STRATEGIC WATER USE MANAGEMENT AFFECTED THE WATER USE EFFICIENCY OF THE INDUSTRIAL FACTORIES LOCATED IN THAILAND'S RIVER BASINS OF THE CENTRAL AND NORTHEASTERN REGIONS

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ABSTRACT

The objectives of this research article were: to examine the strategic water use management of industrial factories, to assess the level of water use efficiency among industrial factories located in Thailand's the river basins of the Central and Northeastern regions, and to investigate the factors of strategic water use management that influence water use efficiency in these factories. The 120 samples of industrial factories that have implemented the 3Rs concept (Reduce, Reuse, and Recycle). Data were collected from factory representatives through structured questionnaires. Statistical methods used for data analysis included percentage, mean, standard deviation, correlations and multiple regression analysis.

The results revealed that both overall level of strategic water use management and level of water use efficiency were rated as high. Moreover, the strategic formulation for water reuse had a statistically significant effect on water use efficiency at the 0.05 level. In addition, the strategic formulation for water recycling, as well as strategic evaluation and control, had statistically significant effects on water use efficiency at the 0.01 level. These findings indicate that systematic strategic management, particularly through evaluation, control, and recycle initiatives, plays a crucial role in enhancing water use efficiency within the industrial sector.

Keywords: Strategic water use management, Industrial factories, Water use efficiency, Thailand's river basins of the Central and Northeastern regions, the 3Rs concept.

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INTRODUCTION

Thailand's Gross Domestic Product (GDP) comprises eleven major production sectors, including agriculture, mining, trade, manufacturing, transportation, and government services. Among these, the industrial manufacturing sector plays a crucial role in driving national economic growth by converting raw materials into high-value finished goods through technology and innovation. According to the Office of the National Economic and Social Development Council (NESDC, 2023), the industrial sector contributes approximately 30% of Thailand's GDP, while agriculture, trade, and other services account for 10%, 16%, and 44%, respectively. Despite its economic importance, the industrial sector is highly dependent on reliable and sufficient water resources. The Office of the National Water Resources (ONWR, 2018) reported that agriculture consumes about 113,961 million cubic meters of water annually (77% of national use), whereas the industrial sector accounts for only 1,913 million cubic meters (1%). Limited freshwater availability has led to recurring droughts, water shortages, and deteriorating water quality, particularly in the river basins of the Central and Northeastern regions. Between 2010 and 2020, severe drought events occurred five to six times (ONWR, 2021), and projections by the World Resources Institute (2025) indicate that these areas will remain at high drought risk. In 2017, the Federation of Thai Industry reported a 7.05% gap between industrial water demand and supply, highlighting the growing challenge of water scarcity for production. To address such challenges, Mohanty (2011) proposed applying the 3Rs principle—reduce, reuse, and recycle-as an environmentally sustainable approach to enhance water resource efficiency. The 3Rs concept has since been widely adopted in industrial water management to improve efficiency amid increasing demand. However, previous research has mainly focused on local contexts without fully integrating broader factors such as drought, pollution, and seawater intrusion that impact water availability.

This study therefore focuses on Strategic Water Use Management in industrial factories located within Thailand's river basins of the Central and Northeastern regions. Building upon Wheelen and Hunger's (2002) Strategic Management Concept, it proposes an integrated framework combining the 3Rs principle with strategic environmental analysis, formulation, and implementation. The framework aims to improve factory-level water efficiency, mitigate risks arising from regional water scarcity, and fill existing research gaps regarding sustainable industrial water management in drought-prone regions.

