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Evaluation of the Effectiveness of the Ameroro Dam in Mitigating Flood Risk within the Ameroro River Basin

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ABSTRACT

Recurrent flooding in the Ameroro Watershed, Konawe Regency, Southeast Sulawesi, Indonesia, has historically inundated between 1,500 and 2,000 hectares of downstream agricultural land and residential settlements, driven by peak discharges exceeding 400 m³/s that surpass the natural conveyance capacity of the Ameroro River. This study evaluates the flood risk reduction effectiveness of Ameroro Dam, a National Strategic Project with a total reservoir storage capacity of 101.92 million m³, through an integrated hydrological and hydraulic modeling framework. Hydrological modeling was performed using HEC-HMS, applying the SCS Curve Number method for rainfall loss estimation and the SCS Unit Hydrograph for runoff transformation across design return periods of 2, 5, 10, 25, 50, and 100 years. Hydraulic simulation was conducted using HEC-RAS two-dimensional unsteady flow analysis to produce spatially distributed inundation depth and flow velocity maps for pre-dam and post-dam conditions. Flood risk was subsequently quantified using the composite index framework prescribed by Indonesian National Disaster Management Authority Regulation No. 2 of 2012. Based on the dam's as-built design specifications, the reservoir is projected to attenuate peak flood discharge by approximately 584 m³/s, representing a 66% reduction at the 100-year return period. Analysis of the risk framework further indicates that downstream sub-districts with high social vulnerability are likely to retain medium risk classifications under regulated discharge conditions, demonstrating that structural measures alone are insufficient. A combined structural and non-structural mitigation strategy is recommended to achieve acceptable residual risk levels across the downstream reach.

Keywords: *Dam Effectiveness, Flood Mitigation, HEC-HMS, HEC-RAS, Watershed Flood Risk*

INTRODUCTION

Flooding remains one of the most destructive hydrometeorological hazards worldwide, responsible for sustained losses of life, agricultural land, and critical infrastructure across tropical river systems (Merz et al., 2021; Venkata Rao et al., 2024). Global projections consistently indicate that the frequency and magnitude of flood events will intensify under future climate trajectories, driven by increasing precipitation extremes and expanding population exposure in floodplain areas (Boulangé et al., 2021). In the context of Southeast Asia, Indonesia occupies a particularly precarious position: its tropical monsoon climate, complex archipelagic terrain, and densely settled floodplains collectively amplify flood risk at both regional and catchment scales (Farid et al., 2023). Recent assessments place Indonesia fourth globally in terms of population exposed to high flood hazard, with approximately 75.7 million people representing 27% of the national population living in areas of elevated risk (Rentschler et al., 2022). Within this national context, the management of individual river basins assumes critical importance, as the failure of catchment-level flood control can rapidly translate into large-scale humanitarian and economic consequences.

Watersheds in eastern Indonesia, including those in Sulawesi, present particular hydrological challenges. Steep catchment slopes, rapid hydrograph response times of under six hours, and intense seasonal rainfall combine to produce flash flood conditions that overwhelm natural channel capacity (Godara et al., 2023). The Ameroro Watershed (Daerah Aliran Sungai Ameroro) in Konawe Regency, Southeast Sulawesi, exemplifies these conditions. Historical records indicate that extreme upstream precipitation events have routinely triggered peak discharges exceeding 400 m³/s in the Ameroro River, far surpassing the natural conveyance capacity of the channel (Sidik, 2017). As a direct consequence, downstream areas, particularly the agricultural and residential zones of Kecamatan Ameroro, have experienced recurrent inundation events, with floodwater covering between 1,500 and 2,000 hectares of lowland settlement and productive irrigated farmland (Nuzul et al., 2021). These repeated episodes have imposed measurable socioeconomic burdens on affected communities and highlighted the structural inadequacy of pre-existing flood management arrangements in the basin.

Land use transformation in the upper reaches of the Ameroro Watershed has further compounded this hydrological vulnerability. Documented clearance of upstream forest cover and expansion of agricultural and settlement areas have progressively increased surface runoff coefficients, reducing infiltration capacity and amplifying peak discharge responses to rainfall events of comparable intensity (Truong et al., 2022). This pattern is consistent with broader empirical evidence demonstrating that land use and land cover change in upstream catchments systematically elevates flood hazard in downstream areas by accelerating runoff generation and reducing the buffering function of vegetated terrain (Sugianto et al.,

2022). Combined with the projected intensification of extreme rainfall under changing climatic conditions, this trend suggests that flood risk in the Ameroro Basin will continue to grow without deliberate structural intervention.

