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Analysis of Trends and Composition of Forest and Vegetative Land Rehabilitation Activities in the Limboto Lake Catchment Area for the Period 2021-2025

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ABSTRACT

This study analyzes the temporal trend and activity composition of vegetative forest and land rehabilitation (RHL) in the catchment area of Lake Limboto for 2021–2025. A quantitative descriptive approach was applied to secondary data from the BPDAS Bone Limboto 2025 database, strengthened with year-on-year change rates, the coefficient of variation, concentration ratios, and the Herfindahl-Hirschman index to assess the program portfolio structure. The total area of vegetative RHL over five years reached 693 ha, with an annual mean of 138.6 ha and a coefficient of variation of about 79.9%, indicating a dynamic, phase-based implementation rhythm. The highest achievement occurred in 2022 (340 ha; 49.06%), while the two leading years (2022–2023) accounted for 74.31% of the total. By composition, core RHL planting dominated (262 ha; 37.81%), followed by watershed rehabilitation (200 ha; 28.86%) and the Community Nursery/KBR (183 ha; 26.41%); these three pillars formed 93.07% of the portfolio, with an effective number of activities of 3.33. The annual composition revealed a tiered pattern from seedling provision toward larger-scale planting. Spatial interpretation of the activity map showed interventions concentrated on the buffer hill belts to the north, west, and south of the catchment, consistent with an upstream-priority logic. The findings emphasize that RHL evaluation should consider temporal continuity and compositional balance, not only area achievement.

Keywords: *Forest and Land Rehabilitation, Limboto Lake Watershed, Trend Analysis, Program Composition, Rehabilitation Evaluation*

1. INTRODUCTION

Forest and Land Rehabilitation (RHL) is a key policy instrument for restoring the ecological function of watersheds and water catchments in Indonesia. Conceptually, RHL is not limited to planting activities, but rather a systematic effort to improve vegetation cover, restore hydrological functions, and strengthen the area's carrying capacity against environmental pressures [1], [2]. Within the framework of tropical landscape restoration, the success of RHL is determined by the integration of technical, institutional, and sustainable funding dimensions [3], [4].

The Limboto Lake Catchment Area (DTA) in Gorontalo Province is a strategic area with crucial hydrological functions for regional water management. Various studies have revealed that Lake Limboto is experiencing environmental pressures such as declining water quality, sediment accumulation, and shrinking lake area, making rehabilitation efforts in its catchment area urgently necessary [5]. Biophysically, the study in [5] reported that the Limboto watershed is dominated by very severe erosion (29.28%) and requires extensive vegetative-based land restoration, namely approximately 16,362 ha through reforestation and afforestation and 33,530 ha through agroforestry, with vegetation-based mitigation effectiveness reaching almost 90%. These findings place vegetative RHL activities as a crucial part of the management strategy for the Limboto Lake catchment area.

Evaluations of RHL programs in Indonesia generally fall into several main focuses. Some researchers emphasize plant physiological aspects, such as survival and growth rates [6], [7], [8], [9]. On the other hand, physical hydrological impacts, such as runoff coefficients or erosion rates, are also often used as success parameters [10], [11], alongside the involvement and active role of local residents in program implementation [12], [13]. These approaches make important contributions, but they generally focus on biophysical outcomes or social dimensions, and few examine the program's internal structure, specifically how the scope of activities evolves over time and how the composition of activity types is structured at the catchment level. Available composition studies generally examine the diversity of seed or vegetation types [14], [15], not a portfolio of rehabilitation activity types.

To date, no study has specifically combined temporal trend analysis and composition analysis of vegetative RHL activities in the Limboto Lake catchment area for the period 2021–2025 within a single, measurable evaluative framework. Based on the Bone Limboto Watershed Management Agency (BPDAS) database for 2025, vegetative RHL activities during that period showed wide annual area variations and a wide range of activities, making them relevant for quantitative analysis.

