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Irrigation Modernization Readiness in Environmental Quality Management Framework: Case Study of Range Irrigation, West Java

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ABSTRACT: The quality of irrigation projects in supporting sustainable development was achieved through modernization in aspects of technology, information, irrigation system management, and governance. This study aimed to develop a measurement model to evaluate irrigation modernization in supporting the quality of irrigation system management. The study was conducted in two stages. The first stage involved developing a measurement tool based on a literature review. The second stage involved testing the measurement tool to evaluate the modernization of irrigation network quality using a case study of the Rentang Irrigation Area in West Java. The evaluation was based on the preferences of staff from 14 construction service providers involved in the Rentang irrigation network improvement project. Data were analyzed using Confirmatory Factor Analysis (CFA) and multiple linear regression analysis. The results identified several important elements in the modernization of irrigation network quality, including the quality of water supply reliability, irrigation infrastructure, irrigation management systems, irrigation management institutions, and human resources. The modernization of irrigation network quality comprising improvements in water supply reliability, irrigation network reliability, irrigation management systems, irrigation management institutions, and human resources, had a positive effect on irrigation system performance. The findings provide implications for developing an irrigation modernization readiness model within a quality management framework.

KEYWORDS: Irrigation system; modernization; irrigation management; irrigation modernization readiness; management quality

1. Introduction

Irrigation infrastructure played a crucial role in supporting agricultural productivity and national food security [1]. Adequate and well-managed irrigation systems directly contributed to increased crop yields and ensured the stability of food supply, particularly for water-intensive crops such as rice. In Indonesia, efforts to improve national food productivity and achieve food security included the construction of new irrigation networks and the rehabilitation of existing ones [2]. However, malfunctioning or damaged irrigation infrastructure negatively affected irrigation system performance, leading to reduced effectiveness in water distribution. As a response, irrigation network rehabilitation was undertaken to restore or improve irrigation functions and services, either by maintaining original conditions or by expanding irrigation service areas.

Despite these efforts, the overall condition of irrigation infrastructure in Indonesia remained unsatisfactory. Agriculture accounted for approximately 80 percent of national water use, yet nearly 46% of irrigation systems were classified as being in poor condition [1, 2]. Although only about 15% of agricultural land was irrigated, this land contributed approximately 95% of national rice production, highlighting the critical importance of irrigation system performance. Evaluations of irrigation systems revealed several persistent problems, including unreliable water distribution, low efficiency levels (35% or less), farmer dissatisfaction with irrigation services, inadequate funding and human resources for operation and maintenance, insufficient maintenance practices, and an urgent need for rehabilitation and modernization [1]. Limited budgets resulted in many irrigation networks being damaged or neglected, while social, institutional, and non-technical constraints further hindered system efficiency. Weak governance and lack of legal certainty exacerbated inefficiencies in water allocation, ultimately reducing agricultural yields and posing risks to long-term food security.

To address these challenges, irrigation network modernization became a strategic necessity to improve agricultural productivity, optimize water use, enhance system reliability, and reduce operation and maintenance costs [1]. Modern irrigation systems ensured stable and timely water supply aligned with crop water requirements, thereby improving plant growth and yields. The adoption of improved infrastructure and modern technologies enabled better regulation and distribution of water, minimized losses, and extended services to remote agricultural areas. Technologies such as monitoring systems, telemetry, sensors, and automation facilitated real-time data collection and supported more efficient and responsive water management. Furthermore, irrigation modernization helped address emerging challenges associated with climate change, population growth, urbanization, and industrial development. Participatory irrigation management approaches, involving farmers and local communities, also contributed to more equitable water distribution and improved system efficiency [3].