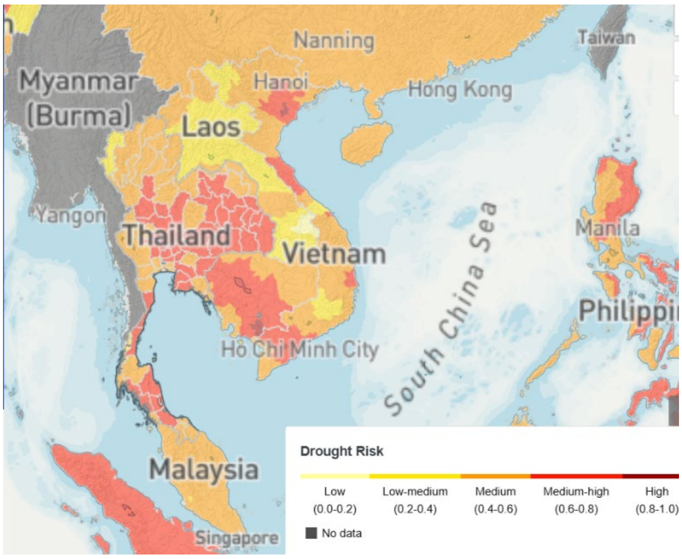

Figure 1 High level of drought risk in Thailand's central basins and northeastern region. World Resources Institute. (2025)

Research objective

The objectives of this research article were to 1) study the strategic water use management 2) study the water use efficiency of the industrial factories located in Thailand's river basins of the Central and Northeastern regions and 3) study factors of the strategic water use management influencing the water use efficiency of the industrial factories.

Expected Benefits

1) Benefits for Industrial Sectors: The outcomes of this study are expected to provide industrial factories across various sectors with practical guidelines for improving the efficiency of water utilization in production processes. The adoption of these management approaches will contribute to mitigating water scarcity issues in Thailand's river basins of the Central and Northeastern regions.

2) Benefits for Relevant Authorities and Organizations: The findings of this research can serve as valuable input for governmental agencies and related organizations in formulating policies and strategies for sustainable water resource management. Furthermore, the results may support efforts to address freshwater shortages and enhance the availability of raw water sources for municipal water supply systems, thereby promoting long-term water security and sustainability.

Literature review

Water Management and the 3Rs Concept

Water management following the 3Rs concept (Reduce, Reuse, and Recycle) has been recognized by the United Nations Centre for Regional Development (UNCRD) as an environmentally friendly approach to minimizing wastewater generation and mitigating adverse impacts on health, the economy, and ecosystems (Mohanty, 2011). The first stage, reduce, focuses on minimizing unnecessary water use and discharge. The second, reuse, involves the repeated use of water in suitable processes before treatment, often through preliminary filtration or temporary storage. The third, recycle, refers to reclaiming treated wastewater through advanced separation technologies for reuse as a new water source. Similarly, the Pollution Control Department (2021) highlights the 3Rs as a practical framework for sustainable resource management that reduces consumption, reuses materials, and recycles resources to maintain circular use efficiency.

Strategic Management Concept

Strategic management provides the foundation for systematic planning and long-term organizational sustainability. According to Wheelen and Hunger (2002), the process includes four main stages: (1) environmental analysis and evaluation, (2) strategy formulation, (3) strategy implementation, and (4) strategy evaluation and control. These stages involve analyzing internal and external environments, setting measurable objectives, executing strategic plans, and monitoring outcomes to ensure alignment with the organization's mission. Certo and Peter (1991) similarly identify environmental analysis, direction setting, strategy formulation, implementation, and control as the essential stages of effective strategic management.

Strategic Water Use Management

The concept of strategic water use management integrates the principles of the 3Rs with the stages of strategic management to enhance sustainable industrial water utilization. The framework consists of four key components. First, environmental analysis and assessment examined internal and external factors, such as drought, seawater intrusion, and pollution, using tools like SWOT analysis. Second, strategy formulation develops organizational strategies aligned with sustainability goals, incorporating 3Rs-based actions: reducing unnecessary water use, reusing water within processes, and recycling treated wastewater. Third, strategy implementation translates these strategies into operational plans, assigning responsibilities and ensuring effective coordination. Finally, strategy evaluation and control involve continuous monitoring, performance assessment, and adjustment of strategies to maintain efficiency and relevance under changing conditions.

