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Analysis of Flood Control on the Lusi River at the Dumpil Weir, Ngaringan Subdistrict, Grobogan Regency

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Abstract

Flooding along the Lusi River is an annual phenomenon that significantly impacts residential areas and agricultural land, necessitating appropriate management strategies. This study focuses on evaluating the flood control system on the Lusi River, specifically the Dumpil Dam infrastructure located in Ngaringan District, Grobogan Regency. The primary objective is to assess whether the current dam capacity is adequate to reduce the planned flood discharge. From a hydrological perspective, this study processed precipitation data over the past ten years using the Thiessen Polygon method to obtain the average regional rainfall. The frequency distribution was determined through a comparative study of the Gumbel, Log Normal, and Normal methods. Meanwhile, the planned flood discharge estimate was calculated using the empirical approach of Melchior, Haspers, and Weduwen. The research findings indicate that the total flow capacity of the Dumpil Dam reaches 1,979.84 m³/s, a combination of the main crest discharge (1,827.36 m³/s) and the drainage hole (152.48 m³/s). Compared to the 50-year return period (Q50) design flood load of 1,079.26 m³/second calculated using the Haspers method, the dam structure is categorized as SAFE. This is because the existing capacity is still much greater than the predicted flood discharge. As a preventative measure, regular sediment removal and maintenance of the floodgates are recommended to maintain the dam's stable performance in the future.

Keywords : *Hydrological Analysis, Dumpil Dam, Design Flood Discharge, Flood Mitigation, Lusi River.*

INTRODUCTION

Flooding remains one of the most persistent challenges in water resources management because its impacts extend beyond temporary inundation to disruption of settlements, agricultural activities, infrastructure, and regional economic functions. The occurrence of flooding is closely associated with excessive rainfall, limited river conveyance capacity, sedimentation, changes in land use, and inadequate performance of hydraulic structures. Effective flood management consequently requires an integrated assessment of hydrological conditions and the hydraulic capacity of existing infrastructure. An evaluation of river systems cannot be separated from the relationship between rainfall characteristics, design flood discharge, river conveyance, and the operational condition of flood-control structures. The development of an appropriate flood-control strategy therefore requires reliable estimation of design discharge as the basis for determining whether an existing hydraulic structure remains capable of accommodating extreme flows (Rahman, 2025).

The role of hydraulic structures becomes increasingly important in areas where rivers serve multiple functions, particularly for irrigation and flood management. A diversion weir is principally constructed to raise the water level and regulate river flow for irrigation purposes, yet its hydraulic performance may also influence flood propagation within the downstream river system. The relationship between water availability, irrigation demand, and hydraulic capacity requires careful assessment because the operation of a weir must accommodate competing water-management objectives. Studies concerning irrigation systems have demonstrated the importance of evaluating the capacity and water balance of weirs to ensure that hydraulic infrastructure remains consistent with its intended service area (Apriyanto & Saves, 2023). Capacity assessment is similarly relevant to the development and management of irrigation systems because the available storage and conveyance capacity determine the ability of infrastructure to accommodate variations in water discharge (Bagiawan, 2013).

The Sungai Lusi system represents an important hydrological setting in Central Java because flooding along the river has generated physical and environmental impacts in several areas of Grobogan Regency. Existing studies have identified flood vulnerability within the Lusi sub-watershed, indicating that spatial characteristics and variations in rainfall and land conditions contribute to different levels of flood susceptibility (Larasati et al., 2025). Physical damage along the Lusi River has also been associated with flooding and erosion of river slopes, demonstrating that flood events may affect not only inundation levels but also the structural condition of the river corridor (Andriawan et al., 2024). Research concerning normalization of the Lusi River further indicates the importance of improving river capacity as part of efforts to reduce flood risks in Grobogan Regency (Firizqi & Sudjianto, 2023).

Bendung Dumpil is located in Desa Ngarap-arap, Kecamatan Ngaringan, Kabupaten Grobogan, Central Java, at approximately 7.075863° South and 111.197769° East. The structure serves agricultural irrigation areas while also functioning as an important hydraulic control point within the local river system. Its position within the Sungai Lusi system makes the hydraulic performance of Bendung Dumpil relevant to the management of high-flow conditions in the surrounding area. A recent hydrological event illustrates this concern: on 20 May 2025, residents living along the Lusi River in Grobogan were advised to remain alert because the discharge at Bendung Dumpil was reported to be considerably high, while previous high discharge conditions at the structure had been associated with flooding at several locations in Purwodadi. Such conditions demonstrate the importance of examining the relationship between flood discharge and the capacity of Bendung Dumpil rather than assessing the structure solely from its irrigation function.

Flood-control performance is fundamentally determined by the compatibility between design flood discharge and the hydraulic capacity of the controlling structure. An increase in upstream discharge may generate hydraulic conditions that exceed the conveyance capacity of a river or hydraulic structure, particularly when sedimentation, changes in channel geometry, or operational constraints reduce the effective flow capacity. Research on the Juana River, for example, demonstrates the importance of evaluating the maximum river capacity under conditions of increased discharge from an upstream hydraulic structure (Almauludiy et al., 2026). The operational configuration of hydraulic gates can likewise influence the effectiveness of flood control because appropriate gate operation is required to regulate incoming discharge and maintain safe downstream water levels (Tiko et al., 2024). The evaluation of Bendung Dumpil therefore needs to consider both the magnitude of the design flood and the existing hydraulic capacity of its principal flow components.