The novelty of this research lies in three aspects. First, the study measures the annual dynamics of the program through the rate of change, coefficient of variation, and concentration ratio. Second, the study examines the structure of the activity portfolio using a concentration index so that the program's orientation can be explained objectively. Third, the study interprets the relationship between program findings, and the context of the area's restoration needs as reported in the Limboto watershed biophysical literature. Based on this description, this study aims to: (1) analyze the trend of vegetative RHL activities in the Limboto Lake watershed during 2021–2025; (2) examine the composition of activity types based on area and proportion; and (3) interpret the relationship between program patterns and area rehabilitation needs academically.

2. LITERATURE REVIEW

2.1 Forest and Land Rehabilitation in Water Catchment Areas

Conceptually, RHL is an effort to restore land and vegetation conditions in areas experiencing ecological decline. In water catchment areas, vegetative rehabilitation strengthens land cover, increases infiltration capacity, and maintains the stability of buffer zones that contribute to the flow system toward the main water body [10], [16]. Therefore, the success of RHL in a watershed is measured not only by the number of hectares addressed, but also by the accuracy of the location, continuity of implementation, and the suitability of the activity type to the spatial character [1], [17]. This framework places trend and composition analysis as essential complements to the evaluation of area achievement.

2.2 Trend Analysis in Environmental Program Evaluation

Trend analysis is used to assess the direction and stability of changes in activities over time. In environmental program evaluations, trends are useful for identifying the initial phase, acceleration phase, peak phase, and maintenance phase. Multi-year RHL studies have shown that program outcomes are often influenced by planning and budget cycles, as well as the availability of plant material [8], [18]. Therefore, variations in area between years can be interpreted as a reflection of the normal program stages in rehabilitation management, and their interpretation needs to be linked to the implementation context.

2.3 Analysis of Composition and Portfolio of Activities

Activity composition describes the proportion of each type of intervention within the overall program. Composition analysis helps in understanding the dominance of certain activities, the balance between instruments, and shifts in rehabilitation orientation between periods. Studies on the composition of rehabilitation seedlings and vegetation confirm that a well-structured portfolio contributes to the appropriateness of interventions to site variations [14], [15]. In the context of vegetative RHL, differences in composition can indicate stages of plant material provision, planting expansion, or maintenance adjustments, thus enhancing trend analysis.

2.4 Spatial Approach and Land Priority in Rehabilitation

The spatial dimension is important because rehabilitation works in specific areas with varying levels of criticality. Identification of critical land distribution and plant suitability forms the basis for prioritizing rehabilitation locations [19], [20], [21]. In water catchment areas, the orientation of activities toward hilly areas and buffer slopes is generally consistent with the logic of restoring upstream areas, which play a role in retaining runoff and sedimentation toward water bodies [5]. The four theoretical foundations above provide a framework for interpreting vegetative RHL data in the Lake Limboto watershed in an integrated manner, namely from the perspective of trends, composition, and the relationship between space and needs.

3. METHODS

3.1 Type and Approach of Research

This study used a quantitative descriptive approach combined with analytical interpretation. This approach was chosen because the research objective was not to test causal relationships between variables, but rather to evaluate program implementation patterns based on available implementation data. In rehabilitation program evaluation, this approach is relevant for assessing the rhythm, composition, and orientation of interventions in a catchment area [8].

3.2 Research Location and Object

The research location is the Limboto Lake Catchment Area (DTA), Gorontalo Province. The research objects are all vegetative RHL activities recorded during the 2021–2025 period, grouped according to the data source nomenclature: RHL, Community Seed Gardens (KBR), Village Seed Gardens (KBD), Natural Resource Conservation Efforts (UPSA), and Watershed Rehabilitation (DAS Rehab).

3.3 Data Sources and Types

The data used are secondary data sourced from the Bone Limboto BPDAS database for 2025, comprising a recapitulation of vegetative RHL activities in the Limboto Lake watershed for the 2021–2025 period and a distribution map of vegetative RHL activities, supplemented by information on forest areas, river networks, and Limboto watershed and sub-watershed boundaries. Area units are expressed in hectares (ha). The use of official secondary data from watershed management agencies is commonly applied in RHL evaluation studies in Indonesia [10], [15].