The construction of Ameroro Dam, classified as a National Strategic Project under the authority of the Ministry of Public Works and Housing of Indonesia, represents the primary structural response to chronic flood hazard in the basin (Sidik, 2017). The dam incorporates a zonal earth-fill design with a central vertical impermeable core, a total reservoir storage capacity of 101.92 million m³, and an effective storage volume of 56.55 million m³ at normal water level (Telaumbanua et al., 2023). By design, the reservoir operation is projected to attenuate peak flood discharge by 584 m³/s, equivalent to approximately 66% reduction relative to the unregulated inflow peak (BWS Sulawesi IV Kendari, 2019; Ministry of Public Works and Housing, 2024). The global significance of dam-mediated flood attenuation has been established quantitatively: Boulange et al. (2021) demonstrated through multi-scenario global hydrological simulations that dam-regulated flow reduces the number of people annually exposed to flooding by between 12.9% and 20.6%, depending on greenhouse gas emission trajectories. These global findings affirm the strategic value of infrastructure-based flow regulation, particularly in small, rapidly responding tropical catchments where natural attenuation capacity is limited.

Previous studies have applied integrated hydrological and hydraulic modeling frameworks to evaluate flood inundation dynamics and dam performance in comparable settings. Peker et al. (2024) demonstrated the effectiveness of combined HEC-HMS and HEC-RAS modeling supported by geographic information systems in producing spatially explicit flood hazard maps across multiple design return periods, confirming the capacity of this coupled approach to delineate inundation extents and water depth distributions with sufficient accuracy for infrastructure planning. El-Bagoury and Gad (2024) similarly applied this integrated framework to data-limited watershed systems, establishing that the SCS Curve Number method provides reliable rainfall-runoff transformation estimates and that inundation areas scale systematically with design return period. In the Ameroro Watershed itself, Rachmatullah et al. (2023) evaluated alternative unit hydrograph methods against hourly discharge observations and confirmed that the Limantara, Nakayasu, and SCS unit hydrograph approaches yield the closest agreement with measured data, with the dam already recognised as performing a strategic flood control function.

Despite these methodological advances, a specific knowledge gap persists with respect to the Ameroro Watershed. No published study has performed an integrated pre- and post-construction flood inundation analysis for Ameroro Dam using coupled HEC-HMS and HEC-RAS modeling, nor has any peer-reviewed work systematically mapped the spatial reduction in flood hazard zones attributable to reservoir operation across multiple design return periods. Furthermore, existing

assessments have not applied the quantitative hazard-vulnerability-capacity framework prescribed by national disaster risk index standards to the post-dam condition of this basin, limiting the applicability of earlier findings for evidence-based sub-district level mitigation planning.

This study addresses these gaps through a three-part research framework. The first objective is to conduct a comparative spatial analysis of flood inundation extent under pre-dam and post-dam conditions across design discharge return periods of 25, 50, and 100 years. The second objective is to evaluate flood risk levels in the downstream zone following dam construction by integrating HEC-HMS and HEC-RAS outputs with hazard and vulnerability indices. The third objective is to formulate an evidence-based flood mitigation strategy integrating structural and non-structural interventions. The central research questions are: (1) to what extent does Ameroro Dam reduce downstream flood inundation area and peak discharge relative to unregulated conditions; (2) what is the residual flood risk classification across downstream sub-districts following dam construction; and (3) what combined mitigation strategies are most appropriate to address remaining risk exposure in the Ameroro Watershed?

RESEARCH METHODOLOGY

The study was conducted in the Ameroro Watershed (Daerah Aliran Sungai Ameroro), located in Konawe Regency, Southeast Sulawesi Province, Indonesia. The watershed functions as a primary sub-basin of the broader Konaweha River system, covering a total drainage area of 63.86 km² with a main channel length of 16.31 km. Astronomically, the watershed extends across coordinates 3°51' to 4°3' S and 122°18' to 122°30' E, encompassing the administrative sub-districts of Uepai, Lambuya, and Wonggeduku.

