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Determination Of The Priority Scale Of Flood Management In The Landak Sub-Watershed

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Abstract

The Landak Sub Watershed is part of Indonesia's Kapuas River Basin, covering an area of approximately 7,921 km^2 and comprising three administrative regions: Landak Regency, Kubu Raya Regency, and Pontianak City. Like other regions in Indonesia, the frequency of flood events in the Landak Sub Watershed has been increasing each year, becoming a severe problem as it has caused losses for the community. Therefore, a study is needed to provide an overview of the most suitable flood management measures to minimize floods in the Landak Sub Watershed.

This article presents the research results to determine the priority scale of flood mitigation measures suitable for implementation in the Landak Sub Watershed using the Analytic Hierarchy Process (AHP). The determination of criteria, sub-criteria, and flood management alternatives is based on the results of a Focus Group Discussion (FGD) held in Ngabang City on August 30, 2022. The selected flood management alternatives combine both structural and non-structural measures. Once the hierarchy is established, a questionnaire is distributed to determine the appropriate options for flood mitigation in the Landak Sub Watershed.

The study results indicate that the priority scale for flood mitigation in the Landak Sub Watershed is by revising regulations and policies. The analysis shows that the priority criterion is Law and Institutions with a weight of 0.376, the priority sub-criterion is Legislation with a weight of 0.213, and the priority alternative is the revision of regulations and policies with a weight of 0.1984. For the correction of rules and procedures to be effectively carried out, all stakeholders related to flood control in the Landak Sub Watershed must be involved.

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1. Introduction

Flooding is a frequent disaster in West Kalimantan, including the Landak Subwatershed, part of the Kapuas River Basin (Soeryamassoeka et al., 2017, 2018; BNPB, 2021).

Currently, floods in the Landak Sub-watershed occur in urban and rural areas, particularly in the central and upper parts of the Landak Sub-watershed. Since 2002, sites previously unaffected by floods have become flood-prone areas. The occurrence of floods in rural areas, which are part of the upper region of the Landak Sub-watershed, indicates environmental degradation in the upstream area of the river. In the Landak Sub-watershed, floods are generally caused by natural factors, such as high rainfall and the influence of tidal seawater (Soeryamassoeka et al., 2017).

So far, the flood management in the Landak Sub-watershed has primarily emphasized disaster mitigation measures and structural flood control. Nonetheless, it has demonstrated its inadequacy in effectively reducing the frequency of floods. Apart from natural factors, the surges in the Landak Sub-watershed are also influenced by non-natural factors. These factors encompass land conversion to accommodate the growing land requirements driven by population growth from natality and migration and river siltation resulting from sedimentation and waste from diverse activities along the river.

This article presents the research findings on determining the priority scale for flood control to support the development of integrated flood management strategies in the Landak Sub-watershed.

2. Material and Methods

2.1 Theoretical Frame Work

The Landak Sub Watershed is a component of the Kapuas River Basin in Indonesia. It spans an area of approximately 7,921 km^2 and includes three administrative regions: Landak Regency, Kubu Raya Regency, and Pontianak City (Alfaro et al., 2023). Like other areas in Indonesia, flood events in the Landak Sub Watershed have increased yearly, posing a severe problem and resulting in losses for the local community (Soeryamassoeka et al., 2017). Therefore, a study is required to assess the most suitable flood management measures to minimize the impact of floods in the Landak Sub Watershed.

One study that can be conducted to support integrated flood management actions in the Landak Sub Watershed is to develop a priority scale for flood control both in terms of integrated structural and non-structural measures. Therefore, a multi-criteria decision-making (MCDM) technique is required to determine the most appropriate priority for flood control. One frequently used MCDM algorithm is the Analytic Hierarchy Process (AHP).