Water Use Efficiency

Water use efficiency reflects the optimization of resources within industrial operations. Following Peterson and Plowman (1953), it can be evaluated across four dimensions: (1) cost efficiency, focusing on reducing operational expenses through technological improvement; (2) quality efficiency, ensuring compliance with or exceeding water quality standards; (3) quantity efficiency, minimizing water consumption through 3Rs practices; and (4) time efficiency, emphasizing timeliness and responsiveness in water management processes. Together, these dimensions provide a holistic framework for sustainable and effective industrial water use.

Conceptual Framework of the Study

The conceptual framework of this study integrates Strategic Management Theory (Wheelen & Hunger, 2002) with the 3Rs Principle (Reduce, Reuse, and Recycle) to promote sustainable industrial water use management. The framework aims to investigate the influence of strategic water use management on the efficiency of industrial water utilization in factories located within Thailand's river basins of the Central and Northeastern regions. This integration emphasizes a systematic approach in which strategic management processes: environmental analysis and assessment, strategy formulation, implementation, evaluation and control are aligned with 3Rs-based practices to enhance water use efficiency in industrial operations. The conceptual framework is illustrated as follows.

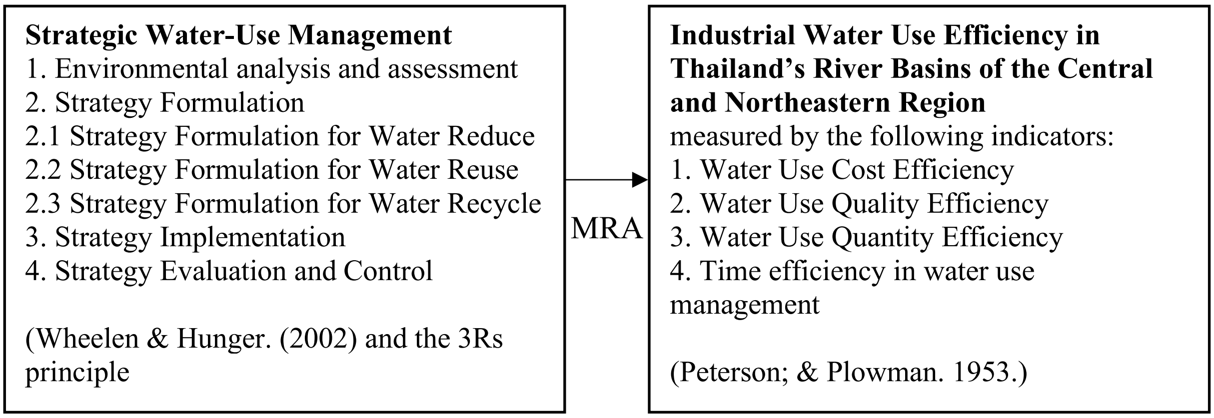

Figure 2 Framework of the Study

Research Hypothesis

Strategic water use management has a significant effect on the water use efficiency in industrial factories located in Thailand's River Basins of the Central and Northeastern Regions.

Research Methodology

A review of both domestic and international literature reveals a significant gap in the practical application of strategic water use management and its effects on water use efficiency in industrial factories located within Thailand's river basins of the Central and Northeastern regions.

In Thailand, studies on industrial water management have primarily focused on the Eastern region. Thanaphon Penrat (2019) examined industrial sectors, particularly hotels and high-rise buildings, implementing 3Rs-based water management integrated with Internet of Things (IoT) technologies. The study demonstrated that IoT-enabled monitoring enhanced water recycling and reuse efficiency through real-time data collection, improving the responsiveness of wastewater management. Similarly, Nitipha Phadungnok (2024) developed a strategic management model to enhance water resource efficiency in the Eastern Economic Corridor (EEC). The study confirmed that the integration of the 3Rs principles (Reduce, Reuse, and

Recycle) significantly improved industrial water management and contributed to sustainable operations across Chachoengsao, Chonburi, and Rayong provinces.