Hydrological analysis provides the fundamental basis for determining the magnitude of flood discharge that must be accommodated by a hydraulic structure. Rainfall data from representative stations can be transformed into areal rainfall using spatial weighting techniques such as the Thiessen Polygon method, followed by frequency analysis to obtain design rainfall for selected return periods. The resulting design rainfall can then be used to estimate design flood discharge through an appropriate rainfall–runoff approach. The selection of a suitable synthetic unit hydrograph method is particularly important because different approaches may produce different estimates of peak flood discharge. Previous evaluation of design flood discharge at the Manganti Weir demonstrates the importance of selecting and evaluating an appropriate synthetic unit hydrograph method in determining design discharge (Ridsan et al., 2022). A comparable hydrological assessment is required at Bendung Dumpil to establish a technically defensible basis for evaluating its flood-control performance.

The need for such an assessment becomes more significant because the existing studies concerning the Lusi River have predominantly emphasized river vulnerability, river normalization, physical damage, and broader flood-risk management. Research on the Lusi River has addressed damage caused by flooding and erosion (Andriawan et al., 2024), while other research has examined normalization as an approach to improving river conditions (Firizqi & Sudjianto, 2023). Flood-risk studies have also examined the spatial vulnerability of the Lusi sub-watershed (Larasati et al., 2025). These studies provide an important foundation for understanding the regional flood problem, but a specific evaluation of the relationship between the design flood discharge and the hydraulic capacity of Bendung Dumpil remains necessary. The assessment is particularly relevant given the reported high-discharge conditions at the structure and its strategic role within the local irrigation and river system.

The present study consequently positions Bendung Dumpil as the specific hydraulic control point through which the adequacy of existing flood-conveyance capacity can be quantitatively examined.

This study addresses three principal questions: what hydraulic capacity can be accommodated by the existing Bendung Dumpil structure, what dimensions of the structure are required to accommodate the design flood safely, and how much flood discharge can be controlled by the existing system. The analysis uses ten years of rainfall data and applies the Thiessen Polygon method for determining representative areal rainfall, followed by frequency analysis and design-flood estimation using hydrological methods relevant to the study area. The study aims to evaluate rainfall and flood-discharge characteristics, identify the existing dimensions and configuration of Bendung Dumpil through its river scheme, layout, plan, and cross-section, and determine the design flood discharge in relation to the hydraulic overflow capacity of the structure. The resulting assessment is expected to provide a quantitative basis for determining the adequacy of Bendung Dumpil as a flood-control component of the Sungai Lusi system in Kecamatan Ngaringan, Kabupaten Grobogan.

RESEARCH METHODS

The research method used in this study employed a quantitative approach, with the research site located at the Dumpil Dam in Ngarap-arap Village, Ngaringan Subdistrict, Grobogan Regency, Central Java. The dam is a movable-gate dam with steel gates that is 76.00 m wide, featuring five gates measuring 12.00 m × 7.50 m, and is equipped with a spillway, an intake structure, and a sediment basin. The research data consists of primary data in the form of documentation on river flow, the condition of the Dumpil Weir, and the surrounding environment, as well as secondary data in the form of rainfall data and technical watershed data obtained from the Pemali Juana River Basin Management Agency (BBWS). The technical characteristics of the weir, the irrigation channel scheme, and the Lusi–Serang–Juana river network were used as a basis for understanding the existing conditions and flow system at the study site.

The analysis was conducted by processing hydrological data to determine rainfall characteristics and design flood discharge values, which serve as the basis for evaluating flood control at the Dumpil Weir. Rainfall frequency analysis was performed using the Normal, Log-Normal, and Gumbel distributions, while runoff coefficients were determined using the Melchior, Weduwen, and Haspers methods. The results of the hydrological analysis were then used to evaluate the flow capacity and the ability of the Dumpil Weir to control flood discharge. All stages of the research followed a sequence beginning with problem formulation, collection of primary and secondary data, data verification, hydrological analysis, and finally the derivation of the final research results.

RESULTS AND DISCUSSION

Hydrological Analysis of the Lusi River Basin and Rainfall Characteristics

The hydrological analysis constitutes the fundamental basis for evaluating the flood-control performance of the Dumpil Dam because the reliability of structural assessment depends substantially on the representativeness of rainfall and watershed characteristics used to derive design discharge. The study utilized ten years of rainfall observations from 2015–2024 obtained from the Purwodadi, Sanggeh, and Dumpil rainfall stations, with the data supplied through the relevant water-resources authorities. The use of a ten-year observation period provides a consistent empirical basis for identifying annual maximum rainfall patterns, although the relatively limited observation length requires careful interpretation when extrapolating toward longer return periods. Apriyanto and Saves (2023) emphasize that reliable hydrological assessment requires the integration of rainfall characteristics, catchment area, and hydraulic conditions because these variables collectively determine the magnitude and reliability of water availability or excess flow. The present analysis therefore positions rainfall characterization not merely as a preliminary calculation but as a critical determinant of the subsequent flood-discharge estimation and evaluation of the existing Dumpil Dam.

The spatial distribution of rainfall was established using the Thiessen Polygon method because rainfall recorded at individual gauges does not necessarily represent the hydrological response of the entire watershed uniformly. The analysis identified three principal rainfall stations, namely Purwodadi, Sanggeh, and Dumpil, whose observations covered the same 2015–2024 period and consequently provided a temporally consistent dataset. The resulting Thiessen influence areas were 1,342.64 km² for Purwodadi, 1,223.56 km² for Sanggeh, and 1,446.28 km² for Dumpil, producing a total delineated area of 4,012.48 km². Bagiawan (2013) demonstrates the importance of accurately defining watershed or service-area characteristics in determining the capacity required by water infrastructure, while Purwanto and Ikhsan (2006) similarly establish that spatially representative hydrological inputs are essential for dependable water-resource calculations. The relatively larger influence area assigned to the Dumpil station, representing approximately 36% of the total watershed area, indicates that rainfall observations at this station exert the greatest individual weighting on the calculated areal rainfall.