From a management perspective, irrigation modernization was closely linked to quality management principles. Quality management in infrastructure projects focused on ensuring that services met stakeholder requirements, technical standards, and sustainability objectives within defined cost and time constraints [4]. In the context of irrigation systems, quality management encompassed planning, operation, maintenance, and continuous performance evaluation to improve efficiency, reliability, and service quality. Effective quality management reduced the risk of system failure, minimized repair costs, enhanced operational efficiency, and increased user satisfaction [4, 5]. Therefore, integrating irrigation modernization within a quality management framework was essential to ensure long-term system sustainability.

Previous studies on irrigation modernization primarily focused on technical indicators such as water use efficiency, infrastructure condition, and irrigation performance ratios [6, 7]. Other studies expanded the evaluation framework to include management practices, institutional capacity, and governance aspects [8, 9]. In Indonesia, the Irrigation Modernization Readiness Index was developed to assess readiness across five key pillars: water availability, infrastructure, irrigation management, institutions, and human resources. This index provided a comprehensive overview of modernization readiness and supported policy and investment prioritization. However, existing evaluation approaches largely relied on technical or administrative assessments and paid limited attention to stakeholder preferences, particularly those of construction service providers and practitioners involved in irrigation network development.

Moreover, current evaluation models rarely integrated irrigation modernization indicators with sustainable performance outcomes within a quality management framework. Sustainability in irrigation systems extended beyond technical efficiency and included economic viability, environmental protection, and social equity. Water availability influenced both economic productivity and environmental sustainability by preventing overexploitation of water resources. Reliable infrastructure supported cost efficiency, reduced water losses, and improved service delivery to farmers. Effective irrigation management enabled equitable water allocation and adaptive responses to climate variability. Strong irrigation institutions ensured transparent governance, stakeholder participation, and regulatory compliance, while competent human resources determined the effectiveness of infrastructure utilization and management innovation [6–9]. Despite the recognized importance of these dimensions, a comprehensive evaluation model that linked irrigation modernization, quality management, and sustainable performance based on stakeholder preferences remained underdeveloped.

This study addressed this gap by proposing and testing a measurement model for irrigation modernization within a quality management framework that incorporated stakeholder preferences and sustainability considerations. The aim of this study was to develop and validate an evaluation model for irrigation modernization quality and to examine its effect on irrigation system performance using a case study of an irrigation network improvement project in Indonesia.

2. Materials and Methods

2.1. Study area and research object.

The object of this study was an irrigation network modernization project located in the Rentang Irrigation Area, West Java, Indonesia. This area was selected because it represented a large-scale irrigation rehabilitation and modernization project that incorporated both technical and managerial quality management practices.

2.2. Research design and data collection.

The study employed a quantitative research design using an online survey approach. Data were collected through a structured questionnaire distributed via Google Forms to assess the preferences of construction service providers. Service providers were selected as key stakeholders because they possessed a comprehensive understanding of both technical and non-technical aspects of irrigation modernization and quality management system (QMS) implementation. Respondents were selected using purposive sampling. A total of 98 staff members from 14 construction service providers participated in the survey. All respondents were directly involved in the irrigation network improvement project and had professional experience relevant to QMS implementation. The respondents held positions including Project Manager, Quality Assurance/Quality Control staff, Health, Safety, Security, and Environment personnel, Site Engineering Manager, Site Operations Manager, Site Administration Manager, Logistics Manager, and Equipment Manager.

2.3. Variables and measurement.

Irrigation Modernization Readiness was measured using five dimensions developed from previous studies [8, 9]: Improved Reliability (X1), Improved Irrigation Facilities and Infrastructure (X2), Irrigation Management System (X3), Irrigation Management Institution (X4), and Human Resources (X5). These dimensions were identified as key components of irrigation modernization readiness, particularly within a quality management framework, and were previously validated using the Analytical Hierarchy Process. The dependent variable (Y) represented service provider satisfaction with sustainable performance and consisted of three indicators developed from earlier studies [10–12]: economic sustainability, social sustainability, and environmental sustainability. Economic sustainability reflected efficiency, cost–benefit outcomes, and productivity impacts. Social sustainability represented equitable access to water resources and stakeholder participation, while environmental sustainability related to water resource utilization, energy efficiency, and ecological impacts. All questionnaire items were measured using a five-point Likert scale, ranging from 5 (very good) to 1 (very bad).