Internationally, Gadanakis, Bennett, Park, and Areal (2015) investigated Improving Productivity and Water Use Efficiency: A Case Study of Farms in England. Their findings indicated that adopting efficiency-oriented practices such as water recycling, use of decision support tools, and installation of drip or spray irrigation systems positively influenced water use efficiency at the operational level. In contrast, reliance on traditional overhead irrigation systems was shown to negatively affect efficiency.

From these reviews, several key research gaps were identified: 1) There is limited research focusing on 3R-based strategic water management in Thailand's river basins of the Central and Northeastern regions. 2) Existing studies on 3R applications have emphasized economic growth–related water scarcity rather than drought-induced shortages. 3) Few studies have integrated the concept of strategic management into analyses of industrial water use efficiency. To address these gaps, this study investigates the influence of strategic water use management based on the integration of the 3Rs principles and strategic management concepts on the efficiency of industrial water use. The research aims to establish an empirical understanding of how strategic planning, implementation, and evaluation can enhance sustainable water utilization at the factory level within Thailand's major river basins. Accordingly, the study titled "Strategic Water Use Management Affecting Water Use Efficiency of Industrial Factories in Thailand's River Basins of the Central and Northeastern Regions" was conducted following systematic research procedures designed to examine these relationships comprehensively and to contribute to policy and practical frameworks for sustainable industrial water management in Thailand.

Population and Sample Group

The population consists of industrial factories with water management systems located in Thailand's River Basins of the Central and Northeastern Regions, totaling 120 factories. The respondents include senior executives, factory managers, engineering managers, or personnel responsible for decision-making related to industrial water use management, who serve as representatives providing information from industrial factories implementing water management practices water use management in contexts where scarcity arises from drought and degraded water quality caused by environmental pollution or seawater intrusion into freshwater systems in Thailand's River Basins of the Central and Northeastern Regions, totaling 120 participants. Sample group consists of industrial factories that implement industrial water use management practices located in Thailand's River Basins of the Central and Northeastern Regions. The sample size is equal to the total population, meaning that all identified factories were included in the study.

Research Instrument

A structured questionnaire was employed as the primary research instrument to collect data from factory representatives or management personnel responsible for industrial water management. The questionnaire comprised both closed-ended and open-ended questions and was organized into five sections. Section 1: Respondent Information included demographic details such as gender, age, educational background, and job position. Section 2: General Information of the Factory gathered data on daily water consumption, wastewater volume, and existing water management practices based on the 3Rs principle (Reduce, Reuse, Recycle). Section 3: Strategic Water Management Factors focused on strategies concerning water reduction, reuse, and recycling. Section 4: Industrial Water Use Efficiency assessed key performance aspects, including water cost, maintenance or improvement of water quality, stability or increase of water quantity, and time efficiency in water management operations. Section 5: Additional Suggestions provided open-ended questions allowing respondents to propose recommendations for enhancing industrial water management efficiency. To ensure instrument validity, five experts evaluated the questionnaire to assess content relevance and clarity using the Index of Objective Congruence (IOC) method. Each item was reviewed for alignment with the research objectives and operational definitions. The average IOC value obtained was 0.92, indicating a high degree of content validity and consistency with the study's conceptual framework. Instrument reliability was subsequently examined through a Cronbach's Alpha test conducted on 30 pilot samples, covering both independent and dependent variables. The reliability coefficients, as presented in Table 1, demonstrated acceptable internal consistency, confirming the questionnaire's suitability for full-scale data collection and ensuring dependable measurement of strategic water management and water use efficiency in industrial settings.

Instrument Quality and Reliability Testing

The quality of the research instrument (questionnaire) was evaluated by five experts to determine its content validity. The evaluation was conducted using the Index of Objective Congruence (IOC), which measures the consistency between each question item and the research objectives as defined in the operational definitions. The calculated IOC value was 0.92, indicating a high level of content validity, meaning that the questionnaire items were well-aligned with the study's conceptual framework and research objectives. The reliability of the instrument was examined using Cronbach's Alpha coefficient for both independent and dependent variables, based on data obtained from 30 sample responses. The reliability test results are presented in Table 1.

