International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 8 ǁ August 2025 ǁ PP. 16-23

Analysis of Factors Affecting Construction Quality in the Rehabilitation and Reconstruction Works of the Gumbasa Irrigation Canal

Rahmat [1], Sukiman Nurdin [2], Tutang Muhtar Kamaludin [3]
[1,2]Civil Engineering Study Program, Faculty of Engineering, Tadulako University, Palu 94111, Indonesia*
[3]Postgraduate Student of Civil Engineering Department, Tadulako University, Palu 94111, Indonesiaent of
Corresponding Author: rahmatnindicupu98@gmail.com

Abstract
This study analyzes the effect of precast concrete quality and the use of geotextiles on construction quality in the rehabilitation project of the Gumbasa primary irrigation canal in Central Sulawesi, Indonesia. A quantitative approach using multiple linear regression methods was employed, based on primary data from 30 project respondents and laboratory test results. The analysis results show that both variables significantly affect construction quality, both simultaneously and partially. The regression model yields a coefficient of determination (R^2) of 0.997, indicating that 99.7% of the variation in construction quality is explained by the quality of precast concrete and geotextiles. The compressive strength of K-225 precast concrete ranges from 259.9 to 280 kg/cm², while the tensile strength of geotextiles reaches 13.6 kN/m. These materials have been proven to be key determinants of structural performance in post-disaster irrigation infrastructure projects. This study emphasizes the importance of quality control and compliance with technical specifications to ensure construction excellence in disaster-prone areas.

Keywords: construction quality, precast concrete, geotextile, regression, Gumbasa irrigation

---

Date of Submission: 27-07-2025 Date of acceptance: 05-08-2025

I. INTRODUCTION

Irrigation infrastructure plays a crucial role in supporting agricultural resilience and food security. Following the earthquake and liquefaction disaster in 2018 in Central Sulawesi, the Gumbasa irrigation system suffered severe damage, disrupting water supply to thousands of hectares of agricultural land. The rehabilitation and reconstruction of the primary canal became essential, not only for economic recovery but also for enhancing disaster preparedness in the future. Among the many variables affecting construction quality, material quality—particularly precast concrete and geotextiles—has been identified as a key factor in the durability and functionality of irrigation structures.

In addition to precast concrete and geotextiles, construction quality is also influenced by geomembrane performance, embankment soil compaction, and overall field supervision. Geomembranes serve as essential lining materials to prevent seepage, while proper soil compaction ensures slope stability and structural resilience. Lack of supervision can result in deviations from technical drawings and reduced work performance. These additional factors have been validated in recent field studies and must be considered holistically in irrigation infrastructure projects.

Despite the critical importance of these materials, few studies have quantitatively assessed their impact on construction quality in post-disaster infrastructure projects. Therefore, this research aims to examine the extent to which the quality of precast concrete and geotextiles contributes to construction quality through statistical modeling, technical testing, and field validation.

Construction quality refers to the degree of compliance with project specifications, technical standards, and the needs of end users. According to Juran (1999), quality is achieved through design, control, and continuous improvement. In irrigation projects, quality indicators include hydraulic performance, structural stability, material strength, and service life. Precast concrete, commonly used for canal lining and culverts, offers advantages such as dimensional accuracy and faster construction. However, its effectiveness depends on production consistency, curing conditions, and handling during installation. Geotextiles, used as separators, filters, and reinforcement layers, enhance the strength of the subsoil and prevent soil particle migration. Their performance is determined by tensile strength, elongation, and compatibility with local soil conditions. Previous studies have linked material quality to infrastructure performance.

Sitorus & Dewi (2020) demonstrated the vital role of concrete properties in canal rehabilitation. Prasetya et al. (2021) found that nonwoven geotextiles improve slope stability and erosion control. However, most of these studies have not integrated statistical and laboratory validation as done in this research.

In addition to the main factors such as the quality of precast concrete and geotextiles, there are several other factors that potentially hinder the achievement of construction quality in the irrigation canal rehabilitation project. Based on field observations and previous literature, these factors include:

1. Delayed material procurement which may lead to work pile-ups and the use of materials that do not meet specifications.
2. Lack of skilled labor in the installation of precast elements and the application of geotextiles.
3. Extreme weather conditions such as prolonged rainfall that disrupts work schedules and subsoil stability.
4. Weaknesses in field supervision, both in terms of inspection frequency and strictness in enforcing quality standards.
5. Limited availability of heavy equipment that results in suboptimal work, particularly in compaction or transportation of structural components.

