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Design of Protective Structures to Anticipate Flood-Induced Damage to the *Jenelata* Bridge Abutment

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ABSTRACT

The extreme flood in January 2019 caused significant damage to the *Jenelata* Bridge in *Gowa* Regency, including the collapse of protective structures and disruption of abutment stability. This study aims to design protective structures capable of preventing similar damage in the future. The methodology includes hydrological and hydraulic analysis, geotechnical evaluation, and assessment of gabion effectiveness as an alternative protective structure. Results indicate that a 100-year return period flood generates a peak discharge of approximately 1058 m³/s, which poses a high risk of scouring along the riverbanks. A Type-C gabion structure with dimensions of 4 × 1 × 1 m was designed for a total length of 100 m (50 m upstream and 50 m downstream) to protect the abutment. Stability analysis confirmed the structure's ability to withstand water and soil pressures with adequate safety factors. The estimated construction cost is Rp 346,190,130. This study recommends gabions as an effective solution for the rehabilitation of *Jenelata* Bridge to ensure sustainable transport connectivity in flood-prone areas.

Keywords: *Jenelata* Bridge, flash flood, abutment, gabion, rehabilitation

INTRODUCTION

Bridges are vital infrastructure that ensures connectivity between regions. However, their location across rivers makes them vulnerable to flood-related damage, particularly at the abutments. The flash flood in *Gowa* Regency on January 22, 2019, triggered by extreme rainfall and spillway releases from the Bili-Bili Dam, caused severe damage to the *Jenelata* Bridge. The abutment was scoured by strong currents, compromising structural stability and disrupting community transportation.

Local scour around foundations is a major cause of bridge failures. Without protective measures, riverbed degradation will continue to threaten bridge integrity. Therefore, a protective structure design is required to resist hydraulic forces and safeguard the abutments.

This study aims to identify the primary causes of abutment damage, determine effective rehabilitation methods, and design a protective structure with its cost estimation.

LITERATURE STUDY

Suripin (2004) argues that erosion is the main factor that weakens foundations, which can cause them to lose stability, often leading to bridge collapse. Similarly, according to Asdak (2010), the severity of flooding is greatly influenced by the conditions of the river basin, making it very important to conduct a hydrological analysis in every bridge design, especially bridges located above rivers. Several bridge protection methods have been implemented to protect bridge structures and support the sustainability of bridges. The method of selecting gabions in Indonesia is more dominant than other methods because of its cost effectiveness, adaptability, and suitability to the environment, namely that vegetation can grow through the

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wire mesh, thereby increasing long-term stability.

Wulandari (2025) also stated that the opening of the Bili-bili dam floodgates was due to the water level almost reaching its maximum elevation. As a result of the opening of the floodgates, water overflowed downstream at a very high speed and discharge rate. Meanwhile, Zaldi et al. (2023) explained that uncontrolled erosion due to flooding was the main factor in the damage to the bridge construction, namely the twisting of one of the abutments and the collapse of the safety structure with a severe level of damage. This study expands on previous research by designing a gabion-based protective structure specifically for the *Jenelata* Bridge, based on hydrological, hydraulic, and structural analyses.

Sri Harto (1993) states that there are several types of hydrographs commonly used, namely water level hydrographs, discharge hydrographs, and sediment hydrographs. Water level hydrographs relate changes in water level to time. Meanwhile, discharge hydrographs relate discharge to time. Finally, sediment hydrographs relate sediment content to time.

The correlation between this study and previous studies can be said to be quite complex and complementary. The research by Asdar Azis (2024) and Calvin Sandi et al. (2022) serves as a basic reference because both directly discuss the failure of the *Jenelata* Bridge construction and design restoration efforts and risk management. The research explains the importance of identifying the main factors causing damage and implementing safe and sustainable reconstruction solutions in line with the objectives of this study in designing safety structures.

Furthermore, the research by Nenny et al. (2020) and Erwin et al. (2020) provides knowledge about the influence of flow characteristics and water depth on local scouring around bridge structures, which can also be one of the factors causing damage to bridge structures due to flooding. Their research results explain the importance of designing each element of a safety structure that can mitigate the impact of scouring.

Zul Hidayat's (2019) research on the flow capacity of the lower *Jeneberang* River is also very relevant because it provides an overview of how to evaluate the potential discharge that can trigger flooding, especially when the river can no longer accommodate water flow at its peak. Meanwhile, the study by Muhammad Rahmat et al. (2020) on riverbank reinforcement provides a useful technical approach to protecting bridge structures from damage caused by erosion.