2.4. Instrument validity and reliability.

Instrument validity and reliability were evaluated before further analysis. CFA was applied to validate the measurement model, as the factor structure had already been established in the literature. CFA was used to statistically confirm the construct structure, assess indicator validity, and ensure the reliability of the measurement instruments. This approach was considered more appropriate than Exploratory Factor Analysis because it allowed the confirmation and refinement of an existing theoretical model.

2.5. Data analysis.

Multiple linear regression analysis was employed to examine the influence of the Irrigation Modernization Readiness dimensions (X1–X5) on service provider satisfaction with sustainable performance (Y). Multiple regression analysis was selected because the study aimed to analyze the effects of multiple independent variables on a single dependent variable. Prior to regression analysis, classical assumption tests were conducted to ensure unbiased regression results, including tests for normality, autocorrelation, multicollinearity, and heteroscedasticity. The regression model was formulated as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon \qquad (1)$$

where β_0 represented the constant, β_1–β_5 were the regression coefficients, and ε denoted the error term.

Data analysis and interpretation were conducted using SPSS Statistics software. Model feasibility was evaluated using the Goodness-of-Fit test through analysis of variance (ANOVA). A model was considered fit if the F-test significance value was less than 0.05. The coefficient of determination (R^2) was used to assess the proportion of variance in the dependent variable explained by the independent variables. Hypothesis testing was performed using a two-tailed t-test. An independent variable was considered to have a significant effect on the dependent variable if the t-test significance value was less than 0.05.

3. Results and Discussion

3.1. Profile respondents.

The characteristics of respondents in this study included gender, level of education, job position, and length of service. Based on gender, the respondents were predominantly male, with 94 respondents (95.92%), while female respondents accounted for 4 individuals (4.08%). In terms of educational background, 7 respondents (7.14%) held a Diploma degree (D3/D4), 85 respondents (86.73%) held a Bachelor's degree (S1), and 6 respondents (6.12%) held a Master's degree (S2). Regarding job position, all positions were equally represented among the 98 respondents, with each position accounting for 14 respondents (14.29%). Based on length of service, 84 respondents (85.71%) had a minimum of five years of work experience in their current positions, while 14 respondents (14.29%) had at least fifteen years of work experience.

Table 1. Respondent profile.

	Number (n)	%age (%)
Gender		
Man	94	95.92
Woman	4	4.08
Total	**98**	**100.00**
Education		
Master	6	6.12
Bachelor	85	86.73
Diploma	7	7.14
Total	**98**	**100.00**
Position		
PM	14	14.29
QA/QC	14	14.29
HSSE	14	14.29
SEM	14	14.29
SQM	14	14.29
SAM	14	14.29
Loglat Manager	14	14.29
Total	**98**	**100.00**
Length of work		
>15 years	14	14.29
5-15 years	84	85.71
Total	**98**	**100.00**

3.2. Measurement model.

CFA was used in this study to test the measurement model of Irrigation Modernization Readiness, which consisted of five dimensions: water supply reliability, irrigation infrastructure reliability, irrigation management system, irrigation management institution, and human resources. Water supply reliability consisted of three indicators. Irrigation infrastructure reliability consisted of five indicators. The irrigation management system consisted of five indicators. The irrigation management institution consisted of six indicators. Human resources consisted of two indicators. The CFA results (Table 2) showed that the validity correlation coefficients in the Corrected Item–Total Correlation column (factor loadings) for almost all questionnaire items were greater than 0.5, with significance values less than 0.05. One item, namely item X2.5 in the infrastructure dimension, had a factor loading of 0.465, which was below the recommended threshold of 0.5. In CFA, factor loadings are ideally above 0.5, or preferably above 0.7 for strong construct validity; however, values above 0.4 are considered acceptable in empirical research as a minimum criterion. Therefore, all questionnaire items were retained and declared valid for measuring the research variables. Reliability testing results (Table 2) indicated that the Cronbach's alpha values for all research variables exceeded 0.60, demonstrating satisfactory internal consistency. Accordingly, all questionnaire instruments were considered reliable and suitable for use as measurement tools in this study. In addition, Table 3 shows that all latent variables had Average Variance Extracted (AVE) values greater than 0.5 and Composite Reliability (CR) values greater than 0.7. These results confirmed that all constructs met the criteria for convergent validity and reliability [13].