Non-compliance in field implementation with design drawings, which directly impacts the hydraulic and structural performance of the canal. These factors must be anticipated through thorough planning, regular supervision, as well as enhancing the capacity of human resources and project logistics.

According to Kerzner (2017), construction quality is defined as the degree to which project deliverables meet stakeholder requirements and project specifications. Quality is achieved through proper planning, execution, inspection, and continuous improvement.

In the context of irrigation projects, quality control includes monitoring the strength of concrete, stability of slopes, and durability of geosynthetic materials. Juran's Trilogy (Juran, 1999) identifies three components of quality management: quality planning, quality control, and quality improvement, all of which must be integrated in infrastructure development.

de Brito and de Brito (2012) argue that sustainable construction must consider environmental factors, resource efficiency, and long-term performance, which is relevant for rehabilitation projects in disaster-prone areas like Gumbasa.

II. METHODOLOGY

This explanatory quantitative research uses multiple linear regression to examine the simultaneous and partial effects of precast concrete quality (X1) and geotextile performance (X2) on construction quality (Y). This method aligns with the analytical approach in civil engineering research, as described by Ghozali (2016) and Hair et al. (2010), who recommend using linear regression to assess the relationships between quantitative variables.

Population and Sample: The sample consists of 30 respondents involved in the rehabilitation project of the Gumbasa primary canal, including field engineers, supervisors, foremen, and quality control staff. Data

Collection Techniques: Likert scale questionnaires, field observations, and material testing results (Sugiyono, 2019).

Statistical Analysis Tools: Descriptive analysis, classical assumption tests (normality, multicollinearity), and regression analysis using SPSS software.

This study employs a Sequential Explanatory Mixed Method Design. The first phase uses a quantitative approach through surveys, laboratory material tests, and statistical modeling, while the second phase integrates qualitative insights from field observations and expert interviews.Instrument Validation: The questionnaire used a Likert scale (1–5) and was validated using Cronbach's Alpha ($\alpha = 0.84$), indicating high internal consistency. Laboratory tests followed SNI standards: SNI 03-2834-2000 for concrete compressive strength and ASTM D4595 for geotextile tensile strength.

Classical Assumption Tests: Normality was tested using the Kolmogorov-Smirnov method, multicollinearity was assessed through tolerance and VIF values, and heteroscedasticity was checked via scatterplot analysis. All assumptions were met, confirming the validity of the regression model.Software Used: SPSS version 25 was used for quantitative analysis, while qualitative data was manually coded and thematically analyzed.

Factors Potentially Affecting Construction Quality

Several field-related and material-based factors were observed to potentially hinder construction quality: Geomembranes used in the project showed varying degrees of resistance to environmental degradation. Local membranes, in some cases, did not meet tensile strength or UV resistance standards. Soil compaction levels differed significantly between on-site native soil and imported fill materials. Lower compaction could result in slope instability. The availability and condition of heavy machinery affected compaction and placement consistency, particularly in peak wet seasons. Irregular site supervision and lack of real-time inspection increased the risk of non-conformity with technical drawings. Weather conditions such as prolonged rain caused delays and impacted subgrade stability. These findings were supported by technical laboratory testing and field observation logs.

The application of a mixed-method design in this study provided a more comprehensive perspective on irrigation construction quality. While quantitative data captured numerical conformity (e.g., compressive strength, tensile force), qualitative inputs revealed operational challenges and site-specific variations.

Interviews with project engineers and field supervisors unveiled gaps between procedural standards and field realities. These insights would not have emerged through statistical analysis alone. Therefore, future infrastructure quality studies are encouraged to combine objective measurements with on-ground contextual exploration to produce findings that are both accurate and actionable.

III. RESULT AND DISCUSSION’

1. Descriptive Statistics

Descriptive statistics provide an initial overview of the data tendencies. The mean value of variable X1 (precast concrete) is 3.52, indicating that respondents generally rate the quality of precast concrete as good. Likewise, the mean value of variable X2 (geotextile) is 3.60, suggesting positive perceptions regarding the use and effectiveness of geotextiles. Variable Y (construction quality) has a mean value of 3.58, which means that most respondents assess construction quality as good.

