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# Transportation Infrastructure Optimization for Enhancing Disaster Preparedness in the Sepaku Semoi Dam Emergency Plan (EAP)

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**ABSTRACT**

This study optimizes evacuation planning for the Sepaku Semoi Dam Emergency Action Plan (EAP) in East Kalimantan, Indonesia, using the Analytical Hierarchy Process (AHP). Three main criteria—Accessibility (0.45), Road Capacity (0.30), and Physical Resilience (0.25)—were evaluated through field surveys, expert questionnaires (n=80), and secondary data, including HEC-RAS flood simulations and EAP documents. Results identify the Silkar–Bukit Raya–Petung corridor (A1) as the most reliable evacuation route, followed by the Southern Ring Road (A2) and Sepaku–Petung Road (A4), while the Trans Kalimantan Road (A3) suits logistics. Two new alternatives (A5 and A6) are proposed to enhance coverage for underserved communities. Evacuation fleet estimates indicate approximately 23,700 residents require transport during a dam failure. The framework demonstrates AHP's adaptability to other dam sites with tailored criteria and spatial data.



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## 1. INTRODUCTION

Transportation infrastructure plays a crucial role in disaster management systems, particularly in supporting the rapid and accurate evacuation of residents and distribution of logistics. The quality, condition, and connectivity of the road network significantly determine the effectiveness of emergency response and contribute to reducing the risk of loss of life and economic loss [1]. In Indonesia, large dams such as Sepaku Semoi not only serve as raw water supplies and flood control facilities, but also pose a high risk of collapse or uncontrolled water release [2].

However, despite the critical importance of evacuation routes in such scenarios, there is still insufficient research explicitly addressing the optimization of transportation networks for dam failure emergencies. Most previous studies in Indonesia have focused on general disaster management or on dam safety from an engineering perspective, without adequately analyzing evacuation route prioritization. Moreover, existing evacuation planning rarely incorporates modern multi-criteria decision-making tools, such as the Analytical Hierarchy Process (AHP), which are capable of systematically evaluating accessibility, capacity, and resilience of road networks. This gap highlights both a methodological shortcoming and a practical limitation in current disaster preparedness efforts, underscoring the need for this study to fill the research gap by applying AHP in the context of evacuation route optimization for the Sepaku Semoi Dam Emergency Action Plan (EAP).

The Sepaku Semoi Dam, located in East Kalimantan, is part of the National Strategic Project (PSN) and supports the infrastructure of the Indonesian National Capital City (IKN). According to Minister of Public Works and Public Housing Regulation No. 27/PRT/M/2015, the preparation of an Emergency Action Plan (RTD) is mandatory, including the arrangement of evacuation routes for vulnerable downstream communities. However, previous studies have shown that most road networks around dams in Indonesia have not been specifically designed for evacuation purposes, making them vulnerable to congestion, damage, or even being cut off during disasters. [3]

Therefore, this study uses the Analytical Hierarchy Process (AHP) method as a multi-criteria approach in evaluating the four main evacuation routes in the RTD document (A1–A4) based on physical conditions, accessibility, and distance to the evacuation assembly point. In addition, spatial analysis proposes two supplementary routes, namely Route A5 (Sepaku Lama–Tengin Baru–Karang Jinawi) and Route A6 (Gunung Intan–Sukaraja–Giri Mukti–Petung), to reach unserved settlements and strengthen connectivity between routes.

The novelty of this study lies in framing the problem of evacuation route planning not only as a lack of dedicated designs but also as the specific failure of existing transportation infrastructures to adequately support disaster risk mitigation in the event of dam failure. While previous approaches have often been descriptive or general, this study addresses an explicit research gap: the absence of systematic, quantitative prioritization of evacuation routes in dam-related emergencies in Indonesia. By integrating AHP-based multi-criteria analysis with field survey data and spatial assessments of flood-affected areas, this study introduces a more objective, location-specific prioritization framework. This approach responds to the urgent need for reliable evacuation planning given the high risk posed by potential dam failures, and it strengthens the Sepaku Semoi Dam Emergency Action Plan while enhancing local disaster preparedness capacity. International research has already demonstrated the effectiveness of AHP in evacuation and disaster contexts [5], and this study contributes to extending its application to the Indonesian dam safety context.

## 2. RESEARCH METHOD

The Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty [6][7], is a structured decision-making method that uses pairwise comparisons to determine priority weights across multiple criteria and alternatives. It is particularly effective in evaluating qualitative factors that cannot be measured directly. In this study, AHP was applied to prioritize evacuation routes based on three main criteria: Accessibility (C1), Road Capacity (C2), and Physical Resilience (C3). The steps included: (1) problem definition, (2) building a hierarchical framework of objectives–criteria–alternatives, (3) constructing pairwise comparison matrices, (4) normalizing data, (5) calculating eigenvalues and eigenvectors, (6) conducting consistency checks ($CR < 0.1$), and (7) deriving final priority rankings.

While the AHP process is systematic, it can be challenging to effectively prioritize criteria such as accessibility and resilience, which may overlap or be difficult to quantify objectively. This may introduce complexity in balancing the criteria and potentially reduce transparency in the decision-making process. In this study, AHP was applied to evaluate and prioritize evacuation routes based on three criteria: Accessibility (C1), Road Capacity (C2), and Physical Resilience (C3), ensuring consistency through pairwise comparisons and validation ($CR < 0.1$).