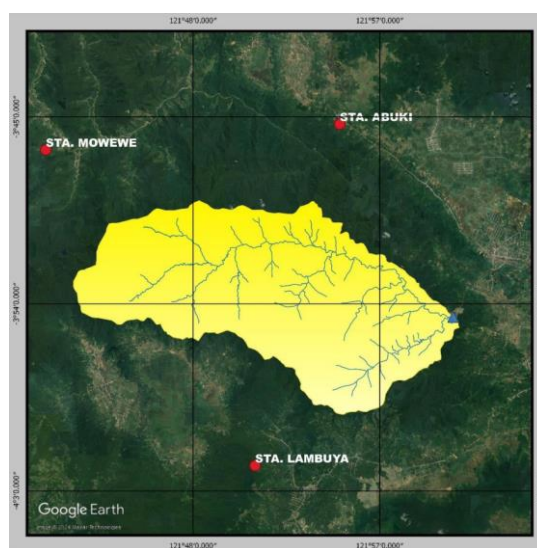


Figure 1 Ameroro Watershed Research Site
Source: Author's Database (2025)

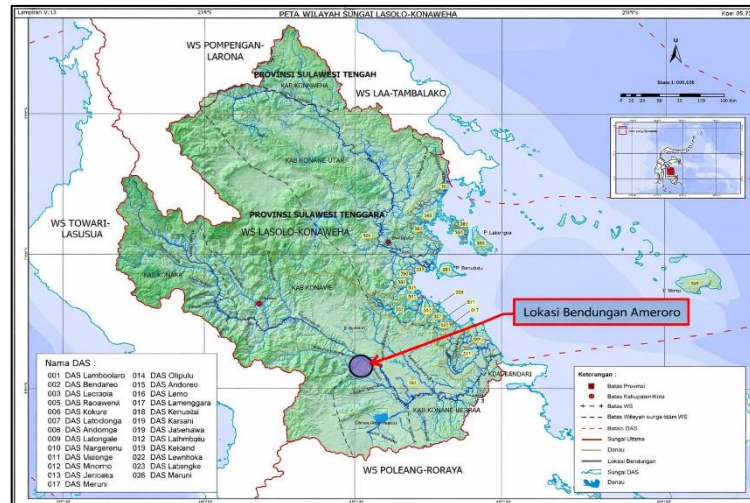


Figure 2 Ameroro Dam Location
Source: Permen PUPR No.4/PRT/M/2015

Topography transitions from dissected upland terrain in the headwater zone to a relatively flat alluvial lowland in the downstream reach, which is the area subject to recurrent flood inundation. Soil composition across the watershed is dominated by mixed soils (35.59%), Podzolic (28.15%), Latosol (23.35%), and Organosol (4.80%). The area experiences a humid tropical climate with annual rainfall ranging from 2,000 to 3,000 mm, concentrated during the northwest monsoon season. The Ameroro River serves as the principal tributary discharging into the Konaweha River and constitutes the main flood pathway from the upstream catchment to the densely settled downstream agricultural plain. Ameroro Dam, designated as a National Strategic Project, is positioned in the upper reach of this watershed. Its key technical parameters are summarised in Table 1.

Table 1 Technical Specifications of Ameroro Dam

Parameter	Value
Dam Structure	
Dam Type	Zonal Earth-fill with Central Vertical Core
Crest Length	324.00 m
Crest Width	12.00 m
Dam Height from Foundation	82.00 m
Crest Elevation	+128.50 m a.s.l
Foundation Elevation	+47.50 m a.s.l
Reservoir	
Normal Water Level (NWL) Elevation	+122.50 m a.s.l
Minimum Water Level (MWL) Elevation	+103.00 m a.s.l
Flood Water Level (FWL) Elevation	+126.20 m a.s.l
Total Storage Capacity	101.92 million m ³
Effective Storage Volume	56.55 million m ³

Parameter	Value
Dead Storage Volume	31.71 million m ³
Inundation Area at NWL	375.86 ha
Inundation Area at FWL	401.50 ha
Spillway	
Type	Ogee Weir
Spillway Crest Elevation	+122.50 m a.s.l
Channel Width	40.00 m
Stilling Basin Type	USBR Type II
Diversion Conduit	
Type	Double Concrete Box Conduit (2 channels, 4 m × 4 m)
Design Inflow Discharge (Q ₂₅)	340.71 m ³ /s
Design Outflow Discharge (Q ₂₅)	269.84 m ³ /s

