectoral Water Circularity Assessment Matrix (SWCAM)[2]

Sector	Water consumption intensity	Water use efficiency	Water reuse potential	Circular economy readiness
Agriculture	High	Medium	Medium	Medium
Energy	Medium	High	High	High
Chemical industry	High	Medium	High	Medium
Metallurgy	High	High	High	High

Note: The qualitative assessment (High, Medium, Low) is based on the comparative analysis of sectoral water consumption characteristics, technological development, water reuse opportunities, and management practices identified from national statistics and international reports.

As presented in Table 2, considerable differences exist among the selected sectors in terms of their readiness to implement circular water management practices. Agriculture demonstrates the highest water consumption intensity and therefore represents the greatest opportunity for improving water use efficiency through modern irrigation technologies and water-saving practices.

The energy and metallurgical sectors show relatively higher levels of technological readiness for water recycling and closed-loop water systems. The chemical industry also has substantial potential to increase water reuse through cleaner production technologies and advanced wastewater treatment systems.

Overall, the SWCAM provides a practical tool for prioritizing sector-specific management strategies within the framework of the circular economy.

CONCLUSION AND RECOMMENDATIONS

This study examined water resource use across the major water-consuming sectors of Uzbekistan within the framework of circular economy principles. The findings indicate that significant differences exist among agriculture, the energy sector, the chemical industry, and metallurgy in terms of water consumption intensity, water use efficiency, and opportunities for water reuse.

Agriculture remains the largest consumer of water resources, highlighting the urgent need to improve irrigation efficiency and reduce water losses through modern water-saving technologies. In contrast, industrial sectors demonstrate greater potential for implementing circular water management practices, particularly through water recycling, wastewater treatment, and closed-loop production systems.

Based on the comparative sectoral analysis, the study proposes the Sectoral Water Circularity Assessment Matrix (SWCAM) as a practical framework for evaluating sectoral performance and identifying priority areas for improving water resource management. The proposed matrix can support policymakers and decision-makers in developing sector-specific strategies aimed at increasing water use efficiency and promoting the transition toward a circular economy.

The findings of this study contribute to the development of organizational and management approaches for sustainable water resource utilization in Uzbekistan. Future research may expand the proposed framework by incorporating quantitative performance indicators and empirical sector-level data to further improve the assessment of circular water management practices.

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Proofreader: Xondamir Ismoilov

Layout and Designer: Hasan Maqsudov

2026. № 7

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