Table1 Reliability test results

Variables	Number of items	Cronbach's Alpha
1. Environmental analysis and assessment	4	.920
2. Strategy formulation for water reduce	10	.926
3. Strategy formulation for water reuse	10	.970
4. Strategy formulation for water recycle	10	.982
5. Strategy implementation	2	.869
6. Strategy evaluation and control	5	.976
7. Water use cost efficiency	5	.856
8. Water use quality efficiency	6	.952
9. Water use quantity efficiency	2	.836
10. Time efficiency in water use management	2	.866

Interpretation for reliability test result

As shown in Table 1, all variables demonstrated Cronbach's Alpha coefficients above 0.80, which exceeds the generally accepted threshold of 0.70 for satisfactory reliability (Nunnally & Bernstein, 1994). These results indicate that the measurement items exhibit high internal consistency, meaning the items within each construct are homogeneous and reliably measure the same underlying concept. Therefore, the questionnaire can be considered a valid and reliable instrument for collecting data in this study. Multiple regression analysis is employed in this study because it enables the examination of the simultaneous influence of multiple independent variables on a single dependent variable, industrial water use efficiency. Given that the conceptual framework integrates several strategic management factors, multiple regression provides a robust statistical method for determining the strength, direction, and significance of each factor's contribution to overall water use efficiency.

Data Processing and Data Analysis

Data Processing: 1) The accuracy of responses obtained from the questionnaire was verified, and the data were categorized according to the analytical themes specified in the research objectives. 2) The collected data were then organized, coded, and processed to compute descriptive statistics. The data were classified into appropriate categories and recorded for preliminary statistical analysis. Data Analysis: 1) Analysis of strategic water management practices among the sample group was conducted using descriptive statistics, specifically mean and standard deviation. 2) Analysis of industrial water use efficiency among the sample group was also performed using descriptive statistics, including mean and standard deviation. 3) The levels of opinion from items analyzed in steps (1) and (2) were interpreted using the criteria established by Best and Kahn (1993) for determining levels of responses based on the mean scores. 4) Analysis of the Effect of Strategic Water-Use Management on Industrial Water-Use Efficiency in Thailand's River Basins of the Central and Northeastern Regions. The independent variables are measured at the interval level and the dependent variable is also measured at the interval level. The relationship between the strategic water use management variables and water use efficiency is examined using multiple regression analysis (MRA). Running the regression with the "Enter" method.

Statistical Methods Used for Data Analysis

This research employed the following statistical methods for data analysis: 1) Descriptive Statistics, to analysis of opinions, opinions regarding factory water use management factors and water use management efficiency factors were analyzed using descriptive statistics, specifically mean and standard deviation (SD). The levels of opinions based on mean scores were interpreted according to the criteria established by Best and Kahn (1993). 2) To examine the relationship between strategic water use management factors and water use management efficiency, Multiple Regression Analysis (MRA). was conducted using statistical indicators such as Adjusted R^2, F-values, and t-values.

Research Result

Water use management

Table 2 Mean and Standard Deviation of Overall Water Use Management

Water use management	Mean	S.D.	Level of water use Management*
1.Environmental analysis and assessment	4.23	.619	High
2.Strategy formulation for water reduce	4.18	.786	High
3.Strategy formulation for water reuse	4.14	.925	High
4.Strategy formulation for water recycle	3.43	1.602	Moderate
5.Strategy implementation	4.30	.647	High
6.Strategy evaluation and control	4.37	.683	High
Overall water use management	4.11	.564	High

*Level of water use management: Mean 4.5-5.0 = Most, 3.5-4.49 = High, 2.5-3.49 = Moderate, 1.5-2.49 = Low, and 1.00-1.49 = Lowest

The results indicate that the overall level of strategic water use management in industrial factories was high (Mean = 4.11, S.D. = .564). Among the six aspects, strategy evaluation and control had the highest mean score (4.37), followed by strategy implementation (4.30) and environmental analysis and assessment (4.23). The aspect with the lowest mean score was strategy formulation for water recycling (3.43), which was rated at a moderate level. This suggests that while most dimensions of water management are effectively practiced, recycling strategies may require further improvement and promotion within industrial operations.