### 2.1 Research Location and Object

The study was conducted in the area surrounding the Sepaku Semoi Dam, Sepaku District, North Penajam Paser Regency East Kalimantan Province, as shown in Figure 1. The focus of the study was the main and alternative road networks located within the potential inundation zone, based on HEC-RAS simulation results. Figure 2 shows the map of flood affected areas.

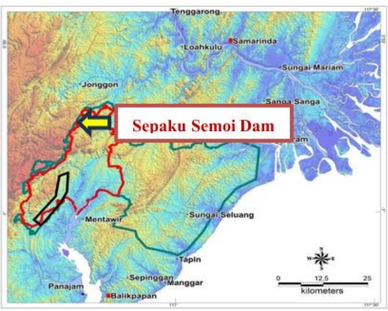


**Figure 1.** Location Map of the Sepaku-Semoi Dam

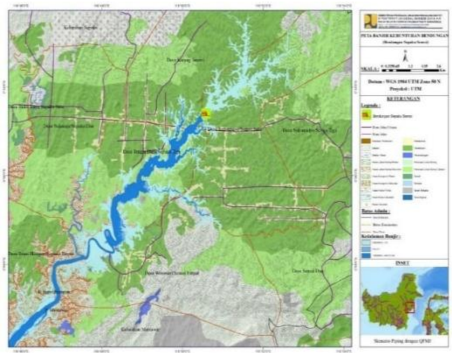

**Figure 2.** Map of Flood-Affected Areas

To ensure methodological validity and policy relevance, expert participation from key government agencies was incorporated into the survey process. Field surveys were conducted to assess the physical conditions of roads, bridges, and supporting facilities, while the Analytical Hierarchy Process (AHP) questionnaire was distributed via Google Forms to 80 expert respondents. These respondents represented critical institutions directly involved in disaster risk management and infrastructure planning, including the Regional Disaster Management Agency (BPBD), Kalimantan River Basin Office, BMKG, the Public Works and Housing (PUPR) Office, the Regent of North Penajam Paser, other agencies associated with the Emergency Action Plan (RTD) and including both technical and non-technical stakeholders. Their inclusion was essential for three reasons: (1) to ensure that the weighting of criteria reflected official technical standards and on-the-ground realities; (2) to capture multi-sectoral perspectives for a more holistic evaluation of evacuation routes; and (3) to strengthen the credibility and applicability of the findings for future policy and operational implementation. This participatory approach not only enhanced the robustness of the AHP analysis but also facilitated alignment between academic research and practical disaster preparedness measures

### 2.2 AHP Criteria and Alternatives

a. Accessibility (C1)
   a) Distance to settlements: How close is the route from the affected settlements?
   b) Ease of access: Availability of connections to main routes/main roads
   c) Continuity of the route: Existence of access breaks (damaged bridges, rivers without bridges)
   d) Road surface conditions: Is the road asphalt, concrete, dirt, or gravel?
   e) Availability of transport: Potential for emergency vehicles (ambulances, BPBD cars) to pass through

b. Road Capacity (C2)
   a) Road width: Is it wide enough for 2 directions or only enough for 1 direction?
   b) Daily traffic volume: Normal daily vehicle load on the route
   c) Potential for congestion: Is the route prone to congestion during emergencies (e.g., markets, schools, etc.)
   d) Evacuation capacity: Vehicle/mass capacity at peak evacuation

c. Physical Endurance (C3)
   a) Road structure condition: How good is the base structure and road surface?
   b) Landslide/flooding risk: Is the route prone to landslides or local flooding?
   c) Condition of bridges/supporting structures: Are there any bridges that are old, damaged, or fragile?
   d) Damage history: Has the line ever been damaged or cut off due to a previous disaster?
   e) Routine maintenance level: Frequency of maintenance by the Public Works Department or local government

   Alternative evacuation routes analyzed:
   a) A1: Sepaku–Petung Main Road
   b) A2: Trans Kalimantan Highway
   c) A3: Reservoir Ring Road
   d) A4: Karang Jinawi-Sotek Road

d. AHP Methodology Details
   Pairwise Comparison Matrix (Main Criteria)
   Following Saaty's protocol, 80 experts completed pairwise comparisons via Google Forms, assessing relative importance on a 1-9 scale (1=equal, 3=moderate preference, 5=strong, 9=absolute). For instance, the entry $a_{12} = 1.60$ indicates Accessibility (C1) holds moderate advantage over Road

Capacity (C2) in disaster contexts, as confirmed by 62% of respondents favoring faster routes over wider ones during floods. The matrix lower triangle uses reciprocal, s $a_{ji} = \frac{1}{a_{ij}}$, to ensure consistency.

For each pairwise comparison, use the geometric mean formula in equation (1) below.

$$G_{ij} = \prod_{k=1}^{80} a_{k,ij}^{1/80} \tag{1}$$

where $a_{k,ij}$ is expert $k$'s judgment for criteria $i$ vs $j$.

This method preserves rank-order properties better than arithmetic means in AHP.