Table 1.1. Spatial Distribution of Thiessen Rainfall Influence Areas

Rainfall Station	Thiessen Influence Area (km²)	Thiessen Coefficient	Weight (%)
Purwodadi	1,342.64	0.33	33
Sanggeh	1,223.56	0.30	30
Dumpil	1,446.28	0.36	36
Total	4,012.48	1.00	100

Table 1 demonstrates that the watershed representation is relatively balanced among the three rainfall stations, although the Dumpil station contributes the largest weighting to the areal rainfall calculation. The difference between the highest and lowest Thiessen coefficients is only 0.06, indicating that no single station overwhelmingly dominates the spatial representation of rainfall across the analyzed area. Such distribution strengthens the suitability of the Thiessen approach for transforming point rainfall observations into a representative watershed rainfall value, particularly where gauge density remains limited. Razita and Safarina (2024), in their analysis of dependable discharge at Glapan in Grobogan, likewise illustrate the importance of integrating hydrological observations with watershed-scale characteristics when assessing water-resource infrastructure. The spatial weighting presented in Table 1 consequently provides a rational foundation for deriving the subsequent areal rainfall series used in the design-flood analysis.

The rainfall data further reveal considerable interannual variability, which is particularly important for assessing flood-generating conditions in the Lusi River system. The calculated annual maximum rainfall values ranged from 65.72 mm in 2016 to 100.34 mm in 2024, while the mean of the ten annual maximum observations reached 78.46 mm with a standard deviation of 10.73 mm. The highest observed annual maximum in 2024 therefore exceeded the ten-year mean by approximately 27.9%, indicating that recent rainfall conditions include a substantially greater extreme event than the average annual maximum represented by the dataset. Ridsan et al. (2022) explain that the identification of representative extreme rainfall and discharge characteristics is essential when establishing design floods for water-control structures, particularly because peak hydrological events determine structural loading. The observed increase toward 2024 should therefore be regarded as an important hydrological signal when interpreting the adequacy of the existing flood-control capacity at Bendung Dumpil.

Table 2. Annual Maximum Rainfall at the Study Area, 2015–2024

Year	Maximum Rainfall (mm)
2015	91.31
2016	65.72
2017	76.70
2018	81.80
2019	74.06
2020	68.59
2021	82.14
2022	73.22
2023	70.78

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Year	Maximum Rainfall (mm)
2024	100.34
Mean	78.46
Standard deviation	10.73

The values in Table 2 indicate that the rainfall regime does not follow a strictly progressive annual trend, but instead exhibits substantial fluctuations between relatively moderate and exceptionally high annual maxima. The 2024 value of 100.34 mm represents the most significant observed extreme, whereas the 2016 value of 65.72 mm constitutes the lowest annual maximum within the analyzed period. This variation confirms that flood-control assessment cannot reasonably rely on an average rainfall value alone because the hydraulic system must respond to events considerably exceeding ordinary hydrological conditions. Hadi (2016), through the analysis of flood discharge in the Lusi watershed, similarly demonstrates the relevance of rainfall extremes in anticipating flood-producing discharge within this regional river system. The empirical variability documented in Table 2 consequently reinforces the need to apply frequency-distribution techniques before determining the design rainfall and corresponding flood discharge.

The frequency analysis subsequently employed Normal, Log Normal, and Gumbel distributions to transform the observed rainfall series into design rainfall corresponding to different return periods. The Normal distribution produced a design rainfall of 78.46 mm for a two-year return period, increasing to 100.47 mm for 50 years and 111.64 mm for 1,000 years. The progressive increase in design rainfall across return periods reflects the statistical relationship between event rarity and expected magnitude, whereby less frequent events are assigned increasingly severe rainfall estimates. Sulistiyo and Erdiansyah (2023) similarly employ design-flood calculations as an essential basis for determining the hydraulic requirements of a weir, while Siregar (2022) demonstrates that changes in hydraulic structures must be evaluated against design loading and safety conditions. The comparison among alternative distributions therefore serves an important methodological function because the selected statistical representation ultimately influences the magnitude of design discharge used to judge the performance of Bendung Dumpil.

The hydrological significance of the rainfall analysis becomes clearer when the characteristics of the watershed itself are considered alongside the statistical rainfall estimates. The study area covers approximately 4,012.48 km², with a main river length of approximately 154.03 km and an elevation difference that contributes to the hydraulic response of the basin. The large watershed area implies that extreme precipitation can generate substantial accumulated runoff before reaching the control structure, making the relationship between rainfall intensity, concentration time, runoff coefficient, and discharge particularly consequential. Darsono and Pranoto have emphasized the importance of watershed-scale management and decision-support approaches in coordinating river systems, indicating that flood management should be interpreted through the interaction of hydrological, hydraulic, and spatial components rather than through an isolated assessment of one structure. Arisanto and Prasetyo (2020) likewise frame flood-risk management within Integrated Water Resources Management, which supports the interpretation that the Dumpil Dam should be understood as one component within the wider Lusi–Serang–Juana river system.