3.4 Operational Definition of Variables

The variables analysed include: (a) total area of activities per year; (b) total area per type of activity; (c) percentage contribution of each type of activity to the five-year total; (d) rate of change in area between years; and (e) level of temporal concentration and composition. Operational definitions of activity types are presented in Table 1.

Table 1. Operational Definition of Types of Vegetative RHL Activities

Type of Activity	**Operational Definition**
RHL	Tree planting activities on critical land inside/outside forest areas to gradually restore hydrological functions and environmental productivity.
KBR	Establishment of a forest/MPTS plant nursery managed independently by community groups to provide RHL plant supplies.
KBD	Facilitation of village-scale seed facilities to provide wood plant seeds and MPTS independently to support greening of the village environment.
UPSA	Soil and water conservation demonstration plot that integrates technical-civil and vegetative engineering as an educational model for environmentally friendly cultivation.
DAS Rehab	The obligation to plant on critical land within the watershed by holders of Forest Area Use Permits (PPKH) as compensation for non-forestry land use.

3.5 Data Collection and Validation Techniques

Data were collected through documentation techniques by extracting numerical information from source summaries. Internal validation was performed by checking the consistency between the annual area summation, the total per activity type, and the overall total, resulting in mutually consistent figures with a five-year total of 693 ha.

3.6 Data Analysis Techniques

The analysis was conducted through four quantitative stages. First, the composition analysis used the formula $Pi = (Li / L) \times 100\%$, with Pi the proportion of the i-th activity type, Li the area of the i-th activity type, and L the total area of all activities. Second, the inter-annual change rate was calculated by $\Delta Rt = ((Lt - Lt{-}1) / Lt{-}1) \times 100\%$. Third, temporal stability was assessed through the coefficient of variation $CV = (s / \bar{x}) \times 100\%$ to measure the degree of area variability between years. Fourth, the degree of portfolio concentration was assessed through the concentration ratio (CRn) and the Herfindahl-Hirschman Index $HHI = \Sigma\, pi^2$, together with the number of effective activities 1/HHI. Spatial interpretation was carried out descriptively by reading the visual overlay of activity maps against forest area classes, river networks, and catchment morphology to identify trends in intervention locations; this analysis is interpretive and does not involve quantitative geospatial measurements based on Geographic Information Systems (GIS).

3.7 Research Limitations

This study assesses program implementation patterns based on available area data, not on the biophysical effectiveness of rehabilitation outcomes in the field. The spatial analysis is interpretive in nature and therefore does not yet include detailed assessments based on sub-catchments, slope classes, or land cover. Therefore, the study results are appropriately read as an initial evaluation of the direction of vegetative RHL implementation, which can be developed in further research.

4. RESULTS AND DISCUSSION

4.1 Recapitulation of Vegetative RHL Activities 2021–2025

A summary of vegetative RHL activities in the Limboto Lake watershed is presented in Table 2. The total area of activities over five years reached 693 ha. The three largest components were RHL, DAS Rehab, and KBR, while UPSA and KBD contributed less. This structure forms the basis for the trend and composition analysis in the following subsections.

Table 2. Recapitulation of Vegetative RHL Activities in the Limboto Lake Watershed, 2021–2025

Activity	2021	2022	2023	2024	2025	Total (ha)	Percent (%)
RHL	0	90	105	25	42	262	37.81
KBR	58	50	50	25	0	183	26.41
KBD	3	0	0	0	0	3	0.43
UPSA	0	0	20	25	0	45	6.49
DAS Rehab	0	200	0	0	0	200	28.86
Total	**61**	**340**	**175**	**75**	**42**	**693**	**100.00**

Source: BPDAS Bone Limboto Database (2025), Processed

4.2 Temporal Trends of Activities

The distribution of area between years shows a dynamic pattern. In 2021 it recorded 61 ha (8.80%), increasing sharply to 340 ha (49.06%) in 2022 with a change rate of +457.4%, then adjusting to 175 ha (2023; −48.5%), 75 ha (2024; −57.1%), and 42 ha (2025; −44.0%). The average annual area was 138.6 ha with a coefficient of variation of approximately 79.9%, indicating high inter-annual variability. The top two years (2022–2023) covered 74.31% of the total area, indicating a prominent acceleration phase of the program.