Variabel	N	Mean	Std. Dev	Min	Max
X1	30	3.52	0.25	3.10	3.90
X2	30	3.60	0.30	3.00	4.00
Y	30	3.58	0.28	3.00	4.00

2. Multiple Linear Regression

Analysis Regression Equation:

$$Y = -0.530 + 0.504X1 + 0.500X2$$

The constant value (-0.530) represents the construction quality when both X1 and X2 are zero. The regression coefficient of X1 (0.504) means that every one-unit increase in the precast concrete quality (X1) will increase construction quality (Y) by 0.504 units, assuming other variables remain constant. The regression coefficient of X2 (0.500) shows that every one-unit increase in geotextile quality (X2) will increase construction quality by 0.500 units, assuming other variables remain constant. This interpretation shows that both variables (precast concrete and geotextile) have positive and significant effects on construction quality. The regression results indicate a coefficient of determination (R^2) of 0.997, meaning that 99.7% of the variability in construction quality can be explained by the quality of precast concrete and geotextiles.

3. Uji F (Simultan)

ANOFA

Sumber	Jumlah kuadrat	df	mean	F Hitung	F Tabel (df=2,22)	Sig.
Model Regresi	304,860	2	152,430	4573.571	3.354	<0.001
Residu	,900	27	,033			
total	305,760	29				

The model is significant, meaning variables X1 and X2 jointly influence Y. F_calculated = 4573.571 > F_table = 3.354131 Or equivalently, Sig. value < 0.05 (Significant influence present).

4. Uji t (parsial)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-,530	,977		-,543	,592		
	X1	,504	,030	,487	16,884	<,001	,131	7,622
	X2	,500	,027	,529	18,360	<,001	,131	7,622

a. Dependent Variable: Y

X1: t_calculated = 16.884 > t_table = 2.052 → significant X2: t_calculated = 18.360 > t_table = 2.052 → significant.

Furthermore, laboratory results indicated that the tensile strength of some locally procured geomembranes did not reach acceptable quality thresholds. This raises concern about the long-term durability of canal lining in the affected areas. Compaction tests on embankment soil also revealed that density values in areas using locally available fill were 10-15% lower than those using engineered fill. These variations influence not only slope integrity but also canal alignment. Supervision gaps during execution also allowed for deviations in material handling and placement. Collectively, these technical issues further justify the importance of comprehensive quality management in post-disaster infrastructure projects.
Interpretation: Both variables positively and significantly affect construction quality. This indicates that the better the quality of precast concrete (X1) and geotextile (X2), the higher the construction quality (Y). The regression coefficients show that a one-unit increase in X1 improves quality by 0.504 units, and a one-unit increase in X2 improves quality by 0.500 units, assuming other variables remain constant.

5. Coefficient of Determination (R^2)
$R^2 = 0.997$ indicates that 99.7% of the variation in construction quality is explained by the model.
The laboratory compressive strength results of K-225 precast concrete showed consistency above the standard threshold of 225 kg/cm², with the average value of 270.2 kg/cm². This demonstrates production control adherence and proper curing during manufacture.

Tensile strength tests on geotextiles yielded an average of 13.6 kN/m, meeting design requirements for soil reinforcement and filtration. The elongation at break was measured at 46.5%, indicating high ductility suitable for uneven terrain.

Moisture content of embankment soil samples ranged from 18–24%, while the compaction ratio varied between 91–96%, depending on the equipment and material origin. This variability highlights the need for equipment standardization and site-specific soil treatment.

6. Technical Validation
a. Compressive strength of K-225 precast concrete: 259.9–280 kg/cm² (meets/exceeds specifications).
b. Tensile strength of geotextile: 13.6 kN/m (adequate for expected loads).

Ensuring the enforcement of quality standards in post-disaster reconstruction areas poses unique challenges. In the Gumbasa project, some technical personnel reported difficulties in accessing calibrated equipment or standardized laboratories for material testing.

Additionally, transportation disruptions and supplier delays often led contractors to use alternative materials without complete documentation, making quality validation more difficult. These conditions highlight the need for mobile testing labs, standardized field kits, and simplified reporting mechanisms that can operate even in isolated or disrupted areas. Without such adjustments, formal standards risk becoming aspirational rather than actionable in disaster contexts.

Effective quality control in post-disaster construction projects requires coordination among multiple stakeholders. In the Gumbasa project, quality outcomes were influenced not only by technical decisions but also by the synchronization between government agencies, local contractors, suppliers, and supervisory consultants. Lack of unified documentation systems and inconsistent communication often led to delays in response to quality deviations.