Finally, Muhammad Rizki's (2023) work on slope stability using sheet piles can be an important reference on soil reinforcement and structural protection against potential landslides or shifts caused by hydrostatic pressure. Overall, these studies provide the necessary contributions to this research, both conceptually and technically, for the formulation of a robust and functional protective structure design for the rehabilitation of the *Jenelata* Bridge.

RESEARCH METHODOLOGY

Flow Chart

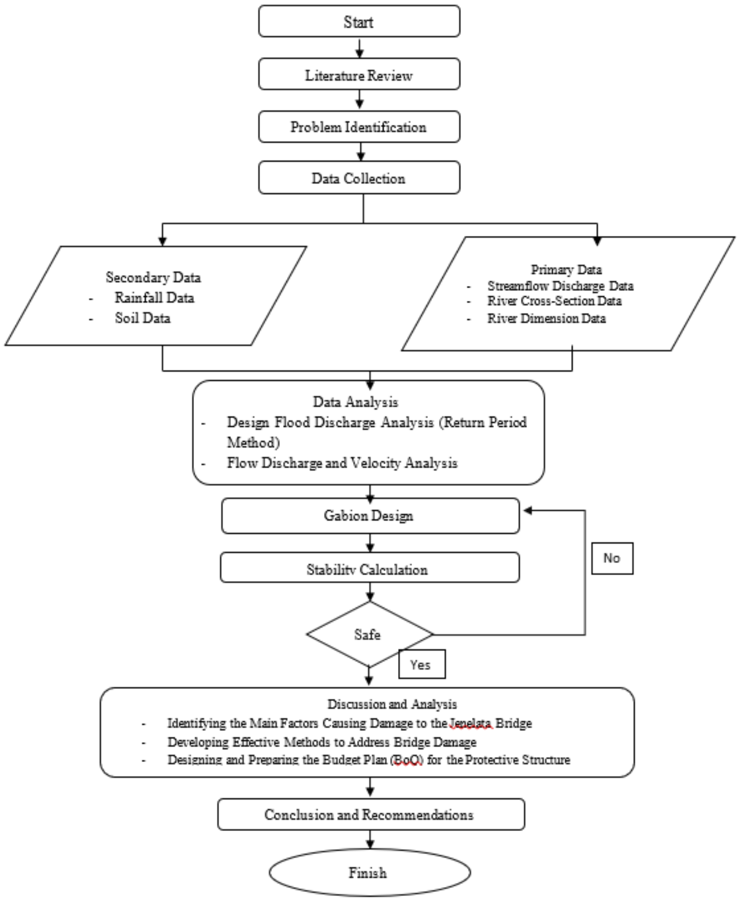

Figure 1. Flow Chart

This study began with a literature review to establish a theoretical basis for reviewing previous research relevant to the topic of this study. This review served as the basis for identifying the main problems, which included structural damage to bridges due to flooding, riverbank erosion, and scouring around abutments. After clearly identifying the problems, the study continued with the collection of the necessary data. The data consisted of primary and secondary data. Primary data consisted of river discharge, cross-sectional profiles, and channel dimensions. Meanwhile, secondary data consisted of rainfall and soil characteristics.

The collected data was analyzed using hydrological and hydraulic approaches. Hydrological analysis was performed to estimate the design flood discharge for various return periods based on the probabilistic distribution method. Meanwhile, hydraulic analysis is used to determine river flow characteristics, such as discharge and velocity. The results of this analysis form the basis for designing gabion structures that aim to reduce the risk of damage to bridges and riverbanks.

The proposed gabion design is then tested through stability analysis to ensure its compliance with safety standards. If the analysis results indicate potential failure, the design will be modified again. However, if the structure meets safety and security criteria, the research will proceed to the discussion and interpretation stage. This final stage focuses on identifying the main factors behind the damage to the *Jenelata* Bridge, then formulating effective technical solutions, and presenting protective structure designs in the form of gabions/gabion baskets that are tailored to local conditions.

The final stage of the research consists of drawing conclusions and providing the best recommendations. The conclusions are compiled based on the analysis results, while the recommendations are presented as technical guidelines for mitigation and future bridge damage. Thus, the research framework systematically integrates theoretical review, data analysis, technical design, stability evaluation, and the formulation of solutions that can be applied sustainably.