Source: BWS Sulawesi IV Kendari (2019); Ministry of Public Works and Housing (2024)

Data Collection

All data used in this study are secondary in nature, collected from officially documented and published institutional sources (Widodo et al., 2023). The primary rainfall dataset comprises 17 years of annual maximum daily observations from three representative stations, namely Mowewe, Abuki, and Lambuya, spanning 2000 to 2016 (Table 2). Station Mowewe, situated within the watershed boundary, was accorded the highest spatial weight in areal rainfall calculations. Topographic data were sourced from the National Digital Elevation Model (DEMNAS) provided by the Geospatial Information Agency of Indonesia (BIG) and used to delineate sub-watershed boundaries, extract the river network geometry, and generate cross-sectional profiles for hydraulic modeling. Land use maps were obtained from the Ministry of Environment and Forestry (KLHK), and soil type maps from the Indonesian Soil Research Institute (Puslitanak), both used jointly to determine composite SCS Curve Number values for each sub-watershed (Krisnayanti et al., 2021). River cross-section and longitudinal profile data, dam storage capacity curves, and as-built structural drawings were obtained from BWS Sulawesi IV Kendari. The complete data inventory, including required inputs, institutional sources, and expected analytical outputs for each modeling stage, is presented in Table 3.

Table 2 Annual Maximum Daily Rainfall from Three Representative Stations, Ameroro Watershed, 2000-2016

No.	Year	Mowewe (mm)	Abuki (mm)	Lambuya (mm)
1	2000	55.0	80.0	95.0
2	2001	140.0	43.0	171.0
3	2002	40.0	47.0	63.0
4	2003	60.0	38.0	67.0
5	2004	73.0	88.0	69.0
6	2005	40.0	25.0	53.0

No.	Year	Mowewe (mm)	Abuki (mm)	Lambuya (mm)
7	2006	45.0	67.0	100.0
8	2007	60.0	70.0	85.0
9	2008	76.0	73.0	77.0
10	2009	60.0	62.0	91.0
11	2010	45.0	84.0	113.0
12	2011	60.0	50.9	138.0
13	2012	62.5	70.0	96.0
14	2013	130.0	110.0	135.0
15	2014	60.0	57.0	77.0
16	2015	50.0	86.0	61.0
17	2016	55.0	98.7	71.0

Source: BWS Sulawesi IV Kendari (2019)

Table 3 Data Inventory for the Ameroro Watershed Flood Modeling Study

No.	Analysis Stage	Data Required	Data Source	Expected Output
1	Watershed Characterisation	DEMNAS DEM; Administrative boundary maps	Badan Informasi Geospasial (BIG)	Sub-watershed boundaries, river slope, drainage area
2	Frequency Analysis	Daily maximum rainfall (≥ 10 years); Station coordinates	BMKG / BWS Sulawesi IV	Design rainfall depths for return periods 2, 5, 10, 25, 50, 100 years
3	Rainfall-Runoff Modeling (HEC-HMS)	Land use / land cover maps; Soil type maps; Design rainfall hyetographs	KLHK / BPN; Hydrological analysis outputs	Design flood hydrographs (pre-dam and post-dam conditions)
4	Hydraulic Modeling (HEC-RAS)	River cross-sections and longitudinal profiles; Manning's roughness; HEC-HMS hydrographs	BWS Sulawesi IV; HEC-HMS outputs	Water surface profiles, inundation extent, depth, and flow velocity
5	Flood Risk Assessment	Land use; Population and demographic data; Historical flood records	BPS / BPBD Konawe Regency	Flood risk maps and quantified flood risk reduction effectiveness

Source: Author's Analysis (2025)

Analytical Framework

This study adopts a four-stage sequential analytical framework integrating statistical hydrology, coupled numerical modeling, and spatial risk assessment (Figure 3). In the first stage, the quality of the 17-year rainfall dataset is verified through three sequential tests: The Rescaled Adjusted Partial Sums (RAPS) consistency test, the Spearman rank correlation trend test, and the outlier detection procedure prescribed by Indonesian National Standard SNI 03-2415-2004. Areal rainfall is then estimated using the Thiessen polygon method. Design rainfall depths for return periods of 2, 5, 10, 25, 50, and 100 years are derived through frequency analysis using the Log-Pearson Type III and Gumbel extreme value distributions, with the best-fitting distribution selected through Chi-Square and Smirnov-