To improve stakeholder coordination, a centralized digital dashboard could be established to integrate project timelines, inspection reports, and material certifications. Such a platform would reduce redundancy, improve traceability, and foster accountability across all parties involved.

7. Project Context

a. Contractor: PT Nindya Karya (Persero)
b. Supervision: BWS Sulawesi III and independent
c. QC consultant Project Type: Post-disaster rehabilitation (Package 5)

The variation in field data emphasizes the importance of combining statistical evidence with technical validations. For instance, while regression shows strong correlation, laboratory testing confirms whether the specified material strengths are achieved in practice.

Additionally, project supervision was noted to vary by sub-package. Packages with consistent third-party QC involvement showed better outcomes in slope uniformity and structural alignment. This supports Wulandari & Santoso (2018), who emphasize the role of proactive inspection in minimizing defects. Moreover, the integration of geomembrane as a lining material not only reduces seepage but also supports sustainability by limiting water loss, aligning with Brito & Brito's concept of environmental control in civil works.

Post-disaster infrastructure projects differ significantly from routine construction due to emergency conditions, supply chain disruptions, limited labor, and urgent timelines. In Gumbasa, for example, the 2018 liquefaction resulted in unstable soil conditions, forcing field engineers to frequently adjust compaction plans. Equipment delays and lack of local material consistency also reduced productivity.

Based on interviews with supervisors and QC staff, several construction deviations were traced back to inadequate handling procedures and supplier-related inconsistencies. Many packages relied on alternative materials when standard units were unavailable, particularly in the case of geomembranes, where tensile tests revealed subpar values in some samples.

Construction quality is directly linked to infrastructure longevity. Improperly compacted soil can cause progressive settlement, endangering slope integrity and water flow uniformity. While precast components may initially pass inspection, improper curing or joint sealing can lead to early cracking. Lessons from similar projects indicate that defects at construction can reduce canal life from 20 to 10 years.

Periodic performance audits and post-occupancy evaluations are recommended to assess real-world degradation. These assessments should include seepage tests, surface settlement surveys, and random coring of concrete for residual strength measurements.

Beyond technical improvements, institutional readiness plays a role in post-disaster quality assurance. Agencies should create disaster-responsive procurement protocols, where emergency suppliers are pre-qualified for quality compliance. Contractors should submit not only completion reports but midterm quality updates validated by independent consultants. Government bodies can also partner with universities to pilot innovative low-cost monitoring tools, such as moisture-sensing geomembrane layers or drone-assisted topography checks for slope alignment.

This study opens up new avenues in construction quality analysis. Future studies may include slope gradient variability, workforce skill levels, or climatic disruptions as explanatory variables in predictive models. Research focusing on digital field supervision tools, AI-based predictive maintenance, and life-cycle cost analysis of geosynthetic materials will help transition infrastructure development toward sustainability.

As climate variability increases, irrigation infrastructure must adapt to more frequent and extreme events such as flash floods, prolonged droughts, and sediment surges. Future designs should incorporate flexible water regulation features, overflow channels, and sediment traps to accommodate shifting environmental patterns. In the Gumbasa region, changes in rainfall distribution due to La Niña and El Niño cycles have affected planting schedules and water demands. Therefore, post-rehabilitation evaluations must consider not only physical durability but also hydrological responsiveness of the infrastructure. These climate-informed adjustments would strengthen the long-term relevance and utility of irrigation networks.

Post-disaster irrigation projects in various regions of Indonesia have demonstrated different outcomes depending on their institutional capacity and material readiness. For example, in the Lombok irrigation rehabilitation project (2020), the use of non-standard geotextiles led to channel wall deformation within two years of service. Conversely, in the Aceh reconstruction program (post-tsunami), adherence to QA/QC protocols resulted in infrastructure that continues to function effectively over a decade later. The Gumbasa project shows positive tendencies in terms of material strength but exhibits variation in field execution, particularly slope finishing and compaction uniformity.

Human factors remain a crucial yet under-researched element in post-disaster construction. Observations from the field show that construction crews at Gumbasa had varying levels of training regarding the placement of geotextiles, handling of precast components, and interpretation of engineering drawings. The integration of capacity building, through routine technical training and visual field guides, must be institutionalized, especially in remote or rural project settings.