This pattern can be interpreted constructively as a phase-based implementation rhythm. The year 2021 served as the preparation phase, 2022–2023 as the accelerated planting phase, and 2024–2025 as the adjustment and maintenance phase. This phasing is common in multi-year RHL programs in Indonesia, where outcomes are influenced by planning cycles and the availability of planting materials [8], [18]. The studies in [3] and [17] emphasize the importance of institutional continuity for successful rehabilitation; findings from the Limboto Lake catchment indicate that the program has been operating with clear momentum and could be strengthened through more equitable inter-annual scheduling.

4.3 Composition of Activity Types

Based on the five-year composition, RHL is the largest component (262 ha; 37.81%), followed by DAS Rehab (200 ha; 28.86%), KBR (183 ha; 26.41%), UPSA (45 ha; 6.49%), and KBD (3 ha; 0.43%). These three main components cumulatively cover 93.07% of the portfolio. The Herfindahl-Hirschman Index is 0.300 with a total of 3.33 effective activities, quantitatively confirming that the portfolio rests on three main pillars. This structure indicates the program’s orientation toward core, large-scale interventions, with supporting activities as complements. In the restoration literature, a focused portfolio structure can effectively achieve priority targets while opening space for compositional arrangements to be more adaptive to site variations [4], [15].

4.4 Annual Composition Dynamics

The annual internal composition exhibits an academically interesting hierarchical pattern, as summarized in Table 3. The year 2021 was dominated by seedling provision; 2022 by watershed rehabilitation accompanied by RHL and KBR; 2023 by RHL; 2024 showed a balanced distribution among RHL, KBR, and UPSA; and 2025 was entirely RHL. This pattern indicates a logical flow from the provision of plant material to larger-scale planting, as emphasized in nursery management to support rehabilitation [18]. Thus, the shift in composition is not merely a fluctuation, but rather reflects the functional interrelationships between types of activities within a rehabilitation series.

Table 3. Dynamics of the Internal Composition of Activities per Year

Year	Internal Composition Structure
2021	Dominated by seed provision: KBR 58 ha (95.1%) and KBD 3 ha (4.9%); total 61 ha.
2022	Dominated by DAS Rehab 200 ha (58.8%), accompanied by RHL 90 ha (26.5%) and KBR 50 ha (14.7%); total 340 ha.
2023	Dominated by RHL 105 ha (60.0%), KBR 50 ha (28.6%), and UPSA 20 ha (11.4%); total 175 ha.
2024	Balanced distribution of RHL, KBR, and UPSA (25 ha each; 33.3%); total 75 ha.
2025	Fully RHL 42 ha (100%); total 42 ha.

Source: BPDAS Bone Limboto Database (2025), Processed

4.5 Program Linkage to Area Recovery Needs

The achievement of 693 ha over five years must be interpreted in the context of the area's restoration needs. The study in [5] estimated the revegetation needs for the Limboto watershed at approximately 16,362 ha, so the vegetative RHL achievement for the catchment area during this period represents a relatively small portion of that need. Academically, this relationship confirms that catchment rehabilitation is a long-term process that requires sustained intervention, as demonstrated by studies of the effect of RHL on improving flow coefficients and controlling erosion [10], [11].