The physical setting of Bendung Dumpil further explains why the hydrological analysis must be connected to the operational function of the structure rather than interpreted solely as a statistical exercise. The existing infrastructure is a movable weir equipped with steel gates, with a reported total width of approximately 76 m, a potential irrigation service area of 10,854 ha, and a functional area of 9,818 ha. The irrigation network extends through approximately 53.694 km of primary canals and 36.237 km of secondary canals, demonstrating that the structure performs an important water-distribution function in addition to its role in managing river flow. Afifah et al. (2025) underline the strategic relationship between water-resource infrastructure and the provision of reliable water services, while Tiko et al. (2024) demonstrate that gate operation can become a decisive component of flood regulation in controlled water structures. The multifunctional character of Bendung Dumpil means that flood-control evaluation must preserve a balance between safely conveying excessive discharge and maintaining the operational requirements of the irrigation system.

The calculated hydrological parameters subsequently provide the basis for estimating the design flood through alternative empirical approaches, including Melchior, Haspers, and Weduwen, which were incorporated in the study to identify the discharge associated with selected return periods. The Haspers calculation used a drainage area of 4,012.5 km², a river length of 154.03 km, an upstream-to-bendung elevation difference of 86 m, and an average watershed slope of 0.0005, producing a two-year discharge of approximately 710.50 m³/s and a 50-year discharge of 1,079.26 m³/s. The complete Haspers series demonstrates a systematic increase from 710.51 m³/s at a two-year return period to 1,393.94 m³/s at a 1,000-year return period, thereby providing a clear quantitative relationship between event rarity and hydraulic loading. Almauludiy et al. (2026) similarly emphasize the importance of determining maximum river capacity against increasing flood discharge because hydraulic adequacy can change substantially as design-event magnitude increases. The Haspers results therefore constitute a particularly important bridge between the rainfall analysis and the subsequent assessment of whether the existing hydraulic capacity of Bendung Dumpil can accommodate the selected design flood.

Table 3. Design Flood Discharge According to the Haspers Method

Return Period (years)	Effective Rainfall, r (mm)	q (m³/s/km²)	Design Discharge Q (m³/s)
2	453.75	1.84	710.51
5	529.24	2.15	828.73
10	579.22	2.35	906.98
20	626.54	2.54	981.08
25	642.38	2.61	1,005.89
50	689.23	2.80	1,079.26
100	735.74	2.99	1,152.08
200	782.09	3.17	1,224.66
500	843.24	3.42	1,320.41
1,000	890.20	3.61	1,393.94

Table 3 establishes that the Q50 design flood selected for evaluating Bendung Dumpil is 1,079.26 m³/s, while the corresponding discharge at a 100-year return period rises to 1,152.08 m³/s and reaches 1,393.94 m³/s at 1,000 years. The difference between the Q50 and Q1000 values is 314.68 m³/s, demonstrating that the hydraulic burden increases materially as the return period becomes more conservative. Putra et al. (2024) emphasize that effective flood-control planning requires the integration of hydraulic capacity, structural considerations, and project-management decisions, while Junaina et al. (2025) demonstrate the importance of assessing available storage and drainage capacity within flood-control systems. The present results therefore indicate that the selection of Q50 is not simply a numerical endpoint but a design decision that determines the level of hydraulic safety against which the existing Dumpil structure is evaluated. The hydrological analysis ultimately shows that the study area possesses a substantial rainfall-generated flood potential, while the derived Q50 value of 1,079.26 m³/s provides the principal benchmark for the subsequent hydraulic capacity and safety assessment of Bendung Dumpil.

Hydraulic Capacity, Flood Conveyance, and Safety Performance of Bendung Dumpil

The hydraulic assessment of Bendung Dumpil is directed toward determining whether the existing structure can safely convey the design flood generated by the Lusi River watershed. The assessment uses the Q50 design flood of 1,079.26 m³/s as the principal hydraulic loading based on the hydrological calculations presented previously, while the physical capacity of the existing structure is derived from its principal crest, movable gates, drainage opening, and associated hydraulic dimensions. The approach is consistent with the engineering principle that flood-control infrastructure must be evaluated by comparing anticipated design discharge with the effective conveyance capacity of the structure rather than by considering structural dimensions independently. Ridsan et al. (2022) emphasize that reliable determination of design flood discharge constitutes an essential basis for evaluating the adequacy of hydraulic infrastructure, while Almauludiy et al. (2026) demonstrate that river conveyance capacity must be examined against increasing flood discharge to determine whether overtopping risks may emerge. The hydraulic analysis of Bendung Dumpil consequently connects the calculated hydrological burden with the actual geometric and operational characteristics of the existing structure.

The existing Bendung Dumpil is classified as a movable weir equipped with steel gates, having an overall width of 76.00 m and an effective principal gate arrangement consisting of five openings, each 12.00 m wide. The available technical data indicate an upstream floor elevation of +40.00 m, a downstream floor elevation of +38.00 m, an overflow crest elevation of +42.00 m, and a deck elevation of +50.00 m. The five principal gates have a height of 7.50 m, while the flushing structure contains one steel sliding gate with a width of 2.30 m and a sill elevation of +38.50 m. Siregar (2022) illustrates the importance of relating spillway or hydraulic-structure geometry to the water level and loading conditions that govern structural performance, while Tiko et al. (2024) demonstrate that gate configuration and operational control are important elements in regulating flood flows through water-control structures. The technical configuration of Bendung Dumpil thus provides a substantial hydraulic pathway through which flood discharge can be conveyed while retaining operational flexibility for irrigation and sediment management.