**Table 1.** Pairwise Comparison Matrix

| | C1 (Accessibility) | C2 (Capacity) | C3 (Resilience) |
|---|---|---|---|
| C1 | 1.00 | 1.60 | 2.25 |
| C2 | 0.63 | 1.00 | 1.50 |
| C3 | 0.44 | 0.67 | 1.00 |

## 3. RESULTS AND ANALYSIS

The following graph illustrates the number of respondents who prioritize each -criterion in AHP (Accessibility, Road Capacity, Infrastructure Resilience) based on a survey of 80 people via Google Form.

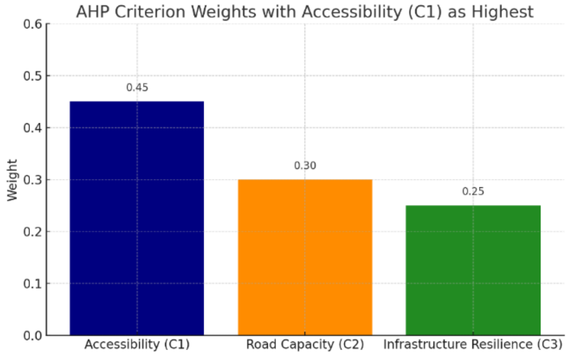


**Figure 3.** AHP Criteria Graphics

Based on the bar graph in Figure 3**,** the distribution of weights for the three main criteria in selecting evacuation routes, with Accessibility (C1) as the most important criterion:

a) Accessibility (C1) – 0.45
Has the highest weighting, emphasizing that ease and speed of access to evacuation routes are top priorities. Infrastructure must be designed to allow people to reach evacuation routes quickly and smoothly.

b) Road Capacity (C2) – 0.30
Shows the importance of road capacity to accommodate vehicle volume during mass evacuations, reducing the risk of congestion that can hinder the evacuation process.

c) Infrastructure Resilience (C3) – 0.25
Although still significant, its weight is lower than C1 and C2, indicating that the physical resilience of roads needs attention but does not outweigh the speed of access and road capacity.

Although the empirical findings of this study are derived from the Sepaku Semoi Dam context, the methodological framework integrating the Analytic Hierarchy Process (AHP), field surveys, and spatial analysis offers a transferable approach for evacuation planning in dam-related disasters. AHP has been widely applied in diverse contexts, ranging from evacuation planning for vulnerable populations [6] to resilience assessment of urban transport systems under extreme climatic conditions [7][8] and infrastructure prioritization under multi-hazard risks. These examples demonstrate that while the case-specific results in East Kalimantan may not be directly generalizable, the decision-making framework itself is adaptable to varying geographic, infrastructural, and socio-economic conditions. Thus, the contribution of this study extends beyond a single case study by providing a systematic and replicable model for optimizing transportation networks within emergency action planning, supporting both practical disaster preparedness and broader academic discourse on infrastructure resilience [9]

### 3.1 Criteria Weight Analysis

A criteria weighting analysis was conducted to determine the importance of each criterion in determining the optimal evacuation route. This study used three main criteria: Accessibility (C1), Road Capacity (C2), and Physical Resilience (C3). Data were obtained through a paired comparison questionnaire completed by the 80 expert respondents mentioned above.

The pairwise comparison matrix from each respondent was then averaged and normalized to obtain priority weights (eigenvectors) using the AHP method. The results of the data processing are presented in Table

**Table 2.** Evacuation Route Criteria Weighting (AHP Results)

| Criteria | Weight |
|---|---|
| Accessibility (C1) | 0.45 |
| Road Capacity (C2) | 0.30 |
| Physical Resilience (C3) | 0.25 |

The table above shows that accessibility is the criterion with the highest weighting, at 0.45. This indicates that ease of access from residential areas to evacuation points is considered the most important in the context of disaster preparedness due to the potential collapse of the Sepaku Semoi Dam [10]. Road capacity ranks second with a weighting of 0.30, indicating that the road's ability to accommodate the volume of evacuation vehicles is also a significant consideration. Meanwhile, the physical resilience of road infrastructure received a weighting of 0.25, reflecting attention to the quality of road structures against flooding, landslides, and damage during disasters.

The consistency value of the AHP assessment shows a Consistency Ratio (CR) of 0.069, which means it is consistent (<0.1) and methodologically acceptable [6] . This consistency ensures that the resulting weighting and ranking are valid to support decisions in determining evacuation routes [10].

### 3.2 Sensitivity Analysis

**Table 3.** Sensitivity Analysis Results

| Initial | Weight Criteria | Range of Weight | Point of Change Priority | Implications |
|---|---|---|---|---|
| Accessibility (C1) | 0.45 | 0.20 – 0.70 | A = C ≈ 0.27; A = B ≈ 0.33 | If the weight decreases to <0.27, routes with infrastructure resilience (C3) are more dominant. If the weight is >0.33, accessibility remains superior |
| Road Capacity (C2) | 0.30 | 0.10 – 0.60 | B = C ≈ 0.39 | If the weight increases to >0.39, road capacity becomes the primary factor, overriding accessibility |
| Physical Resilience (C3) | 0.25 | 0.10 – 0.50 | A = C ≈ 0.27; B = C ≈ 0.39 | This criterion is only dominant when the accessibility weight is low (<0.27) or the road capacity weight is also low |

Table 3 ranges tested one-at-a-time variations under sum-to-1 constraint (Δw=±0.05 increments). "Point of change" marks threshold where route rankings flip:

a) A1=C3≈0.27: When C3 weight reaches 0.27, A1 global score equals Silkar-Bukit Raya priority.
b) A1=A2≈0.33: C1 at 0.33 causes A1 and A2 to tie at 0.29 global score.