An integrated analysis of temporal trends, activity composition, and spatial distribution indicates that the implementation of vegetative RHL in the Limboto Lake watershed is phase-based, focused on several key pillars, and oriented toward buffer zones. The academic implication is that RHL program evaluation should not only focus on the total area achieved but also consider inter-annual continuity, compositional balance, and spatial relationships with regional needs, in line with the landscape restoration framework that emphasizes technical, institutional, and sustainability integration [3], [4]. This is consistent with international evidence showing that watershed-scale restoration projects benefit from quantitative, multi-temporal effect evaluation rather than relying on area achievement alone [22], and that land-capability-based land-use and management options can substantially reduce runoff and sediment loss at the sub-watershed scale [23], reinforcing the relevance of compositional and temporal evaluation for the Limboto Lake catchment.

4.6 Spatial Interpretation of Activity Distribution

To strengthen the reading of trends and composition, the spatial distribution of activities is interpreted through the vegetative RHL activity map of the Limboto Lake watershed (Figure 1). The map displays the boundaries of the Limboto watershed and sub-watershed, the body of Lake Limboto, the river network, forest area classes (HL, CA, HP, HPK, and HPT), and the locations of vegetative activities mapped during the study period, namely KBD 2021, DAS Rehab 2022, and KBR 2023.

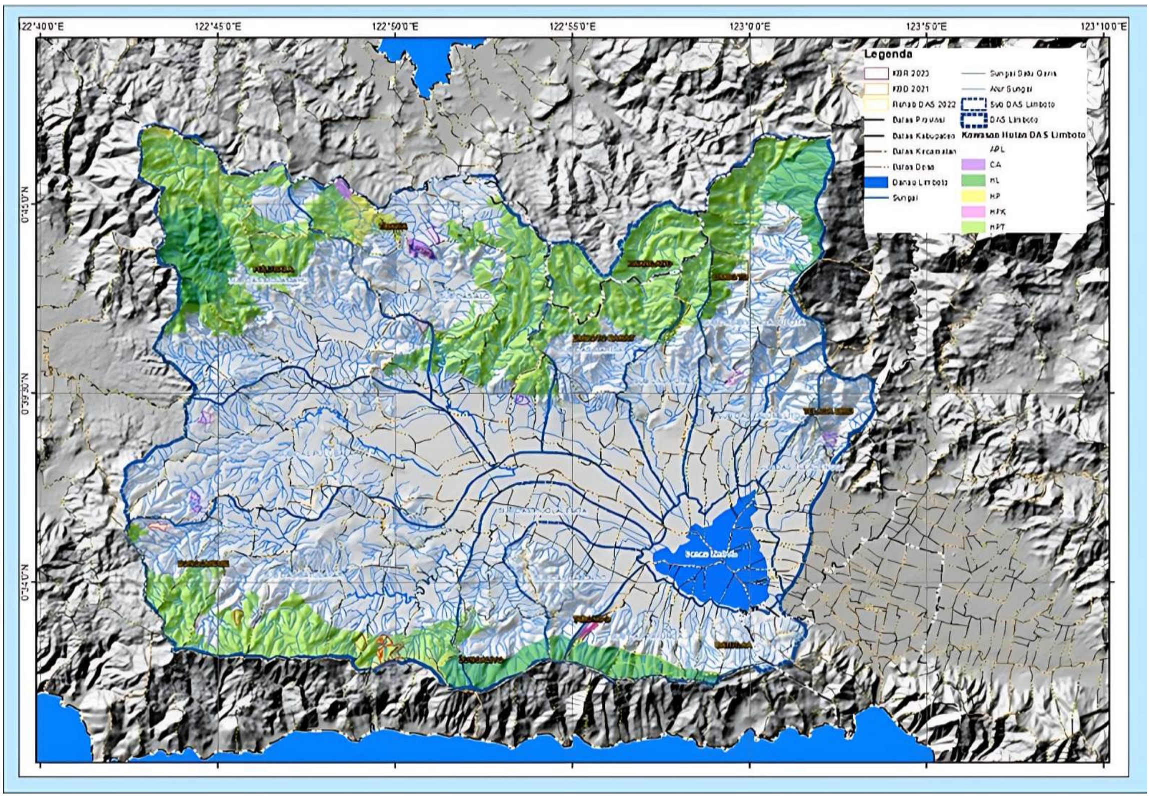

Figure 1. Map of The Distribution of Vegetative RHL Activities in The Limboto Lake Watershed
Source: BPDAS Bone Limboto Database (2025), Processed