Advantages of the Analytic Hierarchy Process (AHP) method (Saaty, 1980):

- Structured decision-making: AHP provides a structured approach to decision-making, allowing for a systematic analysis of complex problems.
- Flexibility: AHP can accommodate various criteria and alternatives, making it suitable for multiple decision-making scenarios.
- Prioritization: The method enables the prioritization of criteria and alternatives, helping decision-makers focus on the most critical factors.
- Considers qualitative and quantitative factors: AHP incorporates subjective judgments and objective data, allowing for a comprehensive evaluation.
- Transparency: The process of AHP is transparent, making it easier to understand and communicate the decision-making rationale.

Disadvantages of the Analytic Hierarchy Process (AHP) method:

- Subjectivity: AHP relies on subjective judgments and pairwise comparisons, which can introduce bias and inconsistency if not carefully managed.
- Complexity: The method can be complex to apply, especially when dealing with many criteria or alternatives.
- Time-consuming: AHP requires significant time and effort to gather necessary data, conduct pairwise comparisons, and perform calculations.
- Sensitivity to input changes: Small changes in input values or pairwise comparisons can lead to significant changes in the final results, making the method sensitive to variations.
- Lack of universal applicability: AHP may only be suitable for some decision-making situations, as it assumes certain conditions and may not capture all relevant aspects of a problem.

To overcome the limitations of AHP, the data used in this study are derived from the results of Focus Group Discussions (FGD). As a result, the prioritization scale is genuinely objective, focusing more on criteria, sub-criteria, and alternatives while minimizing the time required and avoiding changes in input.

In summary, the course of the study is as shown in Figure 1.

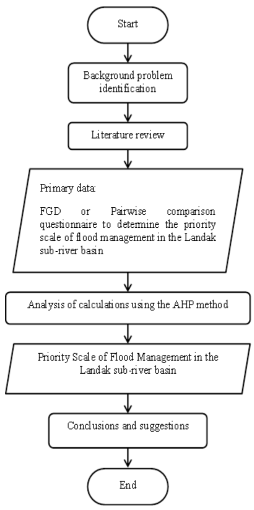

Fig 1. Flow Chart

2.2 Research Location

The research location is in Landak Sub-Watershed, West Kalimantan Province, Indonesia.

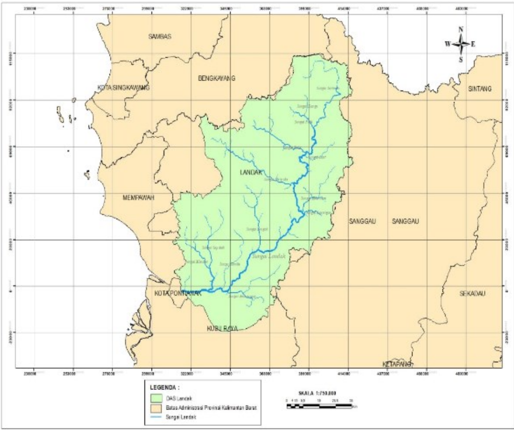

Fig 2. Landak Sub-Watershed

2.3 Data

The data used to develop the flood control prioritization scale in the Landak Sub-watershed consists of data from FGD, including criteria and sub-criteria data, as well as data on flood control alternatives in the Landak Sub-watershed obtained from input provided by 40 FGD participants. The participants include stakeholders in flood control in the Landak Sub-watershed, sub-district heads, and several community representatives.

After identifying the criteria, sub-criteria, and flood control alternatives, the participants also provided assessment points on a scale of 1-9, elaborating the Pairwise Comparison Scale.

Table 1. Pairwise Comparison Scale (Saaty, 1980)

Intensity of Importance	Definition
1	Equally important
3	Slightly more important
5	Quite important
7	Very important
9	Absolutely more important
2, 4, 6, 8	The mean value between two adjacent decisions
Reversed	Activity J has the opposite value when compared to activity I.

2.4 Analysis Method

This study used the Analytical Hierarchy Process (AHP) method to analyze the data obtained from the FGD results. There are 3 (three) main principles in problem-solving using the AHP method: Decomposition, Comparative Judgement, and Logical Consistency.

2.4.1 Decomposition

Decomposition is used to decompose a generalized goal into several hierarchical levels.