Study Location

The research was conducted at *Jenelata* Bridge, Moncongloe Village, Manuju Sub-district, *Gowa* Regency, South Sulawesi. The site lies within the *Jenelata* River watershed, part of the larger *Jeneberang* River basin.

Data Collection

Primary Data: Field surveys measuring cross-sections, soil properties, and visible damage.

Figure 2. Damage to *Jenelata* Bridge

Secondary Data: Rainfall and discharge data from BMKG, river basin management agency reports, and hydrological records.

Data Analysis Techniques

Hydrological analysis was conducted using the Log Pearson Type III distribution to estimate planned rainfall. In addition, the Nakayasu Synthetic method was used to calculate planned flood discharge. Planned rainfall and flood discharge were used as the basis for designing protective structures, as they serve as safety references against flood risks on the *Jenelata* River.

Based on the results of the hydrological and hydraulic analysis, a protective structure design was developed to protect the *Jenelata* Bridge and surrounding riverbanks from further damage and to provide protection in the event of sudden flooding on the *Jenelata* River. After considering several other protective structure alternatives, the gabion method was chosen as the most effective solution. Gabions were chosen for their flexibility against erosion. If the gabion base is eroded and the stones at the bottom of the gabion are carried away by the current, maintenance is carried out by filling stones on top to restore the main function of the gabion.

Gabions consist of galvanized steel wire mesh filled with large stones. This protective structure was also chosen for its structural strength and ability to adapt to the natural environment, as vegetation can grow through the mesh, thereby increasing long-term stability.

To ensure that the proposed design functions effectively in the field, a series of stability analyses were conducted. These analyses covered three main failure modes, namely overturning failure, shear failure, and load capacity failure. Overturning analysis of the protective structure was conducted to ensure that the structure remains strong when subjected to hydraulic forces and soil pressure. Shear analysis was performed to evaluate the structure's resistance to horizontal displacement caused by river currents and erosion, while load capacity analysis evaluated the foundation's ability to withstand loads from gabions and other additional loads such as soil filling, traffic, and water pressure without experiencing excessive settlement that could lead to structural failure. The results of this evaluation will produce a gabion design that is sturdy and guaranteed in strength.

In addition, supporting software such as AutoCAD and SketchUp are used to aid the visualization and modeling process. AutoCAD is used to produce precise technical drawings, including detailed dimensions and layouts, so that the design can be ensured to comply with technical standards. Meanwhile, SketchUp is used to create three-dimensional models that provide a clearer picture of the structure's shape and its interaction with the surrounding environment. The use of these tools improves design accuracy while facilitating communication in concept development.

The final stage of this study is the preparation of a cost plan to assess the financial feasibility of the proposed gabion structure. The calculations refer to the Standard Unit Price Analysis (AHSP) published by the Ministry of Public Works and Public Housing as the main guideline. To produce a more realistic plan, the cost estimates are further adjusted to the regional unit costs applicable in *Gowa* Regency. It is hoped that the proposed design will not only be technically feasible but also economically viable.

RESULTS AND DISCUSSION

Hydrological Findings

Hydrological analysis shows that the maximum average daily rainfall recorded is 102.280 mm. This figure is categorized as an extreme event in the study area. This value indicates that the intensity of rainfall in the area has the potential to increase significantly. This increase will affect the discharge and flow of the river. Based on flood frequency analysis using the probabilistic distribution method, the 100-year flood discharge is estimated at 1,058.17 m^3/s. If this flood discharge or maximum discharge occurs, it will only happen once in that period.

This discharge is far beyond the capacity of the existing river. Under normal conditions, the river can only accommodate a much smaller flow. The river's inability to accommodate this discharge indicates a high risk of overflow and major flooding in the surrounding catchment area, especially during continuous extreme rainfall. These conditions not only increase the risk of damage to bridge and levee infrastructure, but also increase the risk of high erosion around bridge piers.

In addition, the uneven spatial distribution of rainfall in the catchment area contributes to rapid surface flow concentration, shortening the response time to flooding. The combination of extreme rainfall, the topography of the catchment area, and limited channel capacity has been identified as the main causes of excessive flood discharge, which results in increased flow velocity, directly threatening the safety of bridge structures in the study area.