Table 2. Measurement model.

Variable	Indicator	Loading factors	Cronbach's Alpha	CR	AVE
Water Availability (X1)	X 1 .1	0.956	0.951	0.969	0.888
	X 1 .2	0.956			
	X 1 .3	0.888			
Infrastructure (X2)	X 2 .1	0.885	0.933	0.93	0.662
	X 2 .2	0.784			
	X 2 .3	0.901			
	X 2 .4	0.839			
	X 2 .5	0.465			
Management (X3)	X 3 .1	0.900	0.648	0.906	0.71
	X 3 .2	0.880			
	X 3 .3	0.678			
	X 3 .4	0.630			
	X 3.5	0.859			
Institution (X4)	X4.1	0.814	0.677	0.825	0.588
	X4.2	0.655			
	X4.3	0.677			
	X4.4	0.624			
	X 4 . 5	0.883			
	X4. 6	0.673			
Human Resources (X5)	X 5 .1	0.688	0.939	0.879	0.648
	X 5 .2	0.737			
Satisfaction toward	Y1	0.508	0.801	0.904	0.758
Sustainable Performance	Y2	0.535			
(Y)	Y3	0.620			

3.3.Structural model.

Based on the multiple linear regression results presented in Table 3, the adjusted R-square value was 0.64, indicating that 64% of the variation in satisfaction with sustainable performance was explained by the five dimensions of Irrigation Modernization Readiness. The remaining 36% of the variation was influenced by other variables not included in the model. The F-test results shown in Table 3 indicated an F-value of 81.283 with a significance level of $p < 0.01$, demonstrating that the independent variables jointly had a statistically significant effect on the dependent variable. Multicollinearity diagnostics, showed that all Variance Inflation Factor (VIF) values were below 10.00 and all tolerance values exceeded 0.100.

Table 3. Summary of multiple linear regression results.

	β	t	ρ	tolerance	VIF
(Constant)	9,239	1,978	0.027		
X1	2,301	2,705	0.007	0.283	2,701
X2	2.105	2,100	0.003	0.128	2,138
X3	1,966	2,624	0.006	0.120	2,252
X4	1,851	2,326	0.000	0.329	1,139
X5	1,078	1,946	0.000	0.092	1,649
R Square (Adj)	0.64				
F	81,283				
p	< 0.001				
KZ test (p)	0.102				

These results indicated that no multicollinearity problems were present among the independent variables. Normality of the regression residuals was assessed using both graphical and statistical methods. The Normal P–P Plot shown in Figure 1 indicated that the residuals were distributed closely along the diagonal line, suggesting a normal distribution. This finding was supported by the Kolmogorov–Smirnov normality test results presented in Table 3, which showed a probability value of 0.102, exceeding the 0.05 significance threshold. These results confirmed that the regression model met the normality assumption and was suitable for further analysis. Heteroscedasticity was examined using a scatterplot of standardized residuals, as shown in Figure 2. The residuals were randomly distributed both above and below the zero value on the Studentized Residual Regression axis, indicating the absence of heteroscedasticity. Therefore, the regression model satisfied the classical assumption of homoscedasticity [14, 15].