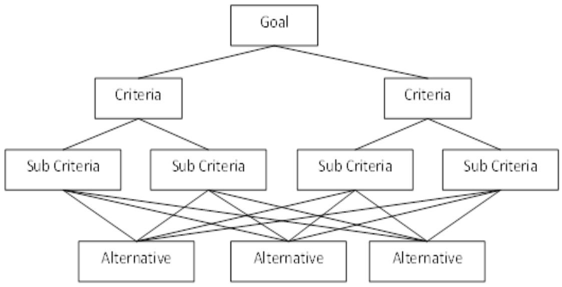

Fig 3. AHP Diagram

2.4.2 Pairwise Comparison

Each element at the same hierarchical level must be compared with each other, so a scale of comparison is needed to reach the two aspects.

2.4.3 Compilation Of Matrix

Geometric mean calculation

The questionnaire data obtained from respondents was calculated, and the geometric mean value was entered into a comparison matrix.

$$G = \sqrt[n]{x_1 \times x_2 \times \ldots \times x_n} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:
G = Geometric mean value
n = Number of data
x_n = n^{th} data

Compilation of comparison matrix

The obtained geometric mean value is entered into the comparison matrix on the upper diagonal, and the lower diagonal value is the inverse of the upper oblique value.

Table 2. Comparison Matrix

Criteria	K1 (1)	K2 (2)	K3 (3)
K1	K11	K12	K13
K2	K21	K22	K23
K3	K31	K32	K33
Total	J1	J2	J3

Compilation of normalization matrix

The value of the normalization matrix is obtained by dividing the value of each comparison by the sum of its columns.

Table 3. Normalization Matrix

Criteria	K1 (1)	K2 (2)	K3 (3)
K1	K11/J1	K12/J2	K13/J3
K2	K21/J1	K22/J2	K23/J3
K3	K31/J1	K32/J2	K33/J3
Total	1,000	1,000	1,000

Calculation of the weight of each element

The weight of each element is obtained by calculating the average value of each row of elements in the normalization matrix.

Table 4. Matrix Normalization and Weights

Criteria	K1 (1)	K2 (2)	K3 (3)	Weights (4)
K1	K11/J1	K12/J2	K13/J3	B1
K2	K21/J1	K22/J2	K23/J3	B2
K3	K31/J1	K32/J2	K33/J3	B3
Total	1,000	1,000	1,000	

2.4.4 *Logical Consistency*

At this point, we calculated the consistency ratio (CR) of the used data.

Calculation of eigenvector value (λ)

The eigenvector value is obtained by multiplying the comparison matrix by the weight of each element.

$$\begin{bmatrix} K11 & K12 & K13 \\ K21 & K22 & K23 \\ K31 & K32 & K33 \end{bmatrix} \times \begin{bmatrix} B1 \\ B2 \\ B3 \end{bmatrix} = \begin{bmatrix} \lambda 1 \\ \lambda 2 \\ \lambda 3 \end{bmatrix} \quad (2)$$

Calculation of maximum eigenvector value (λ_{max})

The maximum eigenvector value is obtained by dividing the eigenvector value by the weight of each element then the results are averaged.

$$\lambda_{max} = \frac{\left(\lambda 1/_{B1} + \lambda 2/_{B2} + \lambda 3/_{B3}\right)}{n} \quad (3)$$

Where:
λ_{max} = Maximum eigenvector value
n = Order of matrix

Calculation of consistency index (CI)

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

Where:
CI = Consistency index
n = Order of matrix

Calculation of consistency ratio (CR)

$$CR = \frac{CI}{RI} \quad (5)$$

Where:
CR = Consistency ratio
CI = Consistency index
RI = Random index

Table 5. RI Value Table (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,46	1,49

Where:
n = Order of matrix

3. Result and Discussion

The following are the results and discussion of the determination of the priority scale of flood management in the Landak Sub-Watershed .