Hydraulic Findings

From observations and literature reviews, it is known that the *Jenelata* River has a fairly winding geometry, a condition known as a river meander. This morphological condition triggers the occurrence of secondary currents on the meander side of the river, where the currents are stronger and cause local scouring around the bridge abutment. During floods, these currents become stronger and faster due to increased water discharge accompanied by strong currents, which exacerbates erosion on the outer part of the river bend.

In addition, flood currents carrying sediment from erosion upstream exacerbate the deposition process, which can reduce flow capacity and structural stability. This results in a smaller wet cross-section of the river, increasing the risk of flooding, especially during peak discharge.

Damage Analysis

Damage analysis is obtained from the correlation between discharge, wet cross-sectional area, and water level. For example, under condition Q2, the river cross-sectional area is known to be 72.56 m^2 with a water level of 4.57 m, while under Qmax, it increases dramatically to 565.11 m^2 with a water level that also increases to 9.25 m. These changes indicate that extreme flooding directly causes an increase in water level and adds hydraulic pressure on river banks and bridge piers.

Field observations show that there is 50 m of erosion on the outer side of the river bend upstream of the bridge, which has worsened due to the absence of protective structures. These structures were eroded during the major floods in 2019. Information from BBWS Pompengan *Jeneberang* on the 2019 flood shows a discharge of 1,200 m^3/s with a water level rise of up to 14 m. The flood caused erosion around the bridge pillars, with an estimated depth of 1.98 m from the foundation depth of 1.5 m. Based on the analysis results, it was also found that Q25 (680.79 m^3/s), Q50 (855.53 m^3/s), and Q100 (1,058.17 m^3/s) also pose a serious threat to the stability of the foundation due to the protective structure and reduced bearing capacity.

Based on these conditions, discharge data, cross-sectional size, and water level fluctuations are important parameters in designing bridge protection systems. The selection of structures such as gabions, retaining walls, or other protective elements must consider not only normal conditions but also extreme discharges to ensure the long-term safety of the bridge, especially at river bends.

Protective Design

The protective structure planned for the *Jenelata* Bridge uses 4 × 1 × 1 meter type C gabions. The total length of the installation is 100 meters, divided into 50 meters on the upstream side and 50 meters on the downstream side, precisely at the outer bend of the river that is often eroded by the current. The selection of this type of structure is not without reason, as gabions are known to be flexible, easily adaptable to ground movement, and capable of reducing hydrostatic pressure thanks to the permeable nature of their stone composition. In addition, the gaps between the stones serve as flow energy dampers, reducing the speed of the current around the cliffs, while providing more durable protection against erosion.

The stability analysis results show that the design is still within safe limits according to technical standards. The safety factor against overturning is more than 1.5, which means that the structure has sufficient resistance to moments caused by water pressure. Similarly, the safety factor against sliding, which is recorded at more than 1.3, indicates adequate friction to withstand horizontal thrust forces during flooding. The bearing capacity of the soil at the site is also considered sufficient, so that the natural foundation at the bottom of the river is able to withstand the load of the gabion without excessive settlement or shear failure.

With these considerations, the use of gabions can be categorized as a practical, economical, and sustainable solution to reduce erosion around the *Jenelata* Bridge abutments. Compared to rigid concrete structures, the maintenance costs of gabions are relatively lower, while the filling material is easily obtained from the surrounding environment. The modular construction facilitates installation and repair, making it more adaptable to field conditions. The combination of hydraulic energy dissipation and permeability makes gabions effective in maintaining riverbank stability, especially in winding channels that are prone to erosion.

Figure 3. Design of Protective Structure

The image shows an example of the application of type C gabions (4 × 1 × 1 m) on the riverbank near the bridge abutment. The gabions are made of galvanized steel wire mesh filled with stones and function as a protective wall against erosion and hydraulic forces. With a total length of 100 meters consisting of 50 meters upstream and 50 meters downstream this structure is expected to provide continuous protection to the most vulnerable parts of the river. Its presence is important to ensure that the bridge remains functional, even when the river experiences high discharge during the rainy season.

Cost Estimation

The total construction cost for the gabion protective structure is estimated at Rp346,190,130. This figure includes all the main components needed for the project. The first stage is site preparation, which includes land clearing, excavation, and compaction of the riverbank to ensure that the foundation for the gabion installation is sufficiently stable. Thorough preparation in the early stages is crucial to the strength of the foundation and the overall success of the construction.

The next component is the procurement of the main materials. Gabions are constructed from galvanized steel wire mesh and specially selected large stones. These two materials are at the heart of this protection system because their strength and durability greatly affect long-term performance, especially when facing water pressure and river currents.