The complexity of post-disaster irrigation projects requires a shift from linear project planning to risk-based quality management. This approach considers the likelihood of failure for each component and integrates mitigation into each construction stage. For example, redundant waterproofing layers can be justified in segments with high seepage risk. Similarly, adaptive construction scheduling can be applied in high-rainfall months.

While quality has traditionally been viewed in terms of structural performance, sustainability indicators are increasingly important in modern irrigation projects. The Gumbasa project, though focused on functional rehabilitation, presents opportunities to assess environmental trade-offs. Future irrigation development should include a sustainability scorecard, incorporating resource efficiency, material reusability, local labor utilization, and ecological impact.

The sustainability of irrigation infrastructure depends not only on initial construction quality, but also on continued performance monitoring throughout its service life. A structured long-term monitoring framework should include periodic inspections, sensor-based seepage detection, slope displacement measurements, and remote data logging. For the Gumbasa site, a proposed monitoring interval could follow a 6-month cycle for the first 2 years, and annually thereafter, covering structural, hydraulic, and environmental indicators. This framework would allow early detection of degradation, reduce repair costs, and extend the effective life of the system. It also creates a feedback loop for learning and improvement in future projects.

The sustainability of irrigation infrastructure depends not only on initial construction quality, but also on continued performance monitoring throughout its service life.

A structured long-term monitoring framework should include periodic inspections, sensor-based seepage detection, slope displacement measurements, and remote data logging.

For the Gumbasa site, a proposed monitoring interval could follow a 6-month cycle for the first 2 years, and annually thereafter, covering structural, hydraulic, and environmental indicators.

This framework would allow early detection of degradation, reduce repair costs, and extend the effective life of the system. It also creates a feedback loop for learning and improvement in future projects. This study opens

One of the less emphasized aspects in post-disaster construction is the mechanism of knowledge transfer from project-level experts to local operators. Many quality issues in rural irrigation projects stem from the knowledge gap between what is planned by consultants and what is implemented on-site. In the Gumbasa project, interviews revealed that some field workers and local supervisors lacked adequate understanding of the specifications for geotextile overlap, compaction techniques, or proper curing times. This gap can significantly affect long-term performance. To address this, future projects should include mandatory training sessions for local teams, simplified construction manuals in visual form, and collaborative inspections that involve both supervisors and local stakeholders. This approach builds not only physical infrastructure but also local capacity, ensuring sustainable operation and maintenance of the system after handover.

IV. CONCLUSION

In addition to the statistically proven effect of precast concrete and geotextile, this study also identifies the influence of geomembrane durability, soil compaction quality, and project supervision on construction outcomes. These components, while not included in the regression model, were validated through lab data and field observations, and should be integrated into future quality management protocols. Efforts should also be directed at enhancing field inspections and ensuring consistent compliance with design specifications.

There is a significant influence between the quality of precast concrete and geotextiles on construction quality in the rehabilitation and reconstruction project of the Gumbasa Irrigation Canal (Package 5). The results of simultaneous and partial tests show that both variables have a positive and significant relationship with construction quality. The regression equation indicates that the largest contribution comes from the geotextile variable, followed by precast concrete. The coefficient of determination value of 0.997 proves that the model can almost entirely explain the variation in construction quality. Precast concrete and geotextiles have a significant and measurable impact on construction quality in irrigation rehabilitation projects. Their influence has been statistically validated and supported by material testing data. For post-disaster reconstruction projects, this underscores the importance of material control and compliance with technical specifications.

Recommendations: Improve on-site material inspections, standardize testing protocols, and provide training for field personnel in quality management practices. One promising direction for improving construction quality is the adoption of digital supervision tools. Currently, most monitoring in irrigation projects is manual and paper-based, which can delay response to deviations.
The integration of digital field forms, GIS-tagged inspections, and UAV (drone) footage can streamline supervision and provide real-time alerts to consultants and contractors.
These tools also allow project owners to remotely verify progress and compliance, reducing reliance on subjective visual assessments. Pilot programs for digital quality control should be launched, especially in remote or disaster-prone regions.

The findings from this study contribute to the broader discourse on disaster-resilient infrastructure planning in Indonesia. The Gumbasa case illustrates how technical compliance alone is insufficient without integrated supervision, adaptive methods, and sustainable material use.
This research supports national efforts to build irrigation systems that can survive seismic shocks, liquefaction, and climate-related stressors. In doing so, it aligns with Indonesia's National Medium-Term Development Plan (RPJMN) 2020–2024, which prioritizes infrastructure that is not only functional but also sustainable and resilient. Incorporating lessons from this study into future policy formulation can enhance public procurement standards, training modules for field engineers, and multi-agency collaboration protocols.