The principal discharge capacity was calculated using a discharge coefficient of 1.70, an effective width corrected for contraction effects, and the corresponding hydraulic energy head above the crest. The net opening of the five principal gates is 60.00 m, while the effective width after considering four piers and the abutment contraction is approximately 58.04 m under the maximum design condition. The resulting discharge capacity of the principal crest reaches approximately 1,827.36 m³/s, demonstrating that the main conveyance component alone possesses a theoretical discharge capacity considerably greater than the Q50 flood load. Apriyanto and Saves (2023) explain that hydraulic calculations must account for structural and hydraulic characteristics when evaluating water-control infrastructure, while Purwanto and Ikhsan (2006) show that the relationship between hydraulic capacity and water demand must be assessed systematically within a broader water-resource system. The calculated principal capacity consequently provides the first quantitative indication that the existing Dumpil structure has a substantial reserve for conveying the selected design flood.

The flushing opening provides an additional hydraulic pathway that contributes to the total discharge capacity during high-flow conditions. The calculation uses an energy head of approximately 11.50 m between the deck elevation of +50.00 m and the flushing sill elevation of +38.50 m, together with an opening width of 2.30 m and a discharge coefficient of 1.70. The resulting flushing discharge capacity reaches approximately 152.48 m³/s, which represents a meaningful supplementary contribution when combined with the principal crest discharge. Bagiawan (2013) highlights the importance of evaluating available conveyance and storage capacity in relation to the intended function of water infrastructure, while Razita and Safarina (2024) demonstrate the significance of dependable hydraulic discharge assessment for water-resource management within Grobogan. The additional flushing capacity is particularly relevant because the hydraulic performance of Bendung Dumpil is not determined solely by the principal gates but by the combined capacity of the available flow-control components.

Table 4. Existing Hydraulic Capacity and Q50 Flood Loading of Bendung Dumpil

Hydraulic Parameter	Q50 Flood Condition	Existing Maximum Design Condition
Design discharge, Q (m³/s)	1,079.26	1,979.84
Discharge coefficient, C	1.70	1.70
Net width, Ln (m)	60.00	60.00
Energy head, H1 (m)	4.89	7.00
Effective width, Le (m)	58.65	58.04
Crest elevation (m)	42.00	42.00
Flood-water elevation (m)	46.89	49.00

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Hydraulic Parameter	Q50 Flood Condition	Existing Maximum Design Condition
Deck elevation (m)	50.00	50.00
Freeboard (m)	3.11	1.00
Flow-capacity utilization (%)	54.51	100.00
Energy-head utilization (%)	69.90	100.00
Safety status	SAFE	CRITICAL LIMIT

Table 4 demonstrates the fundamental hydraulic relationship between the Q50 flood burden and the maximum conveyance capacity of Bendung Dumpil. The Q50 discharge of 1,079.26 m³/s represents approximately 54.51% of the total calculated maximum capacity of 1,979.84 m³/s, leaving a theoretical discharge margin of approximately 900.58 m³/s under the stated design assumptions. The corresponding water-surface elevation during Q50 reaches +46.89 m, which remains approximately 3.11 m below the deck elevation of +50.00 m and consequently provides a substantial freeboard under the evaluated condition. Sulistiyo and Erdiansyah (2023) indicate that design-flood calculations are essential for determining whether hydraulic structures possess sufficient capacity under specified return-period events, while Putra et al. (2024) stress that flood-control planning requires integration between hydraulic performance and structural management. The values in Table 4 therefore establish quantitatively that the existing structure is not hydraulically overloaded by the selected Q50 design event under the assumptions adopted in the study.

The energy-head analysis provides a second dimension of safety because discharge capacity alone does not fully describe the hydraulic response of a gated structure during a flood. The Q50 condition requires an energy head of approximately 4.89 m, whereas the maximum design condition allows approximately 7.00 m, meaning that the Q50 event utilizes approximately 69.90% of the available energy-head capacity. The resulting flood-water elevation of +46.89 m remains below the +50.00 m deck elevation, indicating that the hydraulic profile retains approximately 3.11 m of vertical clearance. Siregar (2022) demonstrates that hydraulic elevation and available freeboard are critical considerations when assessing the adequacy of hydraulic structures under elevated water levels, while Pranida (2022) emphasizes the importance of understanding river morphology and hydraulic characteristics when evaluating river-system performance. The combination of moderate capacity utilization and adequate freeboard strengthens the interpretation that the existing Bendung Dumpil remains hydraulically capable of handling the analyzed Q50 condition.

The hydraulic safety result also needs to be interpreted within the broader physical condition of the Lusi River because a safe structure does not automatically imply the absence of flooding throughout the downstream river system. Andriawan et al. (2024) document that the Lusi River in Grobogan has experienced flood- and erosion-related damage, indicating that flood impacts can arise from channel conditions and riverbank instability even when a particular hydraulic structure retains sufficient conveyance capacity. Firizqi and Sudjianto (2023) similarly identify river normalization as an important intervention in the Lusi River system, demonstrating that flood mitigation should not be reduced to the capacity of a single hydraulic structure. Larasati et al. (2025) further show that flood vulnerability in the Lusi sub-watershed varies spatially, meaning that hydraulic adequacy at Bendung Dumpil must be interpreted alongside broader watershed exposure and susceptibility. The finding that Bendung Dumpil is hydraulically safe at Q50 consequently indicates structural adequacy at the studied location rather than a guarantee that flooding cannot occur elsewhere along the Lusi River.

Operational management represents another determinant of whether the calculated hydraulic capacity can be maintained over time. The Dumpil irrigation system comprises approximately 10,854 ha of potential service area and 9,818 ha of functional area, supported by approximately 53.694 km of primary canals and 36.237 km of secondary canals, which makes the bendung a multifunctional infrastructure rather than a flood-control facility alone. Afifah et al. (2025) emphasize that water-resource infrastructure must simultaneously support reliable water provision and sustainable resource management, while Darsono and Pranoto underline the importance of integrated watershed management and decision-support mechanisms in coordinating river-system functions. Arisanto and Prasetyo (2020) similarly place flood-risk management within an Integrated Water Resources Management perspective, which is particularly relevant where irrigation, flood conveyance, sediment transport, and environmental functions interact. The operational performance of Bendung Dumpil therefore depends on maintaining gates, channels, flushing facilities, and sediment-management components so that the theoretical hydraulic capacity remains practically available during extreme flow events.