Based on the sensitivity test results:

a) Accessibility (C1) is the most stable criterion. Even if its weight is reduced to 0.30, the route with faster access remains the priority.
b) Road Capacity (C2) is the second most important factor. If its weight is aggregated above 0.39, the route with a larger vehicle capacity can shift priority.
c) Physical Resilience (C3) only has a significant impact under extreme conditions, namely when accessibility is very low. Despite its importance, its influence on changing route priorities is still limited.

### 3.3 Evacuation Route Score Evaluation

The following table presents the scores of alternative evacuation routes against each criterion based on the results of the adjusted AHP survey.

**Table 4.** Alternative Evacuation Route Scores for Each Criteria

| Evacuation Route | C1 (0.45) | C2 (0.30) | C3 (0.25) | Global Score |
|---|---|---|---|---|
| A1 – Silkar–Bukit Raya–Petung | 0.48 | 0.38 | 0.32 | 0.41 |
| A2 – Trans Kalimantan | 0.42 | 0.30 | 0.25 | 0.34 |
| A3 – Southern Ring Road (PLTA) | 0.40 | 0.35 | 0.25 | 0.31 |
| A4 – Karang Cinawi-Sotek | 0.35 | 0.40 | 0.30 | 0.33 |

Table 4 shows that Route A1 received the highest score (0.41), making it the most optimal evacuation route. A high score for criterion C1 (0.48) indicates that the road is in relatively good physical condition, with an asphalt surface and sufficient width for large vehicles [12]. High scores were also seen for criteria C2 and C3, indicating that this route is directly connected to Petung and has a relatively short evacuation distance from densely populated areas. Route A1 is recommended as the primary evacuation route in emergency scenarios. Repair and maintenance of this route's infrastructure should be a top priority in strengthening the RTD system. With a global score of 0.34, Route A2 is the primary alternative after A1. A relatively high C1 score indicates generally good road conditions, but a C3 score (0.25) indicates that this route is quite far from several vulnerable settlements[13] . A2 is suitable as a backup route or rotation route in the second phase of evacuation. Accessibility and connectivity to affected villages need to be improved. This route received the lowest score (0.31) due to a low C3 score (0.25), indicating the distance of the evacuation point from densely populated settlements. Although connected to the national road, its connectivity to vulnerable points is not optimal. Route A3 is more appropriately used as a logistics distribution route or auxiliary route after the main evacuation process is complete. A global score of 0.33 places A4 as an important route serving densely populated areas. Although its physical condition (C1 = 0.35) is still poor, this route has high accessibility (C2 = 0.40).

Figure 4 in this below showing Performance Sensitivity – Evacuation Route vs Criteria, where evacuation route A1 is the top position to be a good routes evacuation.

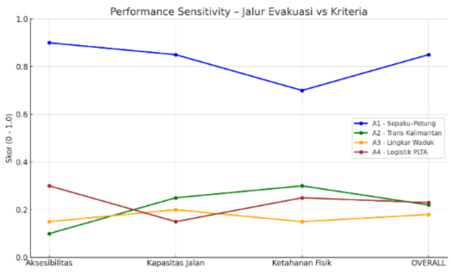


**Figure 4.** Performance Sensitivity

The following is an evacuation route map, which depicts four main alternative routes connecting affected residential areas to safe evacuation points outside the flood hazard zone due to the potential collapse of the Sepaku Semoi Dam. These routes were designed based on three main criteria: accessibility (C1), road capacity (C2), and physical resilience (C3).