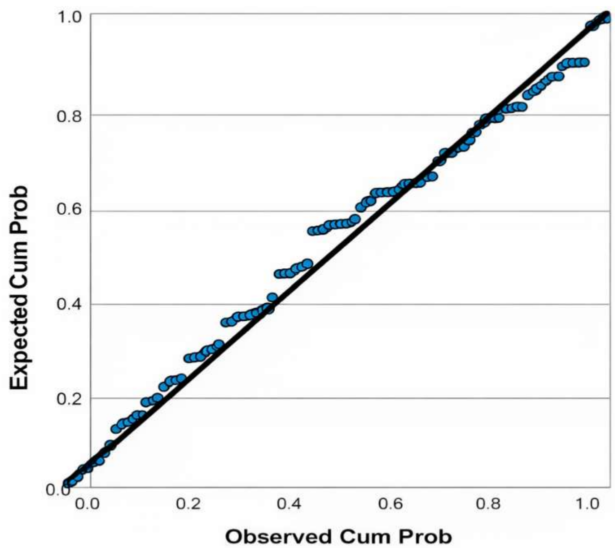

Figure 1. Normality P-Plot.

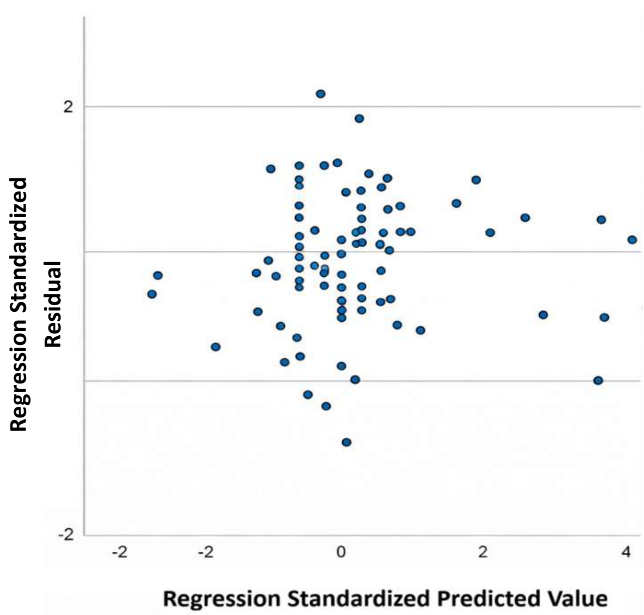

Figure 2. Results heteroscedasticity test.

From the results of the regression equation test above, a multiple linear regression model can be constructed as follows:

$$Y = 9{,}239 + 2{,}301\ X\ 1 + 2.105\ X\ 2 + 1.966\ X\ 3 + 1.851\ X\ 4 + 1.078\ X\ 5 + e$$

The constant coefficient value of 9.239 indicated that if the application of modernization elements for the quality of the irrigation system remained constant, the value of Y (satisfaction with project performance) would be 9.239 units. Water availability had a positive and significant effect on satisfaction with project performance ($\rho < 0.05$). The regression coefficient of variable X_1 (water availability) was 1.966, with a p-value < 0.05. This positive coefficient indicated that an increase of 1 unit in water availability would increase satisfaction with project performance by 1.966 units, provided that other factors remained constant. Infrastructure had a positive and significant effect on satisfaction with project performance ($\rho < 0.05$). The regression coefficient of variable X_2 (infrastructure) was 1.694, also significant with a p-value < 0.05. This indicated that an increase of 1 unit in infrastructure implementation would increase satisfaction by 1.694 units, assuming other factors remained constant. Irrigation management had a positive and significant effect on satisfaction with project performance ($\rho < 0.05$). The regression coefficient of variable X_3 (irrigation management) was 1.052, significant with a p-value < 0.05. This positive coefficient indicated that increasing irrigation management by 1 unit would increase satisfaction by 1.052 units, holding other variables constant. Institutions had a positive and significant effect on satisfaction with project performance ($\rho < 0.05$). The regression coefficient of variable X_4 (institutions) was 1.851, significant with a p-value < 0.05. This indicated that an increase of 1 unit in institutional implementation would increase satisfaction by 1.851 units, provided other factors remained constant. Human resources had a positive and significant effect on satisfaction with project performance ($\rho < 0.05$). The regression coefficient of variable X_5 (human resources) was 1.078, significant with a p-value < 0.05. This positive coefficient indicated that improving human resources by 1 unit would increase satisfaction by 1.078 units, assuming other factors remained constant.