3.1 Decomposition

There are three hierarchies used in this study, which are:

a. Criteria that include engineering, environmental, economic, social, legal and institutional.

b. Sub-criteria that include structural, non structural, operations & maintenance, land use, cost budget, budget allocation, community adaptation, community participation, legislation, and governance.

c. Alternative include flood control buildings, improvement and regulation of river systems, early warning systems, erosion and sedimentation control, waste management, reforestation, green open spaces, zonation of flood-prone areas, revision of spatial policies, and revision of regulations.

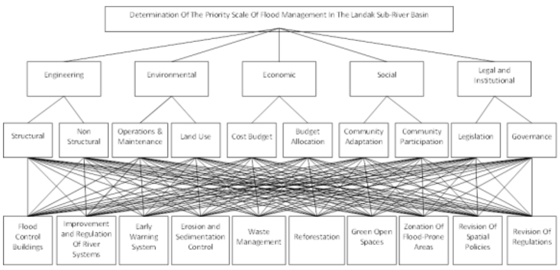

Fig 4. Hierarchical Structure of Flood Management

3.2 Compilation of Matrix

To determine the priorities that will be used in flood management in the Landak Sub-Watershed, it is required to calculate the weight of each element from each level of the hierarchy.

Criteria

The following is the matrix preparation and weight calculation of the criteria hierarchy.

Table 6. Criteria Comparison Matrix

Criteria	Engineering (1)	Environ-mental (2)	Economic (3)	Social (4)	Legal and Institutional (5)
Engineering	1,000	1,328	1,451	1,254	0,464
Environmental	0,753	1,000	0,940	0,695	0,357
Economic	0,689	1,063	1,000	0,752	0,355
Social	0,798	1,438	1,330	1,000	0,475
Legal and Institutional	2,155	2,801	2,813	2,105	1,000
Total	**5,395**	**7,630**	**7,535**	**5,806**	**2,652**

Table 7. Criteria Normalization Matrix

Criteria	Engineering (1)	Environ-mental (2)	Economic (3)	Social (4)	Legal and Institutional (5)
Engineering	0,185	0,174	0,193	0,216	0,175
Environmental	0,140	0,131	0,125	0,120	0,135
Economic	0,128	0,139	0,133	0,129	0,134
Social	0,148	0,188	0,177	0,172	0,179
Legal and Institutional	0,399	0,367	0,373	0,363	0,377
Total	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**

Table 8. Criteria Weight

Criteria	Weight
Engineering	0,189
Environmental	0,130
Economic	0,133
Social	0,173
Legal and Institutional	0,376

Based on the analysis results, the highest weight in the hierarchy of criteria is obtained by Legal and Institutional.

Sub-Criteria

The following is the matrix preparation and weight calculation of the sub-criteria hierarchy.

Table 9. Comparison Matrix of Sub-Criteria on Engineering Criteria

Engineering Criteria	Structural (1)	Non Structural (2)
Structural	1,000	0,733
Non Structural	1,365	1,000
Total	**2,365**	**1,733**

Table 10. Comparison Matrix of Sub Criteria on Environmental Criteria

Environmental Criteria	O&M (1)	Land Use (2)
O&M	1,000	1,400
Land Use	0,714	1,000
Total	**1,714**	**2,400**

Table 11. Comparison Matrix of Sub Criteria on Economic Criteria

Economic Crtiteria	Cost Budget (1)	Budget Allocation (2)
Cost Budget	1,000	0,456
Budget Allocation	2,193	1,000
Total	**3,193**	**1,456**

Table 12. Comparison Matrix of Sub Criteria on Social Criteria

Social Criteria	Community Adaptation (1)	Community Participation (2)
Community Adaptation	1,000	0,698
Community Participation	1,433	1,000
Total	**2,433**	**1,698**

Table 13. Comparison Matrix of Sub Criteria on Legal and Institutional Criteria

Legal and Institutional Criteria	Legislation (1)	Governance (2)
Legislation	1,000	1,314
Governance	0,761	1,000
Total	**1,761**	**2,314**