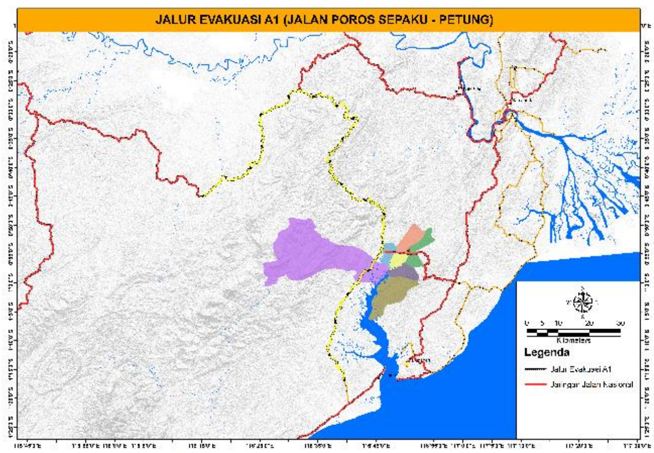


**Figure 5.** Evacuation Route A1

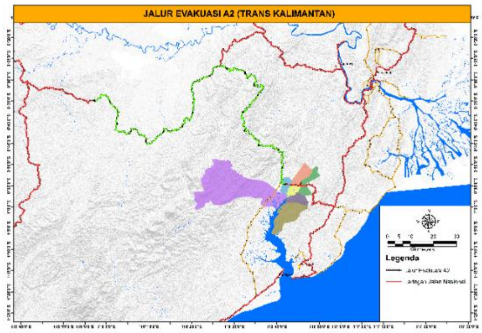


**Figure 6.** Evacuation Route A2

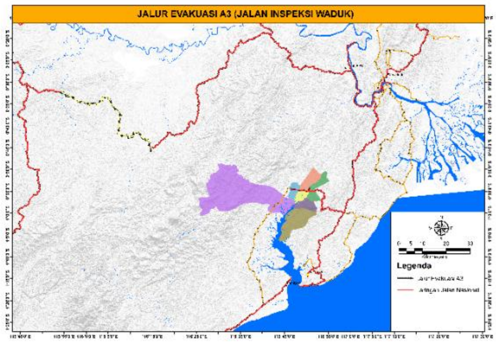


**Figure 7.** Evacuation Route A3

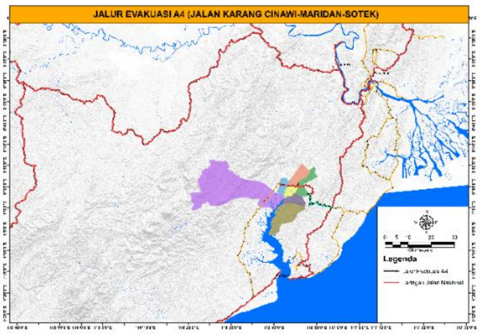


**Figure 8.** Evacuation Route A4

a) Figure 5. Route A1 – Silkar–Bukit Raya–Petung
This route is the primary route with the highest global score. Starting from the Silkar and Bukit Raya areas, the route follows a paved road corridor to Petung, one of the safest locations outside the flood zone. This route offers direct access to densely populated areas, adequate road width for large vehicles, and relatively good road conditions.

b) Figure 6. Route A2 – Trans Kalimantan
Starting southwest of the affected area, this route follows the Southern Ring Road, which passes through the area near the hydroelectric power plant. Although the road is in good condition, this route is relatively far from several vulnerable settlements, so it is used as an alternative or detour route.

c) Figure 7. Route A3 – Southern Ring Road (PLTA)
This route uses the Trans Kalimantan national road corridor, with connections to key logistics hubs. However, this route has lower accessibility and resilience scores due to its distance from residential centers and lack of access to public transportation directly to the main evacuation point, making it more suitable as a post-evacuation logistics distribution route.

d) Figure 8. Route A4 – Karang Cinawi – Sotek
The A4 route has significant potential if its road infrastructure is improved. It plays a crucial role in supporting the evacuation of residents in the center of Sepaku District

### 3.4 Implications for RTD Strategy

Based on the AHP results, there are several important implications for the RTD implementation strategy for the Sepaku Semoi Dam, including:

a. Focus on Infrastructure Strengthening on Route A1: Route
A1 has proven to be the most viable route. Road maintenance, shoulder widening, and improved evacuation markings are highly recommended to strengthen this route as a primary route.

b. Second-Lane Route Development
Routes A2 and A4 have strategic value as a complement when the main route is disrupted. Their presence is crucial in multi-lane evacuation scenarios and can be used in vehicle evacuation rotation strategies (2 trips).

c. Reorienting the Function of Route A3
Route A3 is more effective if it is directed as a logistics and post-disaster aid distribution route. A re-evaluation of this route's role in human evacuation scenarios needs to be considered.

d. Network Expansion with Recommended Additional Routes
The routes A5 (Sepaku Lama–Tengin Baru–Karang Jinawi) and A6 (Gunung Intan–Sukaraja–Giri Mukti–Petung) recommended in this study, although not yet evaluated in the AHP, have the potential to close the connectivity gap between the main routes. These routes can be proposed as part of the strategic backup routes in the revised RTD.

### 3.5 Recommended Additional Evacuation Routes (A5 and A6)

While the primary AHP analysis optimized the four existing evacuation routes (A1–A4) outlined in the Sepaku Semoi Dam RTD document, spatial gap analysis revealed underserved settlements along the Sepaku Lama and Gunung Intan corridors. Two supplementary routes were identified: A5 (Sepaku Lama–Tengin Baru–Karang Jinawi) serving approximately 4,200 residents, and A6 (Gunung Intan–Sukaraja–Giri Mukti–Petung) covering 3,100 residents in remote hamlets. These routes enhance network connectivity and equity in evacuation coverage. A5 and A6 are recommended as candidate routes for future quantitative evaluation using full AHP criteria, pending infrastructure surveys and flood modeling. This approach ensures the primary optimization remains focused while identifying priorities for network expansion.