3.4. Discussion

Irrigation modernization in the Rentang area was carried out through physical developments such as the Jatigede Dam, improvements to irrigation infrastructure (channels, buildings, and measuring instruments), development of information and telemetry systems, and strengthening the participatory irrigation system through the construction of the GP3A building. These efforts aimed to improve water supply reliability, expand planting areas, and optimize water distribution efficiency to support agriculture and the community's economy.

The results of this study indicated that all elements of irrigation quality modernization, water availability, infrastructure, irrigation management, institutions, and human resources, positively affected service provider satisfaction in supporting sustainable performance. These findings support previous studies [8, 9], which showed that the five dimensions are not only important in irrigation modernization but also crucial for supporting sustainable performance [16].

In terms of impact on sustainable performance, irrigation modernization improved farmers' economic welfare by increasing income and productivity and supported national food security. It also supported social sustainability through equitable water access and governance and promoted environmental sustainability by improving efficiency, reducing water waste, and mitigating negative environmental impacts [16−18].

Water supply reliability was the most important element in irrigation modernization for sustainable performance ($\beta = 2.301$, $p < 0.05$). This finding aligns with previous studies, which emphasized that water supply reliability is crucial for sustainable performance in terms of economic efficiency, social equity, and environmental sustainability. Implementation included the construction of the Jatigede Dam to increase water storage capacity, enhance supply reliability, and expand the planting area. Water availability was managed through reservoir and dam development, emphasizing conservation, allocation, and distribution, supporting overall sustainability [16, 19, 20].

Irrigation network reliability was the second most important element ($\beta = 2.001$, $p < 0.05$). A modern and reliable irrigation network supported sustainable performance across economic, social, and environmental dimensions. Key components included main buildings, main network channels, tertiary networks, drainage, and hydraulic structures. Activities involved dredging channels, constructing retaining walls, improving inspection roads, and upgrading discharge measuring instruments [21, 22].

Irrigation management was the third key element ($\beta = 1.966$, $p < 0.05$). Modernized irrigation management positively supported sustainable performance. This included manual operation procedures, farmer participation, financing, maintenance and rehabilitation, information and technology systems, strengthening GP3A, telemetry systems for efficient water monitoring, asset mapping, and preparation of detailed engineering designs (DED) [22].

Institutions were the fourth most important element ($\beta = 1.851$, $p < 0.05$). Sustainable water resource management required strong institutional support through "One System, One Management," annual water supply planning, cropping plans, monitoring, participatory systems, efficient water distribution, and robust supporting institutions. Effective farmer union communities enhanced irrigation network performance [23, 24].

Human resources were the fifth element ($\beta = 1.078$, $p < 0.05$). Development of government and community human resources included training, mentoring, and knowledge transfer programs. Well-trained and qualified personnel improved sustainable performance across economic, social, and environmental dimensions [8, 9, 25, 26].

4. Conclusions

The results of the study found that the quality of water supply and distribution, physical infrastructure, governance, data and information, and policies and institutions are important elements in the modernization of irrigation system quality and have a positive influence on sustainable performance. This study provides theoretical implications for the development of an evaluation model for irrigation network modernization within a sustainable performance framework, incorporating a stakeholder preference approach. The development of irrigation modernization has proven beneficial in supporting sustainable performance. Additionally, this study provides practical implications for creating a QMS manual, particularly for the modernization of national irrigation projects within a sustainable performance framework. This study has several limitations that may affect its results. First, it is limited to the preferences and satisfaction of service users. Findings may differ if other stakeholders, such as farmers or policymakers, were included. Therefore, further research is needed to capture the preferences and satisfaction of a broader range of stakeholders. Second, the measurement and evaluation model relied on a survey approach, which is advantageous for exploring qualitative aspects of stakeholder preferences and ensuring that the project meets stakeholder expectations. However, this approach has limitations related to the development of preference levels alongside the evolving knowledge and experience of stakeholders.