Water use efficiency in industrial factories

The overall level of water use efficiency in industrial factories was found to be high (Mean = 3.98, S.D. = .602). Among the four aspects, water quantity efficiency had the highest mean score (4.23), indicating that most factories effectively manage the amount of water used in their production processes. Meanwhile, water quality efficiency had the lowest mean (3.83) as showed in Table 3, suggesting that although water use practices are generally efficient, further improvements in maintaining or enhancing water quality could help strengthen the overall water management performance of industrial factories.

Table 3 Mean and Standard Deviation of Overall Water Use Efficiency in Industrial Factories

Water use efficiency in Industrial factories	Mean	S.D.	Level of water use Efficiency*
1.Water use cost efficiency	3.91	.633	High
2.Water use quality efficiency	3.83	.679	High
3.Water use quantity efficiency	4.23	.692	High
4.Time efficiency in water use management	3.98	.829	High
Overall water use efficiency	3.98	.602	High

*Level of water use efficiency: Mean 4.5-5.0 = Most, 3.5-4.49 = High, 2.5-3.49 = Moderate, 1.5-2.49 = Low, and 1.00-1.49 = Lowest

Multiple regression analysis results and Analysis of multicollinearity

The correlation coefficients among all variables were found to be below 0.70, indicating the absence of multicollinearity. The results of the multiple regression analysis examining the influence of water use management factors on the overall water use efficiency of industrial factories, along with the collinearity statistics (VIF values), are presented in Table 4. All VIF values were below 10, suggesting that multicollinearity was not a concern in the model. The results of the multiple regression analysis, presented in Table 4 revealed that the six factors of strategic water use management including environmental analysis and assessment, water reduction, water reuse, water recycling, strategy implementation, and strategy evaluation and control collectively explained 43.4% of the variance in overall water use efficiency among industrial factories (Adjusted $R^2 = 0.434$). The overall regression model was statistically significant at the 0.01 level ($F = 16.238$, $p < 0.001$). When examining individual predictors, three factors were found to have statistically significant positive effects on overall water use efficiency: strategy evaluation and control ($\beta = 0.471$, $p < 0.01$), water recycle strategy ($\beta = 0.327$, $p < 0.01$) and water reuse strategy ($\beta = 0.187$, $p < 0.05$). These findings suggest that improvements in strategic evaluation and monitoring mechanisms, as well as in recycling and reuse practices, are strongly associated with higher water use efficiency within industrial operations. Among all factors, strategy evaluation and control exerted the greatest influence, followed by water recycle and water reuse, respectively.

Table 4 Results of Multiple Regression Analysis of Water Use Management Factors Affecting the Overall Water Use Efficiency of Industrial Factories

Water Use Management	**B**	**Unstandardized Coefficients SE(b)**	**Standardized Coefficients Beta**	**t**	**p-value**	**Collinearity Statistic VIF**
Constant	1.304	.349		3.741**	<.001	
Environmental Analysis and Assessment	.044	.081	.046	.550	.583	1.452
Water Reduce Strategy	.036	.060	.047	.597	.552	1.282
Water Reuse Strategy	.121	.055	.187	2.210*	.029	1.499
Water Recycle Strategy	.123	.026	.327	4.639**	<.001	1.045
Strategy Implementation	-.092	.111	-.099	-.826	.410	3.002
Strategy Evaluation and Control	.415	.099	.471	4.174**	<.001	2.684
Model Summary	R	R2	Adjusted R^2	SE (est.)	F	p-value
	.678	.463	.434	.45244	16.238	< .001