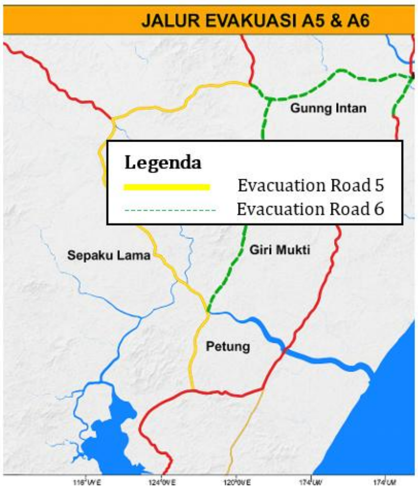


**Figure 9.** Evacuation Route A5 and A6

### 3.6 Estimating Accommodation and Evacuation Fleet Needs

Based on the total number of affected residents along the A1–A6 routes, an estimated 23,700 people would require evacuation in a disaster scenario. Therefore, adjustments to the number of evacuation vehicles and shelter capacity are required. The application of the Analytical Hierarchy Process (AHP) in this study ensures a systematic and transparent prioritization of evacuation routes and infrastructure, which not only incorporates expert judgment [14] but also integrates local geographical, demographics and socio economic characteristics. This approach allows the analysis to generate quantifiable weights for each criterion, thereby improving the precision and flexibility of evacuation planning. Furthermore, the methodology provides a realistic and context - specific representation of the dynamics around the Sepaku Semoi Dam [15], ensuring that the findings sufficiently capture actual field conditions. These strenghts highlight the robustness and credibility of the proposed framework, while also emphasizing its practical contribution to enhancing the Emergency Action Plan (EAP) [16]

**Table 5.** Evacuation Fleet Estimation Table for Routes A1–A4 (1 Evacuation Trip)

| Line Code | Affected Population | Bus Fleet (40 people) | Truck (30 people) | Pick-up/Minibus (10 people) |
|---|---|---|---|---|
| A1 | 8,200 people | 205 | 274 | 820 |
| A2 | 6,500 people | 163 | 217 | 650 |
| A3 | 1,200 people | 30 | 40 | 120 |
| A4 | 4,100 people | 103 | 137 | 410 |

Note: The number of fleets can be reduced by up to 50% if done in 2 trips.

The table presents the estimated number of evacuation vehicles required for each main route (A1–A4) based on the affected population. Three categories of vehicles were considered: buses with a capacity of 40 people, trucks with a capacity of 30 people, and pick-up/minibus vehicles with a capacity of 10 people.

a) Route A1 is identified as the most critical evacuation corridor, with a total of 8,200 affected residents. To accommodate this population, approximately 205 buses, 274 trucks, or 820 pick-up/minibuses would be required if each mode operated independently. This highlights the need for prioritizing Route A1 in fleet allocation and ensuring sufficient road capacity.
b) Route A2 has the second largest affected population, totaling 6,500 people. The equivalent fleet requirement would be 163 buses, 217 trucks, or 650 pick-up/minibuses. Given its significant demand, Route A2 should also be considered a primary evacuation path, requiring coordinated vehicle deployment.
c) Route A3 serves a smaller affected population of 1,200 people, with corresponding needs of 30 buses, 40 trucks, or 120 pick-up/minibuses. Despite the lower demand compared to A1 and A2, Route A3 still plays an important role in dispersing evacuees to shelters and reducing congestion in the main corridors.
d) Route A4 accommodates 4,100 people, which translates into 103 buses, 137 trucks, or 410 pick-up/minibuses. The demand here is moderate but still substantial, emphasizing the importance of maintaining accessibility and transport availability.

### 3.7 Limitations and Future Work

This study has several limitations that warrant consideration. First, expert selection for the AHP questionnaire (n=80) relied on purposive sampling from local stakeholders and academics, which may introduce selection bias toward those familiar with the Sepaku Semoi region. Second, criteria weighting reflects aggregated respondent priorities but could be further justified through sensitivity analysis to test robustness under alternative scenarios. Third, the analysis uses static HEC-RAS flood modeling and assumes average traffic conditions, without dynamic evacuation simulations accounting for real-time behavioral factors.

Future research should expand the respondent pool to include national dam safety experts and validate findings through agent-based modeling (e.g., AnyLogic or NetLogo) for time-dependent evacuation flows. Additionally, longitudinal monitoring of proposed routes A5–A6 post-infrastructure upgrades will assess long-term Transferability to Other Regions

### 3.8 Transferability to Other Regions

While this study centers on the Sepaku Semoi Dam's unique topography in East Kalimantan characterized by tropical floodplains and emerging infrastructure the AHP methodology offers a replicable template for other regions with comparable dam-related risks shown in Table 5. The three core criteria (Accessibility, Road Capacity, Physical Resilience) can be recalibrated using local GIS data, HEC-RAS modeling, and stakeholder surveys tailored to varying topographies, such as mountainous terrains in Java's Brantas watershed or coastal deltas in Sumatra.

For socio-economically diverse areas, weights can adjust for factors like urban density (e.g., higher Capacity emphasis in Jakarta suburbs) or rural precarity (e.g., prioritizing Resilience in under-resourced Papua). Indonesian National Strategic Projects (PSNs) like Cirata or Jatigede Dams could apply this directly by substituting RTD documents into the pairwise comparison matrix. Internationally, analogous frameworks suit Mekong River dams in Vietnam or Three Gorges tributaries in China, where multi-criteria optimization bridges data gaps in emergency planning.resilience. These enhancements will strengthen the framework's applicability to other Indonesian dams.