References

[1] Negera, M.; Dejen, Z.A.; Melaku, D.; Tegegne, D.; Adamseged, M.E.; Haileslassie, A. (2025). Agricultural Productivity of Solar Pump and Water Harvesting Irrigation Technologies and Their Impacts on Smallholder Farmers' Income and Food Security: Evidence from Ethiopia. *Sustainability*, *17*, 1486. https://doi.org/10.3390/su17041486.

[2] Tirtalistyani, R.; Murtiningrum, M. (2022). Indonesia Rice Irrigation System: Time for Innovation. *Sustainability*, *14*, 12477. https://doi.org/10.3390/su14191247.

[3] Ali, A.; Hussain, T.; Zahid, A. (2025). Smart Irrigation Technologies and Prospects for Enhancing Water Use Efficiency for Sustainable Agriculture. *AgriEngineering*, *7*, 106. https://doi.org/10.3390/agriengineering7040106.

[4] Wawak, S.; Ljevo, Ž. (2020). Understanding the Key Quality Factors in Construction Projects — A Systematic Literature Review. *Sustainability*, *12*, 10376. https://doi.org/10.3390/su122410376.

[5] Al-jabri, K.; Al-busaidi, A.; Ahmed, M.; Janke, R.R.; Stefanakis, A. (2025). Optimizing Oilfield-Produced Water Reuse for Sustainable Irrigation: Impacts on Soil Quality and Mineral Accumulation in Plants. *Water*, *12*, 1497. https://doi.org/10.3390/w17101497.

[6] Kirmikil, M. (2025). Irrigation Performance Evaluation for Sustainable Water Management: A Study of Karacabey Water Users Association. *Sustainability*, *17*, 4059. https://doi.org/10.3390/su17094059.

[7] Fan, X.; Qin, J.; Lv, M.; Jiang, M. (2024). An Evaluation System of the Modernization Level of Irrigation Districts with an Analysis of Obstacle Factors: A Case Study for North China. *Agronomy*, *14*, 538. https://doi.org/10.3390/agronomy14030538.

[8] Imron; Murtiningrum, M. (2021). Modernization Readiness Analysis of Belitang Irrigation System at Region Level Using Analytic Hierarchy Process (AHP) Method. *IOP Conference Series: Earth and Environmental Science*, *644*, 1–9. https://doi.org/10.1088/1755-1315/644/1/012070.

[9] Swandani, M.A.; Maulana, M.A.; Savitri, Y.R.; Engineering, E. (2024). Analysis of Modernization Readiness of Irrigation in the Downstream Brantas River Basin Under the Authority of the Central Government. *Civilla Journal of Civil Engineering Universitas Islam Lamongan*, *09*, 1, 73–86.

[10] Kusumastuti, A.I.; Multirejeki, I.; Firmanto, A. (2024). Stakeholder Satisfaction with Physical Infrastructure Development in Rural Areas: Sustainable Construction Approach. *Asian Journal of Management, Entrepreneurship and Social Science*, *04*, 2, 1461–1474.

[11] Li, H.; et al. (2022). Stakeholder Perceptions of Sustainable Infrastructure Project Delivery: A Comparative Analysis between Guangdong, Hong Kong, and Macao. *Journal of Environmental and Public Health*, 1–16. https://doi.org/10.1155/2022/5398706.

[12] Mahmood, S.; Sabir, M.; Id, G.A. (2020). Infrastructure Projects and Sustainable Development: Discovering the Stakeholders' Perception in the Case of the China–Pakistan Economic Corridor. *PLoS One*, *15*, 8, e0237385. https://doi.org/10.1371/journal.pone.0237385.