ACKNOWLEDGEMENT

The authors would like to extend their sincere gratitude to all individuals and institutions who contributed to the successful completion of this research. Special thanks are directed to the research team for their dedication and collaboration throughout the study. The authors are also deeply thankful to the leadership of the Civil Engineering Study Program and the Head of the Faculty of Engineering at Tadulako University for their continuous academic and administrative support. Appreciation is also given to the Ministry of Public Works and Housing (PUPR), Balai Wilayah Sungai Sulawesi III, and project field staff in the Gumbasa area for their assistance in providing data, facilitating site visits, and offering valuable insights into the construction process. Lastly, the authors acknowledge all lecturers and fellow postgraduate students at the Civil Engineering Department of Tadulako University who provided critical feedback and moral encouragement throughout the research and thesis writing process.

REFERENCES

[1] Sitorus, A., & Dewi, N.P. (2020). Evaluation of Concrete Quality in Irrigation Canal Rehabilitation. Journal of Civil Engineering, 24(2), 150–158..
[2] Prasetya, Y., et al. (2021). Utilization of Nonwoven Geotextiles for Slope Stability. Indonesian Journal of Civil Engineering, 9(1), 33–40.
[3] Basuki, R., & Handayani, T. (2018). Study on the Impact of Geotextile Use on Drainage Channel Performance. ITS Engineering Journal, 7(2), D208–D212.
[4] Nugroho, F.A. (2017). Analysis of Construction Implementation Quality in Irrigation Projects. Journal of Civil and Environmental Engineering, 5(1), 10–17.
[5] Nurdiansyah, M. (2020). The Effect of Material Quality on Infrastructure Project Performance. Construction Journal, 6(2), 45–52.
[6] Maulana, R., & Haryanto, E. (2021). Evaluation of Precast Concrete Use in Enhancing Construction Efficiency. Journal of Civil and Architectural Engineering, 3(2), 75–84.
[7] Ramadhan, H., & Widodo, D. (2019). Determinant Factors of Construction Project Quality. Journal of Civil Engineering, Muhammadiyah University, 4(1), 20–30.
[8] Wulandari, S., & Santoso, B. (2018). Implementation of Quality Control Systems in Irrigation Projects. Journal of Infrastructure Engineering, 2(3), 112–119.
[9] Ariyanto, F., & Surya, A. (2017). Analysis of Compliance Levels with Construction Material Specifications. Scientific Journal of Construction, 6(1), 55–61.
[10] Kurniawan, A., & Darmawan, A. (2020). The Role of Supervision Consultants in Ensuring Work Quality. Journal of Construction Technology, 10(2), 22–29.
[11] Kurniawan, A., & Darmawan, A. (2020). The Role of Supervision Consultants in Ensuring Work Quality. Journal of Construction Technology, 10(2), 22–29.
[12] Hakim, L., & Putra, A.W. (2016). Analysis of the Effect of Material Quality on Construction Performance. Scientific Journal of Civil Engineering, 13(1), 45–52.
[13] Surya, D., & Nugraha, I. (2023). Evaluation of Geotextile Effectiveness in Primary Irrigation Channels. Journal of Civil Engineering Innovation, 7(1), 1–10.

[14] Syahrul, H., & Taufik, R. (2015). Feasibility Study of Precast Materials in Irrigation Projects. Journal of Infrastructure Engineering, 4(2), 87–94.
[15] Andika, B., & Permana, Y. (2021). The Effect of Concrete Quality on Secondary Channel Stability. Infrastructure Research Journal, 9(1), 51–59.
[16] Rachman, M., & Yunus, H. (2017). Technical Integrity of Geomembranes in Irrigation. Journal of Infrastructure Studies, 8(2), 77–85.
[17] Maulana, R., et al. (2022). Evaluating Embankment Soil Compaction in Irrigation Projects. Geotechnical Engineering Review, 10(3), 134–142.
[18] Sutrisno Hadi. (2000). Metodologi Research. Yogyakarta: Andi.
[19] Kerzner, H. (2017). Project Management: A Systems Approach to Planning, Scheduling, and Controlling. Wiley.
[20] Brito, J. G., & de Brito, M. J. (2012). Sustainable Construction: Green Building Design and Delivery. Wiley.