Table 14. Normalization Matrix of Sub-Criteria on Engineering Criteria

Engineering Criteria	Structural (1)	Non Structural (2)
Structural	0,423	0,423
Non Structural	0,577	0,577
Total	**1,000**	**1,000**

Table 15. Normalization Matrix of Sub-Criteria on Environmental Criteria

Environmental Criteria	O&M (1)	Land Use (2)
O&M	0,583	0,583
Land Use	0,417	0,417
Total	**1,000**	**1,000**

Table 16. Normalization Matrix of Sub-Criteria on Economic Criteria

Economic Crtiteria	Cost Budget (1)	Budget Allocation (2)
Cost Budget	0,313	0,313
Budget Allocation	0,687	0,687
Total	**1,000**	**1,000**

Table 17. Normalization Matrix of Sub-Criteria on Social Criteria

Social Criteria	Community Adaptation (1)	Community Participation (2)
Community Adaptation	0,411	0,411
Community Participation	0,589	0,589
Total	**1,000**	**1,000**

Table 18. Normalization Matrix of Sub-Criteria on Legal and Institutional Criteria

Legal and Institutional Criteria	Legislation (1)	Governance (2)
Legislation	0,568	0,568
Governance	0,432	0,432
Total	**1,000**	**1,000**

To get the global weight of the sub-criteria, the local weight of the sub-criteria must be multiplied by the weight of the criteria above it.

Table 19. Local and Global Weights of Sub-Criteria

Sub-Criteria	Local Weight	Global Weight
Structural	0,423	0,08
Non Structural	0,577	0,109
Operations & Maintenance	0,583	0,076
Land Use	0,417	0,054
Cost Budget	0,313	0,042
Budget Allocation	0,687	0,091
Community Adaptation	0,411	0,071
Community Participation	0,589	0,102
Legislation	0,568	0,213
Governance	0,432	0,162

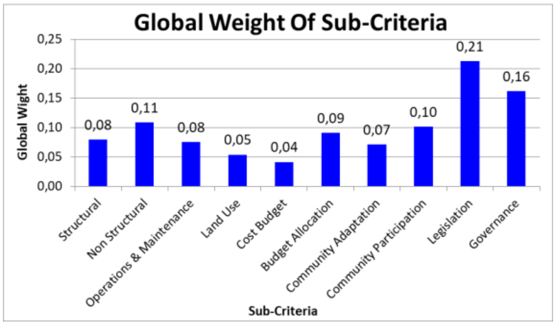

Fig 5. Global Weight of Sub-Criteria

Based on the results of the analysis, the highest weight in the sub-criteria hierarchy is obtained by Legislation.

Alternative

The following is the matrix preparation and weight calculation of the alternative hierarchy.

Table 20. Alternative Comparison Matrix

Alternative	Flood Control Buildings (1)	Improve-ment and Regulation of River System (2)	Early Warning System (3)	Erosion and Sedimenta-tion Control (4)	Waste Manage-ment (5)	Reforesta-tion (6)	Green Open Space (7)	Zonation of Flood-prone Areas (8)	Revision of Spatial Policies (9)	Revision of Regulations (10)
Flood Control Buildings	1,000	1,319	0,760	2,466	0,760	0,977	1,532	0,475	0,369	0,349
Improvement and Regulation of River System	0,758	1,000	0,534	1,707	0,576	0,846	1,151	0,418	0,356	0,341
Early Warning System	1,316	1,874	1,000	2,794	0,950	1,309	1,936	0,606	0,461	0,436
Erosion and Sedimentation Control	0,406	0,586	0,358	1,000	0,315	0,434	0,525	0,298	0,230	0,220
Waste Management	1,316	1,736	1,052	3,173	1,000	1,257	1,972	0,702	0,406	0,384
Reforestation	1,024	1,183	0,764	2,304	0,796	1,000	1,320	0,555	0,422	0,396
Green Open Space	0,653	0,869	0,516	1,905	0,507	0,758	1,000	0,388	0,319	0,304
Zonation of Flood-prone Areas	2,107	2,390	1,650	3,355	1,424	1,802	2,575	1,000	0,684	0,601
Revision of Spatial Policies	2,710	2,805	2,168	4,348	2,463	2,370	3,133	1,462	1,000	0,864
Revision of Regulations	2,863	2,933	2,291	4,539	2,602	2,525	3,295	1,663	1,157	1,000
Total	**14,152**	**16,694**	**11,094**	**27,590**	**11,393**	**13,276**	**18,438**	**7,568**	**5,405**	**4,896**