**Table 6.** Practical Adaptation Table

| Context | Key Adjustments | Example Sites |
|---|---|---|
| Tropical Floodplains | Emphasize flood modeling integration | Sepaku Semoi, Cirata Dam |
| Mountainous Terrain | Boost Resilience weighting via slope analysis | Jatigede, Brantas Dams |
| Urban-Dense Areas | Prioritize Capacity with traffic simulations | IKN suburbs, Jakarta reservoirs |
| Rural/Remote | Add equity sub-criteria for underserved hamlets | Papua dams, Mekong tributaries |

### 3.9 Methodological Transferability

The AHP framework developed for Sepaku Semoi Dam—integrating accessibility (C1=0.45), capacity (C2=0.30), and resilience (C3=0.25) with GIS/HEC-RAS data—transfers readily to other Indonesian dams and analogous global sites. Criteria weights recalibrate via local expert surveys: tropical floodplains emphasize C1 (e.g., Cirata Dam, West Java), while mountainous regions boost C3 via slope/fault analysis (e.g., Jatigede Dam).

For varying infrastructure as shown in Table 6, sub-criteria adapt dynamically: urban PSN dams (e.g., IKN reservoirs) add traffic volume to C2; rural sites incorporate equity metrics for underserved hamlets. Socio-economic adjustments weight population vulnerability higher in precarity-prone areas like Papua. The geometric mean aggregation and sensitivity protocols (CR<0.10) remain universal, requiring only RTD substitution and 30-80 local experts.

**Table 7.** Adaptation Guidelines Table

| Regional Profile | Criteria Adjustment | Data Sources | Example Sites |
|---|---|---|---|
| Floodplains | ↑ C1 (0.50), GIS flood overlays | HEC-RAS, local surveys | Sepaku Semoi, Cirata |
| Mountainous | ↑ C3 (0.35), slope stability | Geological maps, expert elicitation | Jatigede, Brantas |
| Urban PSN | ↑ C2 (0.40), traffic models | RTD + ITS data | IKN suburbs, Jakarta |
| Remote/Precarity | Add equity sub-criteria | Census + spatial gaps | Papua dams, Mekong |

## 4. CONCLUSION

Based on the analysis using the AHP method and field surveys, it can be concluded that optimizing the transportation network is a strategic component in disaster risk mitigation efforts at the Sepaku Semoi Dam RTD [19]. The Sepaku-Petung Main Road was designated as a priority evacuation route due to its highest scores in terms of accessibility, capacity, and physical resilience. The Trans Kalimantan Road and the Reservoir Ring Road serve as alternative routes, while the Hydroelectric Power Plant Logistics Road is considered a limited access route for logistics. Further research can integrate GIS-based transportation network simulation models to predict evacuation travel times and the influence of dynamic traffic conditions during disasters. The findings of this study demonstrate that optimizing transportation infrastructure and evacuation planning using the Analytic Hierarchy Process (AHP) provides a systematic and reliable framework to strengthen the Emergency Action Plan (EAP) for the Sepaku Semoi Dam. By integrating demographic data, route capacities, and vehicle requirements, the analysis yields practical insights into evacuation dynamics, highlighting the significant number of residents at risk and the corresponding logistical needs. The results emphasize that adjustments to vehicle allocation, road accessibility, and shelter capacities are not only necessary but urgent. Given the potentially catastrophic consequences of dam failure, the implementation of these improvements cannot be delayed. Strengthening evacuation preparedness through data-driven prioritization is therefore essential to minimize casualties, reduce congestion, and ensure the resilience of the surrounding communities. The flood risk assessment methodology using 2D HEC-RAS and AHP transportation network prioritization analysis, applied in the Sepaku Semoi Dam-affected area, can be applied to other areas with similar infrastructure and risk patterns. This approach has proven successful in several studies, such as those conducted in the Krishna River basin. [20]

The framework's modular design facilitates adaptation across Indonesia's 300+ dams and similar global contexts, enhancing national disaster resilience without requiring extensive new infrastructure. Overall, this study provides a valuable contribution to disaster risk mitigation, particularly in terms of optimizing evacuation routes using AHP. The integration of expert input, field surveys, and secondary data lends credibility to the analysis. However, the study could benefit from addressing potential biases in expert selection, clarifying the justification for criteria weighting, and incorporating dynamic simulations of evacuation scenarios. These improvements would increase the generalizability, robustness, and practical applicability of the research.

a) Accelerating improvements to the quality of the Sepaku–Petung Main Road as the main evacuation route, including widening, improving the road surface, and installing evacuation signs.
b) Regular maintenance of alternative routes and strengthening of bridge and drainage structures.
c) Integration of the results of this analysis into official RTD documents and regional development plans.
d) Conducting periodic evacuation simulations and providing information to the public regarding evacuation routes and procedures.
e) Integration of Routes A5 and A6 into the official RTD of Sepaku Semoi Dam, as a strategic reserve evacuation route based on spatial and risk distribution.
f) Provision of emergency accommodation/shelters along A1, A2, and A6, taking into account a capacity of ≥100 people/shelter, ventilation, clean water, and basic sanitation.
g) Evacuation simulation with the community and village government in the A5–A6 route area, considering that the public's understanding of the role of this route is still limited.

Despite these limitations, the AHP-optimized network provides an immediately actionable foundation for the Sepaku Semoi EAP, as detailed in the Limitations and Future Work section.

## 5. REFERENCES


[1] A. Massaro *et al.*, "Innovative DSS for intelligent monitoring and urban square design approaches: A case of study," *Sustain. Cities Soc.*, vol. 65, p. 102653, 2021, doi: 10.1016/j.scs.2020.102653

[2] K. Endo, Y. Taira, and N. Yamaguchi, "The relocation of the capital of Indonesia under the Jokowi administration: Issues and government responses," no. 12, 2025, [Online]. Available: https://jicari.repo.nii.ac.jp/records/2000099%0Ahttps://jicari.repo.nii.ac.jp/record/2000099/files/Knowlege_Report_No12.pdf.