The next stage is the assembly and installation process along a 100-meter stretch, divided into 50 meters on the upstream side and 50 meters on the downstream side of the bridge. This part requires experienced workers, from assembling the wire mesh into gabion boxes, filling the boxes with sorted stones, to placing them neatly on the riverbank. Even a small mistake at this stage can affect the alignment and stability of the structure.

In addition, there are also supporting costs such as material transportation, transporting stones from the source to the location, and quality control activities. Transportation is one of the most significant cost components due to the heavy weight of the materials. Meanwhile, quality control includes checking the quality of the wire and stones, checking the density of the gabion contents, and ensuring compliance with the design. All these steps are taken to ensure that the installed structure is completely safe and functions effectively.

This cost calculation refers to the Unit Price Analysis (AHSP) published by the Ministry of Public Works. To suit field conditions, the unit prices are then adjusted to the regional values applicable in *Gowa* Regency. This adjustment is important because the calculation not only emphasizes compliance with technical guidelines but must also be economically realistic and in line with the availability of local labor and resources.

Based on the calculation results, it can be concluded that the construction of a gabion protective structure for the *Jenelata* Bridge is not only technically feasible but also financially justifiable. This realistic cost projection ensures that the design can be realized within the available budget while still meeting safety and performance aspects in the long term.

Table 1. Gabion Budget Plan

No	Description	Volume	Unit	Unit Price (Rp)	Total Cost (Rp)
1	Preparation and Measurement	100	m	15,000	1,500,000
2	Foundation Excavation	100	m³	30,000	3,000,000
3	Sand/Geotextile Backfill	100	m³	50,000	5,000,000
4	Installation of Empty Gabions	25	unit	75,000	1,875,000
5	Stone Filling into Gabions	100	m3	20,000	2,000,000
6	Gabion Joint Stitching	25	unit	25,000	625,000
7	Final Cleaning	100	m	10,000	1,000,000
Total					15,000,000
I. MATERIALS					
1	Gabion Wire	8000	Kg	30,000	240,000,000
2	Crushed Stone	100	m3	142,000	14,200,000
Subtotal I					254,200,000
II. TOOLS					
1	Plier/Cutter	11	Bh	35,000	385,000
2	Shovel	39	Bh	100,000	3,900,000
Subtotal II					4,285,000
III. LABOR					
1	Worker	118	Org	70,000	8,260,000
2	Skilled Worker (Mason)	21	Org	85,000	1,785,000
Subtotal III					10,045,000
Description		Summary of Costs (Rp)			
Total					283,530,000
Overhead (10%)					28,353,000
VAT (11%)					34,307,130
Total Cost					346,190,130

Discussion

Gabions were chosen in this study as the main protective structure because they combine technical reliability, cost efficiency, and environmental benefits. These characteristics make them ideal for hydraulic and geotechnical applications. Compared to rigid reinforced concrete retaining walls, gabions have natural flexibility that allows them to follow uneven ground movements and differential settlement without losing stability. This reduces the potential for sudden failure that often occurs in rigid structures, especially in locations with variable soil conditions such as riverbanks and bridge abutments.

From a technical standpoint, one of the main advantages of gabions is their ability to dissipate hydraulic energy. The space between the fill stones forms voids that act as natural energy absorbers, reducing flow velocity and controlling erosion. This mechanism is highly effective in protecting riverbanks from progressive erosion while maintaining abutment stability. In addition, the porous nature of gabions improves drainage behind the structure, preventing the buildup of hydrostatic pressure that often causes instability in impermeable protection systems. These advantages make gabions function not only as retaining walls, but also as adaptive water control systems.

From an economic perspective, the use of gabions is more cost-effective than rigid protection systems. Installation does not always require advanced construction technology or heavy equipment, making it easier to implement in areas with limited access. In addition, the main material, stone, is usually available near the project site. The use of local materials not only reduces transportation costs but also supports the involvement of local community resources. From field experience, this factor often determines the economic feasibility of a river protection project.

Gabions also offer ecological benefits that rigid structures do not have. Over time, vegetation tends to grow in the gaps between the stones. The presence of these plants strengthens the soil through their root systems while beautifying the natural appearance of the riverbank. This greening process encourages the creation of new habitats for small organisms, improves water quality, and helps maintain the balance of the aquatic ecosystem. Thus, gabions play a dual role: as a protective structure and an element that supports environmental sustainability.