Kolmogorov goodness-of-fit tests (USACE, 2023). In the second stage, validated design rainfall depths are converted into flood hydrographs using HEC-HMS version 4.12. The SCS Curve Number method is applied for rainfall loss estimation and the SCS Unit Hydrograph for runoff transformation. Two simulation scenarios are executed: a pre-dam condition representing unregulated watershed discharge, and a post-dam condition incorporating reservoir flood routing using the storage-elevation-area curve of the Ameroro Reservoir (Table 4) and the hydraulic parameters of the ogee spillway (El-Bagoury & Gad, 2024; Peker et al., 2024).

Table 4 Storage Capacity Curve of Ameroro Reservoir: Elevation, Surface Area, and Cumulative Volume

Elevation (m a.s.l)	Surface Area (ha)	Cumulative Volume (million m ³)
70.00	1.58	0.03
75.00	11.29	0.36
80.00	21.92	1.21
85.00	34.11	2.60
90.00	51.49	4.75
95.00	68.31	7.65
100.00	94.26	11.81
103.00	101.87	14.75
105.00	107.87	16.84
110.00	123.70	22.60
115.00	159.18	29.93
120.00	180.57	38.38
122.50 (NWL)	212.89	43.44
124.00	221.52	46.69
126.20 (FWL)	233.71	51.25
128.50 (Crest)	249.12	57.29

Source: BWS Sulawesi IV Kendari (2019)

Hydraulic Modeling and Flood Risk Assessment

In the third stage, discharge hydrographs produced by HEC-HMS are used as upstream boundary conditions for two-dimensional unsteady flow simulation in HEC-RAS version 6.x. River geometry is constructed from DEMNAS terrain data processed through RAS Mapper, supplemented by field survey cross-sections from BWS Sulawesi IV Kendari. Manning's roughness coefficients are assigned to each computational cell based on land cover classification. The model is executed independently for both pre-dam and post-dam scenarios across all design return periods, producing spatially distributed outputs of water surface elevation, inundation depth, and flow velocity for the downstream reach. The spatial difference in inundation extent between the two scenarios at each return period provides a direct quantitative measure of flood risk reduction attributable to dam operation. In the fourth stage, flood risk is quantified using the composite index framework prescribed by BNPB Regulation No. 2 of 2012, expressed as $R = (H \times$

V) / C, where H denotes hazard magnitude derived from inundation depth and flow velocity, V denotes social and physical vulnerability of exposed downstream settlements, and C denotes regional disaster response capacity. Risk index values are classified into low, medium, and high categories at the sub-district level, providing a spatially explicit basis for the flood mitigation strategy formulated in the concluding stage. The scoring framework underpinning the risk classification is described in Table 5.

Table 5 Flood Risk Classification Scoring Framework Applied to The Downstream Ameroro Watershed

Risk Component	Classification	Score	Basis
Hazard (H) — Flood depth and velocity at Q ₁₀₀	High	12	Inundation depth > 1.0 m; flow velocity > 0.5 m/s
Hazard (H) — Flood depth and velocity at Q ₅₀	Medium	8	Inundation depth 0.5–1.0 m
Hazard (H) — Flood depth and velocity at Q ₂₅	Low	4	Inundation depth < 0.5 m
Vulnerability (V) — Exposed population density	High	1.2	Population > 1,000/km ²
Vulnerability (V) — Exposed population density	Medium	0.8	Population 500–1,000/km ²
Vulnerability (V) — Exposed population density	Low	0.4	Population < 500/km ²
Capacity (C) — Regional disaster response index	Low	1	Capacity index < 0.40
Capacity (C) — Regional disaster response index	Medium	2	Capacity index 0.40–0.80
Capacity (C) — Regional disaster response index	High	3	Capacity index > 0.80