Morphologically, the map shows a clear contrast between the rugged hilly areas in the north and south and the central plain basin, which is traversed by a dense dendritic river network. This network of streams tapers toward Lake Limboto, which occupies the central to eastern part of the basin, thus serving as an accumulation point for runoff and sediment from the entire catchment area. Forest cover, indicated by green hues, is concentrated in the northern hill belt and the southern edge, while the central plains surrounding the lake body are relatively devoid of forest cover and dominated by cultivated land and residential areas.

The mapped vegetative activity locations are small, scattered polygons, with a tendency to be located in or adjacent to the hilly forest belts on the north, west, and south sides of the catchment area. This pattern demonstrates alignment between activity placement and forest area class and the position of buffer slopes and is relatively limited in the central plains close to the lake body. Analytically, this spatial orientation is consistent with the logic of prioritizing critical land in the catchment area, which focuses interventions on upstream areas and slopes that play a role in retaining surface runoff and supplying sediment to the water body [19], [20], [21]. This concentration on the buffer zone is relevant to the function of the Lake Limboto catchment area, as demonstrated by a biophysical study of the Limboto watershed that prioritizes steep slope areas as the primary target for vegetation-based restoration [5].

Map interpretation also clarifies the spatial scope of activities. The activities mapped during this period covered a small area compared to the overall catchment area, resulting in some buffer zones with comparable criticality not being covered by interventions during that period. These spatial findings complement the results of the trend and composition analysis: the program has been targeted to functionally appropriate buffer zones, while a more detailed spatial database at the sub-catchment level is useful for supporting equitable rehabilitation targets in subsequent periods [16], [19]. This need aligns with international watershed-prioritization studies that integrate soil-loss status, morphometry, and land cover to rank sub-watersheds for conservation and restoration intervention [24], and with evidence that watershed management practices should be evaluated through sediment-connectivity and response-based metrics rather than implemented area alone [25], underscoring the value of an evaluation framework that couples temporal continuity, compositional balance, and spatial targeting in the Limboto Lake catchment.

5. CONCLUSION

Vegetative Forest and Land Rehabilitation (FLR) activities in the Lake Limboto Watershed (DTA) follow a dynamic, phase-based implementation rhythm characterized by high temporal variability, moving through distinct operational stages of acceleration and adjustment. Structurally, the program portfolio is concentrated on three main operational pillars: core planting, watershed rehabilitation, and the Community Seed Garden (KBR). These activities demonstrate a logical and gradual annual flow, transitioning functionally from initial seedling provision to broader field planting interventions. Spatially, interventions are systematically directed to the critical buffer hill belt in the upstream zone of the watershed, in line with the ecological logic that prioritizes upstream slope restoration to control surface runoff and sediment supply. Ultimately, this study emphasizes that evaluation of landscape restoration initiatives must go beyond simply achieving cumulative area targets, but must comprehensively consider multi-temporal implementation patterns, structural portfolio composition, and geographic alignment with the restoration needs of the watershed.

Based on these findings, it is recommended that future watershed management frameworks improve institutional and operational stability by designing more equitable implementation schedules and inter-annual budget allocations to minimize extreme implementation spikes. Furthermore, environmental planning agencies need to develop and integrate highly detailed sub-catchment-level spatial databases to accurately identify and prioritize remaining critical buffer zones that remain unreached by interventions. Finally, future research is expected to expand this structural analysis to include field-based biophysical performance monitoring, land cover change analysis, and local community engagement to build a holistically integrated evaluation framework for the long-term sustainability of the watershed.

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