Based on the experience of various similar projects, gabions have proven to have a long service life as long as they are maintained regularly, for example by checking the condition of the galvanized wire and ensuring that there is no damage due to corrosion. Compared to other alternatives such as loose riprap or concrete walls, gabions are easier to repair if they suffer local damage because their modular system allows for the replacement of specific parts without having to dismantle the entire structure.

Considering these factors, the use of gabions on the *Jenelata* Bridge can be considered the most appropriate choice. In addition to addressing the technical need to overcome erosion around the abutments, gabions also offer an economical solution that is in line with environmental sustainability requirements. Their multifunctional advantages ranging from flexibility and durability, cost efficiency, to their contribution to the ecosystem are strong reasons why gabions were chosen as the protective structure at this location.

CONCLUSION

An investigation into the condition of the *Jenelata* Bridge supports revealed that the main damage was caused by extreme flooding, which led to an increase in river discharge and a drastic acceleration in flow velocity. These hydraulic conditions produced high erosive forces, accelerating the erosion of the supporting material around the abutment foundations. The loss of this supporting material directly resulted in a decrease in the structural stability of the bridge. The absence of an adequate riverbank protection system further exacerbated the condition of the abutments, making them even more vulnerable to flooding. These findings confirm that hydraulic forces, if left uncontrolled, pose a serious threat to the sustainability of infrastructure, especially in flood-prone areas. Therefore, protective measures cannot be considered merely complementary, but must be an integral part of bridge planning and design, especially in tropical regions such as South Sulawesi, which often experience high rainfall and recurring floods.

To address the existing damage, a protection system was designed in the form of gabions with a total length of 100 meters, 50 meters on the upstream side and 50 meters on the downstream side of the bridge. Technical evaluation results show that gabions are capable of withstanding high hydraulic pressure while also serving to reduce the energy of flood flows.

Their ability to absorb and reduce flow velocity minimizes the risk of further erosion, thereby extending the service life of the bridge. Stability analysis also shows that this design meets safety factor requirements, making it reliable in dealing with varying hydraulic conditions in the field.

From an economic perspective, the use of gabions offers considerable advantages. The estimated construction cost of IDR 346,190,130 covers site preparation, procurement of galvanized wire and fill stones, assembly and installation, as well as transportation and quality control. Compared to rigid alternatives such as reinforced concrete retaining walls, gabions are much more efficient because the construction method is simple, does not always require heavy equipment, and can utilize local materials. This efficiency is particularly beneficial for projects in rural or semi-urban areas with limited funds. Thus, this system is not only economical but also meets practical needs in the field.

In addition to technical and economic advantages, gabions also provide added value from an ecological perspective. Unlike rigid concrete walls that are separated from the environment, gabions can blend naturally with the river ecosystem. The gaps between the stones allow water to circulate and encourage vegetation growth, which in turn strengthens the slopes through root networks. The presence of this vegetation not only beautifies the riverbanks, but also supports biodiversity by providing new habitats for aquatic and terrestrial organisms. Over time, gabion structures become stronger due to a combination of biological and mechanical factors. These characteristics make gabions the right choice in sustainable engineering that balances infrastructure needs and environmental responsibility.

However, the long-term effectiveness of gabions is highly dependent on regular maintenance and monitoring. Periodic inspections are necessary to detect potential problems such as wire corrosion, stone displacement, or damage caused by debris during floods. Preventive repairs and replacement of damaged parts need to be carried out immediately to maintain optimal protection. Greening efforts combined with gabion structures can also increase stability and extend the system's service life. This approach, which combines civil engineering with bioengineering, is believed to create dual protection, namely mechanical strength and ecological resilience.

Ultimately, this study recommends the need for a comparative study of various river protection methods, including steel sheet walls, reinforced concrete walls, and geosynthetic-based technologies. Such a comparative analysis is important to assess the performance, durability, and life cycle costs of each system. The results of such an evaluation will be very useful for policymakers and engineering practitioners in choosing solutions that suit local needs. In the case of the *Jenelata* Bridge, the choice of gabions shows that the right solution is not always synonymous with high costs, but rather the ability to combine technical, economic, and environmental aspects in a balanced manner to ensure the sustainability of infrastructure in flood-prone areas.

CONFLICT OF INTEREST

The author confirms that there is no conflict of interest to declare.

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