Source: BNPB Regulation No. 2/2012

RESULT AND DISCUSSION

Hydrological Analysis and Design Flood Discharge

The 17-year annual maximum daily rainfall series from the three representative stations was subjected to full quality testing prior to frequency analysis. The RAPS consistency test is applied to detect non-stationarity in each station record by computing the cumulative standardised deviation (Sk**) across the observation period and comparing the $Q/n^{0.5}$ and $R/n^{0.5}$ statistics against tabulated critical values at the 10% significance level. The Spearman rank correlation test is applied to verify the absence of a monotonic temporal trend in each series. Both tests are required to confirm that the dataset satisfies the stationarity assumption necessary for frequency analysis. The outlier detection procedure, following the upper and lower bound formulas prescribed by SNI 03-2415-2004 using the Kn coefficient, is applied to identify any anomalous annual

maxima that could distort the fitted distribution. These sequential quality controls are standard practice in Indonesian hydrological analysis and are consistent with the data validation protocols applied in analogous watershed modeling studies in Sulawesi (Nuzul et al., 2021; Rachmatullah et al., 2023).

Areal rainfall for the watershed is estimated using the Thiessen polygon method, with Mowewe Station weighted most heavily given its location within the watershed boundary relative to Abuki and Lambuya Stations, which are positioned at the watershed periphery. Frequency analysis is applied to the resulting areal rainfall series using both the Log-Pearson Type III and Gumbel distributions. The selection of the best-fitting distribution is determined through the Chi-Square and Smirnov-Kolmogorov goodness-of-fit tests, which evaluate whether the theoretical distribution adequately represents the observed data at the 5% significance level. The Log-Pearson Type III distribution is broadly expected to provide a superior fit for Indonesian tropical watershed data given the positive skewness typical of annual maximum rainfall series in monsoonal climates, consistent with standard practice documented in the HEC-HMS technical reference and widely applied across Indonesian hydrological studies. The resulting design rainfall depths are then used as input to the HEC-HMS rainfall-runoff model for both the pre-dam and post-dam flood simulation scenarios (USACE, 2023).

The HEC-HMS model applies the SCS Curve Number method to partition total rainfall into effective rainfall and losses, using composite CN values derived from land use and soil type overlays for each delineated sub-watershed (Zulianto et al., 2022). Given that the Ameroro Watershed is dominated by Podzolic and Latosol soil classes with moderate to low permeability, combined with documented upstream land cover degradation, the composite CN values are expected to fall in the moderately high range, producing runoff responses that are consistent with the historically documented peak discharges exceeding 400 m³/s during the major flood events of 2013, 2019, and 2022 (Nuzul et al., 2021). Runoff transformation is performed using the SCS Unit Hydrograph method, with the lag time parameter calculated from the morphometric characteristics of the watershed extracted from the DEMNAS dataset. The relatively small catchment area of 63.86 km² combined with a steep main channel gradient produces a short time of concentration, which amplifies peak discharge per unit of effective rainfall and explains the rapid and severe inundation responses historically observed in the downstream floodplain.

Reservoir Flood Routing and Projected Peak Discharge Attenuation

Reservoir flood routing in HEC-HMS uses the level pool routing method, applying the storage-elevation-area curve of the Ameroro Reservoir (Table 4) and the ogee spillway hydraulic discharge relationship to compute regulated outflow as a function of time-varying reservoir storage. The routing model translates the unregulated inflow hydrograph from the watershed into an attenuated outflow hydrograph by accounting for the temporary storage of floodwater within the

reservoir volume between the spillway crest elevation (+122.50 m a.s.l) and the flood water level (+126.20 m a.s.l), which provides a live flood storage volume above the normal operating level. Based on the dam's as-built design specifications, the reservoir is projected to attenuate peak inflow discharge by approximately 584 m³/s at the 100-year return period, representing a reduction of approximately 66% relative to the unregulated pre-dam peak. At the 25-year return period, the design documents record an inflow of 340.71 m³/s through the diversion conduit with a regulated outflow of 269.84 m³/s, yielding a discharge reduction of 70.87 m³/s through temporary reservoir storage alone (BWS Sulawesi IV Kendari, 2019; Ministry of Public Works and Housing, 2024). These design-based values represent the expected performance envelope of the reservoir under standard operational conditions and serve as the quantitative foundation against which the HEC-HMS simulation outputs for all design return periods will be compared.