**Significant at the 0.05 level *Significant at the 0.01 level

Discussion of Findings

The findings revealed that strategic water use management factors collectively explained 43.4% of the variance in overall water use efficiency among industrial factories located in Thailand's River Basins of the Central and Northeastern Regions. This indicates that the implementation of strategic management practices plays a crucial role in promoting efficient and sustainable water utilization within industrial operations. Among the six strategic management factors examined, strategy evaluation and control demonstrated the strongest influence on water use efficiency ($\beta = 0.471$, $p < 0.01$). This finding suggests that continuous monitoring, assessment, and improvement of water management strategies are key drivers of industrial water efficiency. When factories systematically evaluate their performance using indicators such as water consumption rates, recycle ratios, and production water intensity they can identify inefficiencies and adjust their processes accordingly. This aligns with the principle of the strategic management cycle, in which effective feedback and control mechanisms ensure that strategic objectives are met and resources are optimized. The water recycle strategy also exhibited a significant positive effect ($\beta = 0.327$, $p < 0.01$), indicating that factories that invest in technological systems for treating and reusing wastewater achieve higher efficiency levels. This reflects the growing emphasis on circular economy practices in industrial water management, where wastewater is no longer viewed as waste but as a recoverable resource. Implementing water recycling systems not only reduces the demand for freshwater but also mitigates environmental impacts, such as the discharge of pollutants into local water bodies. In addition, the water reuse strategy showed a significant positive relationship with overall efficiency ($\beta = 0.187$, $p < 0.05$). This implies that operational-level practices such as reusing cooling water or rinsing water within production cycles can substantially enhance water conservation. These findings are consistent with studies emphasizing that operational innovation and behavioral management at the factory level are essential for improving resource efficiency. Conversely, other factors such as environmental analysis and assessment, water reduction strategies, and strategy implementation did not show statistically significant effects on efficiency in this model. One possible explanation is that while these factors are foundational, their impact on performance may depend on how effectively they are evaluated and integrated over time. Without systematic monitoring and performance control, strategic plans may not translate into measurable improvements in efficiency. Overall, the results highlight that evaluation and control serve as the central mechanisms linking strategic planning to tangible efficiency outcomes. This underscores the importance of institutionalizing a culture of continuous improvement and data-driven decision-making within industrial water management systems. Future industrial policy and management frameworks should therefore prioritize strengthening monitoring mechanisms, performance audits, and feedback systems to sustain long-term water resource efficiency and resilience.

Conclusion

This study examined the influence of strategic water use management factors on the overall water use efficiency of industrial factories located in Thailand's River Basins of the Central and Northeastern Regions. The regression analysis results demonstrated that the six strategic management factors environmental analysis and assessment, water reduction, water reuse, water recycle, strategy implementation, and strategy evaluation and control jointly explained 43.4% of the variance in water use efficiency. Among these, three factors were found to have statistically significant positive effects: strategy evaluation and control, water recycle, and water reuse. The results highlight that industrial factories with well-established monitoring and evaluation systems, as well as those that adopt recycling and reuse technologies, achieve greater efficiency in water utilization. This finding reinforces the importance of a strategic and continuous improvement approach to industrial water management. Effective water governance within factories depends not only on the adoption of new technologies but also on the establishment of systematic evaluation processes that allow managers to track performance, identify inefficiencies, and implement corrective actions promptly.

Recommendations

For Industrial Factories:

Factories should prioritize the development of systematic monitoring and evaluation frameworks for water use management. This includes setting measurable performance indicators, maintaining water use databases, and conducting regular performance audits. In addition, investments in water recycle and reuse technologies should be encouraged, as these have proven to yield significant improvements in efficiency and sustainability.

For Future Research:

Further studies should explore the long-term impacts of strategic water management practices on environmental and economic performance. Expanding the research to other industrial zones and incorporating variables such as organizational culture, innovation capability, and policy enforcement could provide deeper insights into the mechanisms that drive sustainable industrial water management.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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