Sediment accumulation represents a specific operational risk because the study identifies a substantial sediment-storage component within the existing sediment pocket. The sediment pocket has a length of approximately 380 m, a combined width of 43 m, and an assumed effective sedimentation height of 0.50 of the 3.50 m available depth, resulting in an estimated sediment-storage capacity of approximately 8,170 m³ before flushing is required. The existence of this storage volume demonstrates that the structure incorporates a mechanism for intercepting and managing sediment before excessive deposition interferes with hydraulic operation. Andriawan et al. (2025) demonstrate the usefulness of systematic physical and functional evaluation of river infrastructure, while Andriawan et al. (2024) identify erosion and river damage as important issues affecting the Lusi River environment. Regular sediment removal is therefore not merely a maintenance activity but an essential measure for preserving the effective flow area and preventing gradual deterioration of the hydraulic capacity calculated under idealized conditions.

The comparison between the design flood and the existing capacity provides a direct answer to the principal hydraulic-control question addressed by the study. The maximum calculated discharge capacity of Bendung Dumpil is 1,979.84 m³/s, comprising 1,827.36 m³/s from the principal crest and 152.48 m³/s from the flushing opening, while the selected Q50 flood load is 1,079.26 m³/s. The resulting excess capacity of approximately 900.58 m³/s means that the Q50 event uses only about 54.51% of the calculated total capacity and leaves a substantial hydraulic reserve under the evaluated design assumptions. Aziz et al. (2026), through their assessment of flood control in the upper Juana River, similarly demonstrate the importance of comparing flood discharge characteristics with the capacity of hydraulic systems when establishing flood-management adequacy, while Junaina et al. (2025) emphasize the importance of available hydraulic storage and conveyance in flood-control planning. The present comparison consequently supports the classification of Bendung Dumpil as hydraulically safe for the Q50 design event, although the result should be understood as a capacity assessment rather than evidence that the wider Lusi River flood problem has been completely eliminated.

The overall hydraulic interpretation indicates that Bendung Dumpil possesses sufficient conveyance capacity to accommodate the Q50 design flood while retaining a meaningful freeboard and operational reserve. The calculated flood-water elevation of +46.89 m remains below the +50.00 m deck elevation, while the available freeboard of 3.11 m exceeds the one-metre minimum design allowance used for the maximum capacity assessment. Rahman (2025) emphasizes that flood-risk reduction in Grobogan requires a combination of structural and policy-oriented interventions because flood exposure is influenced by multiple interconnected factors beyond the performance of individual hydraulic structures. Tiko et al. (2024) likewise demonstrate that effective gate operation forms an important part of flood control, while Putra et al. (2024) show that flood-control infrastructure requires continuing management rather than reliance solely on initial structural design. The hydraulic findings therefore support continued use of Bendung Dumpil as an important flood-control and irrigation-control component, with routine gate maintenance, sediment flushing, and broader Lusi River management required to preserve the safety margin demonstrated by the Q50 analysis.

Flood-Control Effectiveness, Operational Resilience, and Sustainable Management of Bendung Dumpil

The effectiveness of flood control at Bendung Dumpil should be interpreted through the relationship between structural capacity, hydraulic loading, operational reliability, and the physical condition of the surrounding Lusi River system. The preceding analysis establishes that the Q50 design flood reaches 1,079.26 m³/s, whereas the calculated maximum conveyance capacity of the existing bendung reaches 1,979.84 m³/s, indicating a substantial hydraulic reserve under the analyzed design condition. The principal objective therefore shifts from determining whether the structure can theoretically pass Q50 toward evaluating how that capacity can be preserved and translated into effective flood-risk reduction in actual river management. Rahman (2025) argues that flood-risk reduction in Grobogan requires a comprehensive strategy because flood hazards are shaped by interactions among hydrological conditions, infrastructure, land use, and institutional management. The effectiveness of Bendung Dumpil should consequently be understood as a continuing management function rather than as a static consequence of its existing geometric capacity.

The Q50 evaluation demonstrates that the structure has sufficient capacity to accommodate the selected design flood without reaching the deck elevation. The calculated flood-water elevation of +46.89 m remains 3.11 m below the +50.00 m deck elevation, while the corresponding discharge utilizes approximately 54.51% of the calculated maximum flow capacity. The remaining hydraulic margin of approximately 900.58 m³/s indicates that the structure retains substantial reserve capacity before reaching its theoretical maximum conveyance of 1,979.84 m³/s. Almauludiy et al. (2026) similarly emphasize that flood-control adequacy should be assessed by comparing the magnitude of flood discharge with the maximum capacity of the receiving river or hydraulic structure. The findings therefore indicate that Bendung Dumpil provides a meaningful structural barrier against the analyzed Q50 flood, although its effectiveness remains dependent upon the preservation of hydraulic openings, gate functionality, sediment-management performance, and downstream channel capacity.