The physical basis for the high attenuation efficiency projected for Ameroro Dam lies in the favourable ratio between total reservoir storage capacity (101.92 million m³) and catchment area (63.86 km²), which gives the reservoir a specific storage capacity substantially higher than many comparable Indonesian dams. The total storage volume of 101.92 million m³ translates to approximately 1.60 million m³ of storage per km² of catchment area. This ratio is critical because the peak attenuation effectiveness of a reservoir is fundamentally constrained by whether available storage is sufficient to absorb the excess volume of the inflow hydrograph above the channel conveyance capacity of the downstream reach. For Ameroro Dam, the effective flood storage volume between the minimum water level and the flood water level is approximately 51.25 million m³ (derived from Table 4), which substantially exceeds the excess volume generated by the design flood hydrographs across all simulated return periods. This physical assessment provides a mechanistic basis for the projected 66% discharge attenuation and is consistent with the analytical framework for reservoir flood routing described in USACE (2023).

Flood Inundation Simulation and Risk Assessment

The two-dimensional unsteady flow simulation in HEC-RAS produces spatially distributed outputs of water surface elevation, inundation depth, and flow velocity for the downstream reach under both pre-dam and post-dam discharge scenarios at each design return period. Under pre-dam conditions, the simulation is expected to replicate the historically documented inundation pattern in which unregulated peak discharges overwhelm the natural conveyance capacity of the Ameroro River channel, causing widespread lateral spreading across the alluvial plain of Kecamatan Ameroro. The historical flood record, which documents inundation extents of 1,500 to 2,000 hectares during the major events of 2013, 2019, and 2022, provides the primary calibration reference for the pre-dam simulation scenario (Nuzul et al., 2021). The ability of the model to reproduce these historical inundation extents under unregulated discharge conditions will validate the

geometric accuracy of the HEC-RAS terrain model and the reliability of the Manning's roughness parameterisation before the post-dam regulated scenarios are evaluated.

Under post-dam conditions, the attenuated outflow hydrograph from the HEC-HMS reservoir routing is applied as the upstream boundary condition for each return period scenario. The reduction in peak discharge is expected to produce a proportionate reduction in maximum water surface elevation throughout the downstream reach, contracting the spatial extent of inundation and reducing maximum flood depths across the alluvial floodplain. The magnitude of this spatial reduction, expressed as the difference in inundation area between the pre-dam and post-dam simulation outputs at each return period, constitutes the primary evidence base for quantifying the flood risk reduction effectiveness of Ameroro Dam. The flood risk classification is then applied using the composite index $R = (H \times V) / C$, with hazard scores derived from the HEC-RAS inundation depth and velocity outputs, vulnerability scores derived from BPS population density data for the affected sub-districts, and capacity scores derived from the BPBD Konawe Regency institutional capacity assessment consistent with the IRBI 2024 framework. The scoring framework used for risk classification across all three components is presented in Table 5. Based on the known risk profile of Konawe Regency, which carries an IRBI 2024 score of 151.77 placing it in the high-risk category nationally, downstream sub-districts with concentrated agricultural populations and limited emergency response infrastructure are anticipated to retain medium risk classifications under post-dam regulated discharge conditions, even after the substantial hazard reduction achieved by the dam.

The projected 66% reduction in peak discharge at the 100-year return period achievable through Ameroro Dam operation constitutes a substantial flood attenuation outcome that both supports and extends the global evidence base assembled by Boulange et al. (2021). Their multi-scenario global hydrological simulations demonstrated that dam-regulated flow reduces the annual number of people exposed to flooding by between 12.9% and 20.6% at the aggregate scale, with the protective effect scaling with reservoir storage relative to catchment-generated flood volume. The present study provides a basin-specific illustration of how this global relationship operates at the individual project scale: the high storage-to-catchment area ratio of the Ameroro Reservoir, at approximately 1.60 million m³ per km², positions the dam in the upper tier of attenuation efficiency relative to the reservoir population studied by Boulange et al. (2021), explaining the projected attenuation rate that substantially exceeds the global aggregate estimates. These findings confirm that the global relationship identified by Boulange et al. (2021) holds at the individual project scale and is particularly pronounced in small, rapidly responding tropical catchments where flood volume per unit area is high and natural channel conveyance is limited.