[13] Hair, G.T.M.; Hult, C.M.; Ringle, C.; Sarstedt, M. (2017). A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM), 2nd Ed.; Sage Publications Inc.: Thousand Oaks, USA.

[14] Klemczak, B.; Bąba, D.; Siddique, R. (2026). Evaluation of Machine Learning Approaches for Hydration Heat Prediction in Energy-Efficient Cement Composites. *Energies*, *19*, 39. https://doi.org/10.3390/en19010039.

[15] Myśliwiec, P.; Szawara, P.; Kubit, A.; Zwolak, M.; Ostrowski, R.; Derazkola, H.A.; Jurczak, W. (2025). FSW Optimization: Prediction Using Polynomial Regression and Optimization with Hill-Climbing Method. *Materials*, *18*, 448. https://doi.org/10.3390/ma18020448.
[16] Zhang, Z.; Li, Y.; Elahi, E.; Wang, Y. (2022). Comprehensive Evaluation of Agricultural Modernization Levels. *Sustainability*, *14*, 5069. https://doi.org/10.3390/su14095069.
[17] Santos, E.; Moreira, J. (2022). Social Sustainability of Water and Waste Management Companies in Portugal. *Sustainability*, *14*, 221. https://doi.org/10.3390/su14010221.
[18] Djukic-Min, D.; Norcross, J.; Searing, E. (2025). The Effect of Shared and Inclusive Governance on Environmental Sustainability at U.S. Universities. *Sustainability*, *17*, 6630. https://doi.org/10.3390/su17146630.
[19] Tao, B.; Sun, Q.; Wang, J.; Zhang, J.; Xing, Z. (2024). Optimizing Multi-Scenario Water Resource Allocation in Reservoirs Considering Trade-Offs between Water Demand and Ecosystem Services. *Water*, *16*, 563. https://doi.org/10.3390/w16040563.
[20] Li, P.; Wu, J. (2024). Water Resources and Sustainable Development. *Water*, *16*, 134. https://doi.org/10.3390/w16010134.
[21] Glória, A.; Dionisio, C.; Simões, G.; Cardoso, J.; Sebastião, P. (2020). Water Management for Sustainable Irrigation Systems Using Internet-of-Things. *Sensors*, *20*, 1402. https://doi.org/10.3390/s20051402.
[22] Kirmikil, M. (2025). Irrigation Performance Evaluation for Sustainable Water Management: A Study of Karacabey Water Users Association, Türkiye (2006–2023). *Sustainability*, *17*, 4059. https://doi.org/10.3390/su17094059.
[23] Alsaeed, B.S.; Hunt, D.V.L.; Sharifi, S. (2024). A Sustainable Water Resources Management Assessment Framework (SWRM-AF) for Arid and Semi-Arid Regions—Part 1: Developing the Conceptual Framework. *Sustainability*, *16*, 2634. https://doi.org/10.3390/su16072634.
[24] Moltz, H.L.N.; Wallace, C.W.; Sharifi, E.; Bencala, K. (2020). Integrating Sustainable Water Resource Management and Land Use Decision-Making. *Water*, *12*, 2282. https://doi.org/10.3390/w12082282.
[25] Lewandowska, A.; Ullah, Z.; AlDhaen, F.S.; AlDhaen, E.; Yakymchuk, A. (2023). Enhancing Organizational Social Sustainability: Exploring the Effect of Sustainable Leadership and the Moderating Role of Micro-Level CSR. *Sustainability*, *15*, 11853. https://doi.org/10.3390/su151511853.
[26] Kang, Y.-C.; Hsiao, H.-S.; Ni, J.-Y. (2022). The Role of Sustainable Training and Reward in Influencing Employee Accountability Perception and Behavior for Corporate Sustainability. *Sustainability*, *14*, 11589. https://doi.org/10.3390/su141811589.