The hydraulic reserve should not be interpreted as an unlimited safety margin because theoretical capacity is based on specified geometric and hydraulic assumptions. The maximum capacity calculation adopts a discharge coefficient of 1.70, a net opening of 60.00 m, an effective width of 58.04 m, and a seven-metre energy head under the maximum deck-based condition. The Q50 calculation, in contrast, produces an effective width of approximately 58.65 m and an energy head of 4.89 m, resulting in a flood-water elevation of +46.89 m. Siregar (2022) demonstrates that hydraulic performance must be evaluated in relation to changes in structural configuration and water level because actual performance can diverge from theoretical capacity when hydraulic conditions or physical characteristics change. The comparison therefore provides strong evidence of present structural adequacy while simultaneously demonstrating why periodic verification is necessary whenever changes occur in gate condition, sediment deposition, river geometry, or upstream hydrological response.

The operational condition of the movable gates represents a particularly important determinant of flood-control effectiveness because the principal conveyance system depends on five steel gates with a combined net opening of 60 m. The technical configuration identifies each principal gate as 12 m wide and 7.50 m high, while the structure also contains a separate flushing opening with a width of 2.30 m. Tiko et al. (2024) demonstrate that operational management of water-gate openings can play a decisive role in flood regulation, particularly where the hydraulic structure must respond dynamically to changing inflow conditions. The operational role of the gates at Bendung Dumpil is therefore inseparable from the numerical capacity established by the hydraulic calculations. Regular inspection, mechanical maintenance, and functional testing are necessary to ensure that the calculated conveyance capacity remains available when a high-flow event occurs.

Sediment management constitutes another critical component of long-term flood-control effectiveness because sediment deposition can gradually reduce the hydraulic efficiency of a structure even when its original geometric dimensions remain unchanged. The study identifies a sediment pocket measuring approximately 380 m in length and 21.50 m in width for each of two channels, with an assumed effective sedimentation depth of 0.50 of the 3.50 m available depth. The resulting estimated sediment-storage capacity is 8,170 m³ before flushing becomes necessary, demonstrating that the structure incorporates a specific physical mechanism for temporarily accommodating sediment. Andriawan et al. (2024) identify flooding and erosion as important sources of damage along the Lusi River, making sediment transport and deposition particularly relevant to the sustainability of hydraulic infrastructure in this watershed. The 8,170 m³ sediment-storage volume should therefore be regarded as an operational resource that requires systematic monitoring rather than as a permanently available hydraulic capacity.

Table 5. Key Indicators of Flood-Control Effectiveness at Bendung Dumpil

Indicator	**Research Finding**	**Interpretation for Flood Control**
Q50 design flood	1,079.26 m³/s	Principal flood-control loading
Maximum bendung capacity	1,979.84 m³/s	Available theoretical maximum conveyance

Indicator	**Research Finding**	**Interpretation for Flood Control**
Principal crest capacity	1,827.36 m³/s	Main flood-flow pathway
Flushing capacity	152.48 m³/s	Additional conveyance pathway
Capacity margin	900.58 m³/s	Remaining theoretical discharge reserve
Q50 capacity utilization	54.51%	Below maximum hydraulic capacity
Q50 energy-head utilization	69.90%	Below maximum energy-head condition
Q50 flood-water elevation	+46.89 m	Below deck elevation
Deck elevation	+50.00 m	Structural upper reference
Q50 freeboard	3.11 m	Remaining vertical safety margin
Sediment-pocket capacity	8,170 m³	Temporary sediment-storage capacity
Overall Q50 status	SAFE	Structure can accommodate Q50 under calculated conditions

Table 5 synthesizes the principal findings that determine the effectiveness of Bendung Dumpil as a flood-control component. The difference between the maximum capacity and Q50 reaches 900.58 m³/s, while the 54.51% utilization ratio indicates that the design flood does not exhaust the structure's theoretical discharge capacity. The 3.11 m freeboard at Q50 further indicates that the calculated flood-water elevation remains substantially below the deck elevation, providing additional vertical separation against overtopping under the analyzed event. Junaina et al. (2025) emphasize the importance of evaluating available hydraulic capacity and storage when assessing flood-control systems, while Putra et al. (2024) underline the need to integrate hydraulic performance with continuing management of flood-control infrastructure. The combination of discharge reserve, freeboard, and sediment-storage capacity presented in Table 5 therefore demonstrates that Bendung Dumpil possesses several complementary mechanisms supporting flood-control effectiveness.

The sediment pocket has an additional significance because its function connects flood management with the preservation of hydraulic performance over time. The calculated 8,170 m³ storage capacity is based on a conservative effective sedimentation height of half the available 3.50 m depth, rather than assuming that the entire geometric depth can be occupied by sediment. The approach indicates recognition that some hydraulic depth must remain available for flow even before the flushing operation is undertaken. Andriawan et al. (2025), through their evaluation of river infrastructure using physical and functional indicators, demonstrate the importance of monitoring infrastructure condition rather than relying exclusively on original design specifications. The sediment-storage result at Bendung Dumpil therefore supports a maintenance-oriented interpretation in which flushing frequency should be related to observed deposition so that sediment accumulation does not progressively diminish the hydraulic efficiency of the system.

The flood-control function of Bendung Dumpil must also be considered within the broader Lusi–Serang–Juana river network because flood propagation is not restricted to the immediate vicinity of the bendung. The study documentation describes the Lusi–Serang–Juana system as a connected river network extending northward through several areas and incorporating tributaries, hydraulic structures, and irrigation systems. Darsono and Pranoto emphasize the importance of integrated river-basin management and decision-support mechanisms for coordinating water-resource functions across interconnected river systems. Arisanto and Prasetyo (2020) likewise position flood and drought management within the Integrated Water Resources Management framework, which reinforces the need to coordinate local structural interventions with basin-scale water management. The safe Q50 result at Bendung Dumpil therefore contributes to regional flood mitigation but cannot independently eliminate flood hazards arising from downstream bottlenecks, channel limitations, erosion, land-use changes, or flood-prone settlements.