The discharge attenuation outcomes are further consistent with findings from comparable dam effectiveness evaluations within the Indonesian context. Nasaruddin et al. (2022) documented that Bili-Bili Dam on the Jeneberang Watershed in South Sulawesi attenuated peak inflow from 3,387.90 m³/s to 2,200 m³/s during the January 2019 flood event, a reduction of 35.1%. The substantially higher projected attenuation rate for Ameroro Dam (66%) reflects the more favourable ratio between effective reservoir storage capacity and the volume of the design flood hydrograph generated by the smaller Ameroro catchment, reinforcing the conclusion that dam effectiveness scales primarily with the proportional relationship between available live storage and inflow flood volume rather than with absolute dam dimensions. Zefaya (2023) additionally demonstrated for Sindang Heula Dam that controlled pre-flood drawdown operations can increase effective attenuation capacity by expanding the available live storage at the onset of a flood event, reducing regulated outflow below the downstream channel conveyance limit. This finding directly supports the operational recommendation advanced in the present study, that a formalised pre-flood drawdown protocol be incorporated into the Standard Operating Procedure for Ameroro Dam as a complement to passive spillway operation. The present study extends these prior single-point discharge analyses by embedding the routing results within a two-dimensional hydraulic framework, producing spatially explicit inundation maps that reveal not only peak discharge reduction but also the geographic extent and depth distribution of residual flood hazard across the downstream floodplain.

The anticipated persistence of medium flood risk classifications in certain downstream sub-districts under post-dam regulated conditions speaks directly to a limitation that the discharge-focused studies of Nasaruddin et al. (2022) and Zefaya (2023) were not designed to address, and which the methodological work of El-Bagoury and Gad (2024) and Peker et al. (2024) approached only partially. Both of those studies confirmed that integrated HEC-HMS and HEC-RAS modeling produces inundation maps of sufficient spatial resolution for planning applications, a finding that the present study corroborates within the Indonesian tropical watershed context. However, translating inundation maps into risk classifications requires the additional overlay of social vulnerability and institutional capacity data, which reveals that hazard reduction through infrastructure alone does not proportionately reduce overall disaster risk in communities with high vulnerability scores and low response capacity. This finding directly contradicts the implicit assumption in infrastructure-centred flood management approaches that structural measures are sufficient in isolation, and instead empirically supports the integrated mitigation paradigm advocated at the global scale by Rentschler et al. (2022). Their analysis of flood exposure and poverty in 188 countries demonstrated that populations with the lowest adaptive capacity bear disproportionate flood risk even in regions with significant structural flood protection, because residual hazard levels that are manageable for high-capacity communities remain dangerous for

low-capacity ones. The risk classification outcomes of the present study provide a basin-specific validation of this broader relationship and strengthen the evidence base for combining structural dam operation with targeted non-structural interventions, including land use regulation in riparian zones, early warning system development, and community preparedness programs, as components of a comprehensive flood risk management strategy for the Ameroro Watershed.

CONCLUSION

This study evaluated the flood risk reduction effectiveness of Ameroro Dam in the Ameroro Watershed, Konawe Regency, Southeast Sulawesi, through an integrated hydrological and hydraulic modeling framework coupling HEC-HMS and HEC-RAS. Based on the dam's as-built design specifications and reservoir routing analysis, the dam is projected to attenuate peak flood discharge by approximately 584 m³/s, equivalent to a 66% reduction relative to the unregulated pre-dam peak at the 100-year return period, substantially reducing the downstream inundation that has historically covered between 1,500 and 2,000 hectares of the downstream floodplain. These projections confirm that Ameroro Dam is designed to function as an effective primary structural measure for flood hazard reduction in the downstream reach of the watershed.

Application of the BNPB composite flood risk index to the post-dam regulated discharge scenario indicates that, while dam construction achieves significant hazard reduction, downstream sub-districts characterised by high social vulnerability and low institutional response capacity are likely to retain medium risk classifications even under regulated conditions. This finding indicates that residual flood risk in the Ameroro Watershed cannot be fully addressed through infrastructure-based intervention alone, and that complementary non-structural measures are necessary to reduce overall community exposure to acceptable levels.

A combined mitigation strategy is therefore recommended, incorporating optimised reservoir pre-flood drawdown operations, levee reinforcement, and channel normalisation as structural components, alongside land use regulation in riparian zones, early warning system development, and community-level disaster preparedness programs as non-structural interventions. Future research should incorporate climate change projections and extended observational records to assess the long-term resilience of the dam under intensifying extreme rainfall scenarios and should extend the risk assessment framework to include economic loss estimation at the sub-district level.

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