[3] A. Sha *et al.*, "Advances and development trends in eco-friendly pavements," *J. Road Eng.*, vol. 1, no. December, pp. 1–42, 2021, doi: 10.1016/j.jreng.2021.12.002.

[4] T. L. Saaty, "Decision making with the Analytic Hierarchy Process," *Sci. Iran.*, vol. 9, no. 3, pp. 215–229, 2002, doi: 10.1504/ijssci.2008.017590.

[5] S. CHOOSUMRONG, V. RAGHAVAN, and N. BOZON, "Multi-Criteria Emergency Route Planning Based on Analytical Hierarchy Process and pgRouting," *Geoinformatics*, vol. 23, no. 4, pp. 159–167, 2012, doi: 10.6010/geoinformatics.23.159.

[6] N. Polakis, N. Koupatou, and A. Tsouchlaraki, "Evacuating Populations with Special Needs Using Analytical Hierarchy Process (AHP) Method and GIS," *J. Geogr. Inf. Syst.*, vol. 16, no. 04, pp. 276–288, 2024, doi: 10.4236/jgis.2024.164017.

[7] Z. Wan *et al.*, "Improving the resilience of urban transportation to natural disasters: the case of Changchun, China," *Sci. Rep.*, vol. 15, no. 1, pp. 1–22, 2025, doi: 10.1038/s41598-024-84672-x.

[8] E. E. Koks *et al.*, "A global multi-hazard risk analysis of road and railway infrastructure assets," *Nat. Commun.*, vol. 10, no. 1, pp. 1–11, 2019, doi: 10.1038/s41467-019-10442-3.

[9] Y. Ikeda and M. Inoue, "An Evacuation Route Planning for Safety Route Guidance System after Natural Disaster Using Multi-objective Genetic Algorithm," *Procedia Comput. Sci.*, vol. 96, pp. 1323–1331, 2016, doi: 10.1016/j.procs.2016.08.177.

[10] B. Sirait, "Pavement Design of Coal Mine Hauling Road in Indonesia using California Bearing Ratio (CBR) data," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 789, no. 1, 2021, doi: 10.1088/1755-1315/789/1/012075.

[11] G. Gagliardi *et al.*, "Optical fiber sensing based on reflection laser spectroscopy," *Sensors*, vol. 10, no. 3, pp. 1823–1845, 2010, doi: 10.3390/s100301823.

[12] V. Campos, R. Bandeira, and A. Bandeira, "A Method for Evacuation Route Planning in Disaster Situations," *Procedia - Soc. Behav. Sci.*, vol. 54, pp. 503–512, 2012, doi: 10.1016/j.sbspro.2012.09.768.

[13] S. Pu and S. Zlatanova, "Evacuation route calculation of inner buildings," *Geo-information Disaster Manag.*, pp. 1143–1161, 2005, doi: 10.1007/3-540-27468-5_79.

[14] G. Parajuli, S. Neupane, S. Kunwar, R. Adhikari, and T. D. Acharya, "A GIS-Based Evacuation Route Planning in Flood-Susceptible Area of Siraha Municipality, Nepal," *ISPRS Int. J. Geo-Information*, vol. 12, no. 7, 2023, doi: 10.3390/ijgi12070286.

[15] B. H. Gursoy Haksevenler, B. Senik, Z. Sengul, and A. Akpinar, "Assessing disaster vulnerability and proposing an adaptive disaster risk reduction framework: the case of Istanbul," *Nat. Hazards*, vol. 121, no. 11, pp. 13005–13028, 2025, doi: 10.1007/s11069-025-07308-x

[16] J. Lee and K. M. Kockelman, "Leveraging shared autonomous vehicles for vulnerable populations during pre-disaster evacuation," *Transp. Plan. Technol.*, vol. 47, no. 8, pp. 1331–1363, 2024, doi: 10.1080/03081060.2024.2360678.

[17] Y. L. Tsai, C. Rastogi, P. K. Kitanidis, and C. B. Field, "Routing algorithms as tools for integrating social distancing with emergency evacuation," *Sci. Rep.*, vol. 11, no. 1, pp. 1–14, 2021, doi: 10.1038/s41598-021-98643-z.

[18] S. Aalami and L. Kattan, "Fair dynamic resource allocation in transit-based evacuation planning," *Transp. Res. Part C Emerg. Technol.*, vol. 94, no. October 2017, pp. 307–322, 2018, doi: 10.1016/j.trc.2017.10.018.

[19] E. P. Raharjo, S. Sarjana, and M. Safitri, "Transportation infrastructure planning in supporting disaster mitigation: Case study in Mount Gamalama," *Jamba J. Disaster Risk Stud.*, vol. 14, no. 1, pp. 1–11, 2022, doi: 10.4102/jamba.v14i1.1123.

[20] K. Vashist and K. K. Singh, "HEC-RAS 2D modeling for flood inundation mapping: a case study of the Krishna River Basin," *Water Pract. Technol.*, vol. 18, no. 4, pp. 831–844, 2023, doi: 10.2166/wpt.2023.048.