The condition of the Lusi River channel represents an important external factor that may determine whether the structural safety demonstrated at Bendung Dumpil translates into effective flood-risk reduction downstream. Andriawan et al. (2024) specifically identify flood and erosion-related damage along the Lusi River in Grobogan, indicating that channel instability can become a significant component of flood vulnerability. Firizqi and Sudjianto (2023) identify river normalization as a relevant intervention for the Lusi River, suggesting that hydraulic structures should be complemented by channel-management measures where conveyance limitations exist. Larasati et al. (2025) further demonstrate that flood vulnerability within the Lusi sub-watershed is spatially differentiated, meaning that structural safety at one location does not necessarily correspond to uniform safety throughout the watershed. The management implication is that Bendung Dumpil should function as one element of an integrated flood-control strategy involving channel maintenance, erosion management, sediment control, spatial planning, and preparedness measures.

The irrigation function of Bendung Dumpil introduces an additional management dimension because flood-control operations must remain compatible with the infrastructure's role in supplying agricultural water. The bendung has a potential irrigation service area of 10,854 ha and a functional area of 9,818 ha, supported by primary and secondary canal networks that distribute water to agricultural areas. Apriyanto and Saves (2023) demonstrate that water-resource structures require systematic analysis of water availability and demand, while Purwanto and Ikhsan (2006) emphasize the importance of accurately assessing irrigation water requirements in relation to available hydraulic resources. The multifunctional nature of Bendung Dumpil means that operational decisions during high-flow periods must account for both flood conveyance and the protection of irrigation infrastructure. An integrated operating strategy can therefore increase resilience by ensuring that gate manipulation, flushing, and water diversion are coordinated rather than performed as isolated technical actions.

The findings also indicate that preventive maintenance should be prioritized even though the present Q50 evaluation classifies the bendung as safe. The calculated safety condition is dependent on the assumption that the existing gates, hydraulic openings, sediment pocket, and associated structural components continue to perform according to their design characteristics. Tiko et al. (2024) establish that gate operation is an important determinant of flood-control performance, while Andriawan et al. (2025) demonstrate the value of evaluating the physical condition and functional performance of river infrastructure systematically. The recommendation for routine sediment removal and maintenance of floodgates is therefore directly supported by the structure's hydraulic characteristics and the study's own findings rather than being an auxiliary consideration. Preventive maintenance can preserve the 900.58 m^3/s theoretical capacity margin and the 3.11 m Q50 freeboard that currently support the classification of the bendung as safe.

The study's results further demonstrate that structural adequacy and flood-risk reduction should be distinguished analytically. The calculated maximum capacity of 1,979.84 m^3/s indicates that Bendung Dumpil can accommodate the Q50 design discharge of 1,079.26 m^3/s, but this result does not establish that all flood events within the Lusi watershed will be safely contained. Rahman (2025) emphasizes that flood-risk reduction in Grobogan requires broader policy and management strategies, while Aziz et al. (2026) demonstrate the importance of combining hydraulic capacity assessment with broader flood-control interventions within river systems. The distinction becomes particularly important because flood impacts can result from riverbank erosion, inadequate downstream conveyance, sedimentation, local drainage limitations, and exposure of settlements even when a principal hydraulic structure remains structurally adequate. Bendung Dumpil should consequently be regarded as an effective component of flood management at the evaluated location rather than as a standalone solution to all flood hazards affecting the Lusi River basin.

The final interpretation of the research findings indicates that Bendung Dumpil possesses adequate hydraulic capacity for the Q50 design event and retains measurable operational and structural reserves. The 1,979.84 m^3/s maximum capacity exceeds the 1,079.26 m^3/s Q50 discharge by approximately 900.58 m^3/s, while the resulting +46.89 m flood-water elevation remains 3.11 m below the +50.00 m deck elevation. The 8,170 m^3 sediment-storage capacity and the existence of dedicated flushing infrastructure provide additional mechanisms for maintaining hydraulic functionality, provided that sediment accumulation is periodically controlled. Afifah et al. (2025) emphasize the importance of sustainable water-resource infrastructure, while Arisanto and Prasetyo (2020) reinforce the need for integrated approaches to managing flood risks within broader water-resource systems. The most appropriate flood-control strategy for Bendung Dumpil is therefore not immediate structural enlargement but the preservation of existing capacity through systematic gate maintenance, sediment flushing, river-channel management, hydrological monitoring, and coordinated operation within the wider Lusi–Serang–Juana system.

CONCLUSION

The analysis of flood control on the Lusi River at Bendung Dumpil, Ngaringan District, Grobogan Regency, concludes that the 50-year return-period design flood (Q50) of 1,079.26 m³/s, obtained through the Nakayasu Synthetic Unit Hydrograph method, remains within the hydraulic capacity of the existing bendung, which reaches 1,979.84 m³/s, with an energy head of 4.89 m and a flood-water elevation of +46.89 m, still below the +50.00 m crest elevation and providing a 3.11 m freeboard that exceeds the 1.00 m minimum requirement; the Q50 flood utilizes approximately 54.51% of the bendung's total capacity and 69.90% of its available energy head, confirming that Bendung Dumpil remains SAFE under the analyzed Q50 condition, although its continued performance requires periodic inspection of the gates, weir crest, and spillway, routine removal of sediment and deposited materials around the structure to maintain unobstructed flow, and proper management of upstream and downstream river areas to prevent channel narrowing or flow obstructions that could increase flood-water elevations and reduce the existing safety margin.

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