Table 21. Normalization Matrix and Alternative Weights

Alternative	Flood Control Buildings (1)	Improve-ment and Regulation of River System (2)	Early Warning System (3)	Erosion and Sedimenta-tion Control (4)	Waste Manage-ment (5)	Reforesta-tion (6)	Green Open Space (7)	Zonation of Flood-prone Areas (8)	Revision of Spatial Policies (9)	Revision of Regulations (10)
Flood Control Buildings	0,071	0,079	0,068	0,089	0,067	0,074	0,083	0,063	0,068	0,071
Improvement and Regulation of River System	0,054	0,060	0,048	0,062	0,051	0,064	0,062	0,055	0,066	0,070
Early Warning System	0,093	0,112	0,090	0,101	0,083	0,099	0,105	0,080	0,085	0,089
Erosion and Sedimentation Control	0,029	0,035	0,032	0,036	0,028	0,033	0,028	0,039	0,043	0,045
Waste Management	0,093	0,104	0,095	0,115	0,088	0,095	0,107	0,093	0,075	0,078
Reforestation	0,072	0,071	0,069	0,083	0,070	0,075	0,072	0,073	0,078	0,081
Green Open Space	0,046	0,052	0,047	0,069	0,045	0,057	0,054	0,051	0,059	0,062
Zonation of Flood-prone Areas	0,149	0,143	0,149	0,122	0,125	0,136	0,140	0,132	0,127	0,123
Revision of Spatial Policies	0,191	0,168	0,195	0,158	0,216	0,178	0,170	0,193	0,185	0,177
Revision of Regulations	0,202	0,176	0,207	0,165	0,228	0,190	0,179	0,220	0,214	0,204
Total	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**

Table 22. Global Weight of Alternative

Alternative	Sub-Criteria									
	Structural (1)	Non Structural (2)	O & M (3)	Land Use (4)	Cost Budget (5)	Budget Allocation (6)	Community Adaptation (7)	Community Participation (8)	Legislation (9)	Governan-ce (10)
Flood Control Buildings	0,008	0,006	0,006	0,004	0,003	0,007	0,005	0,007	0,016	0,012
Improvement and Regulation of River Systems	0,006	0,005	0,004	0,003	0,002	0,005	0,004	0,006	0,013	0,010
Early Warning System	0,010	0,008	0,007	0,005	0,004	0,009	0,007	0,010	0,020	0,015
Erosion and Sedimentation Control	0,004	0,003	0,003	0,002	0,001	0,003	0,002	0,004	0,007	0,006
Waste Management	0,010	0,008	0,007	0,005	0,004	0,009	0,007	0,010	0,020	0,015
Reforestation	0,008	0,006	0,006	0,004	0,003	0,007	0,005	0,008	0,016	0,012
Green Open Spaces	0,006	0,004	0,004	0,003	0,002	0,005	0,004	0,006	0,012	0,009
Zonation of Flood-prone Areas	0,014	0,011	0,010	0,007	0,006	0,012	0,010	0,014	0,029	0,022
Revision of Spatial Policies	0,020	0,015	0,014	0,010	0,008	0,017	0,013	0,019	0,039	0,030
Revision of Regulations	0,021	0,016	0,015	0,011	0,008	0,018	0,014	0,020	0,042	0,032

Table 23. Prioritization of Alternatives

Alternatif	Weight	Rank
Revision of Regulations	0,1984	I
Revision of Spatial Policies	0,1832	II
Zonation of Flood-prone Areas	0,1344	III
Waste Management	0,0943	IV
Early Warning System	0,0938	V
Reforestation	0,0745	VI
Flood Control Buildings	0,0733	VII
Improvement and Regulation of River Systems	0,0591	VIII
Green Open Spaces	0,0542	IX
Erosion and Sedimentation Control	0,0348	X

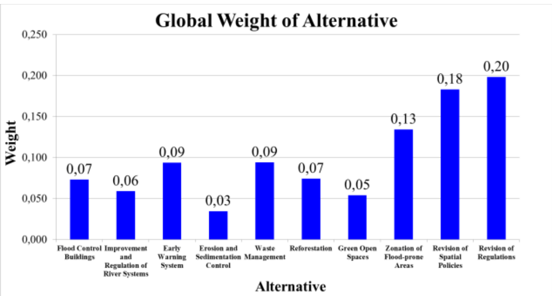

Fig 6. Global Weight of Alternative

Based on the analysis results, the highest weight in the alternative hierarchy is obtained by revising regulations.

3.3 Consistency Ratio Calculation Criteria

Table 24. Consistency Ratio of Criteria

Parameters	Value	Description
	0,945	
	0,651	
λ	0,664	
	0,865	
	1,883	Consistent
λ max	5,009	
CI	0,00220	
RI	1,120	
CR	0,00197	
	0,20%	

Because the value of CR = 0,20% < 10%, the data is considered consistent and the calculation is acceptable.

Alternative

Table 25. Consistency Ratio of Alternative

Parameters	Weight	Description
	0,736	
	0,593	
	0,943	
	0,349	
λ	0,948	
	0,748	
	0,543	
	1,354	Consistent
	1,849	
	2,002	
λ max	10,055	
CI	0,00608	
RI	1,49	
CR	0,00408	
	0,41%	

Because the value of CR = 0.41% < 10%, the data is considered consistent and the calculation is acceptable.

Thus it can be seen that the results of the analysis of flood management in the Landak Sub-Watershed based on the results of the Focus Group Discussion (FGD) require a more optimal role of institutions and the application of appropriate laws. Therefore, existing legal products can be reviewed by the government, whether they have been implemented optimally or not so that it is possible to revise the applicable spatial regulations and policies and can further optimize coordination between related institutions in flood management so that the impact caused by flooding can be minimized.

4. Conclusion

Based on the results obtained from calculations using the Analytical Hierarchy Process (AHP) method, it can be concluded that the weight values of all criteria are accepted in the order of Law and Institutions, Technical, Social, Economic, and Environment. These results indicate that according to the respondents' assessment, the most crucial criterion in flood mitigation in Sub-watershed Landak is Law and Institutions, which means that the government's role and relevant agencies must be carried out to the best of their abilities in handling flood issues. The government must pay attention to all aspects, from legislation to governance, to optimize the flood management process.

Following the Social standard, the community must be educated or empowered to adapt to and participate in flood mitigation efforts, such as waste disposal. Next is the Technical criterion, which assesses whether the mitigation will be done structurally or non-structurally. Then comes the Economic standard, which evaluates the budget size and allocation that will be used to ensure that the budget is utilized appropriately for flood management. Next is the Environment criterion, which considers environmental operations, maintenance, and land use planning in the Sub-watershed Landak area.

As for the alternatives, the priority order is as follows: Revision of Regulations (0.1984), followed by Revision of Spatial Planning Policies (0.1832), Zoning of Flood-Prone Areas (0.1344), Waste Management (0.0943), Early Warning System (0.0938), Reforestation (0.0745), Flood Control Buildings (0.0733), River System Improvement and Regulation (0.0591), Green Open Spaces (0.0542), and Erosion and Sedimentation Control (0.0348). Thus, based on the analysis results of each hierarchy, the revision of regulations in law and institutions is chosen as the priority for flood management in Sub-watershed Landak.

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6. Author’s Note

The author now declares that this article is an original work and does not plagiarize any research, as it has successfully passed the examination to obtain a bachelor's degree in engineering at the Faculty of Engineering, Tanjungpura University, on March 27, 2023.

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