

SPATIAL ASSESSMENT OF LAND DEGRADATION IN THE KRUENG KHEA SUB-WATERSHED, ACEH BESAR, INDONESIA

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ABSTRACT

Land degradation in tropical watersheds is influenced by land-use change, slope, rainfall, and soil characteristics. This study assessed the spatial distribution of land degradation in the Krueng Khea Sub-watershed, Aceh Besar, Indonesia, using a GLASOD-based weighted overlay approach. The analysis covered 9,599.66 ha and integrated four parameters: land cover, slope, rainfall, and soil type. Land-cover data were derived from 2023 Landsat 8 imagery and validated through field observations, while other variables were obtained from secondary spatial datasets. All parameters were scored and weighted using ArcGIS ModelBuilder to produce land-degradation classes. The results show that shrubland dominates the area (48.20%), followed by mixed upland agriculture (14.96%), grassland (12.36%), and paddy fields (10.94%). Although most of the area is relatively flat, 29% occurs on slopes exceeding 15%, increasing susceptibility to degradation. Rainfall is uniformly moderate (2,000–3,000 mm yr⁻¹), and soils are dominated by Chromic Luvisols (70.94%). Moderate degradation is the dominant class (80.05%), followed by low (16.59%) and high (3.37%) degradation. Degradation is mainly associated with shrubland and agricultural land on sloping terrain. These findings highlight the importance of prioritizing rehabilitation in moderately degraded areas to prevent further land degradation.

Keywords: GLASOD, land cover, slope, weighted overlay

INTRODUCTION

Land degradation is a major environmental problem because it reduces land productivity and ecological function through the deterioration of soil physical, chemical, and biological properties. In watershed systems, degradation is commonly expressed as reduced vegetation cover, greater surface runoff, accelerated erosion, sedimentation, and higher risks of flooding and drought. These processes are particularly important in humid tropical environments where high rainfall erosivity and inadequate conservation practices intensify land degradation (Wahyunto and Dariah, 2014; Arsyad, 2010; Barchia *et al.*, 2019).

Recent studies have shown that land cover change is a primary driver of degradation in tropical watersheds. The conversion from forest into agricultural land, shrubland, or open land generally reduce infiltration capacity, increases runoff, and weakens watershed regulatory functions (Kuntoro *et al.*, 2018; Agbenorhevi *et al.*, 2024; Wiwoho *et al.*, 2024). At the national level, these pressures have increased the need for spatially targeted land rehabilitation and more sustainable watershed management in Indonesia (Wahyuningrum and Putra, 2019; Supangat *et al.*, 2023).

The Krueng Aceh watershed in Aceh Province plays a strategic role in supporting water resources and socio-economic activities in Banda Aceh and Aceh Besar. However, previous studies have indicated hydrological degradation associated with upstream land use change in this watershed (Muis *et al.*, 2016; Muis, 2019). Furthermore, Tsabitah *et al.* (2022) also highlighted the importance of the Krueng Aceh watershed for regional ecosystem services, while Nurfitri (2022) identified a high erosion risk in the Krueng Khea Sub-watershed, especially in areas dominated by agricultural and open-land cover. These findings suggest that Krueng Khea is an appropriate unit for a more focused assessment of land degradation.

A widely used framework for identifying land degradation is GLASOD, which integrates land cover,

rainfall, soil properties, and slope to interpret the severity of human-induced land degradation (Oldeman *et al.*, 1990; Lynden and Oldeman, 1997). In geographic information systems, these indicators can be combined using weighted overlay approach to classify degradation levels and to identify areas that should be prioritized for rehabilitation (Wahyuningrum and Putra, 2019). However, studies at the sub-watershed-scale in Aceh remains limited, and the spatial distribution of degradation in Krueng Khea Sub-watershed has not been comprehensively analyzed in relation to dominant land cover types and slope classes.

Therefore, this study aimed to map land-degradation levels in the Krueng Khea Sub-watershed using a GLASOD-based spatial approach and to analyze the relationship between degradation pattern, land cover and slope. The study is expected to provide a scientific basis for prioritizing land rehabilitation and supporting sustainable watershed management in Aceh Besar.

MATERIALS AND METHODS

Study Site

The study was conducted from February to June 2024 in the Krueng Khea Sub-watershed, Aceh Besar Regency, Aceh, Indonesia. Geographically, the Krueng Khea Sub-watershed is located between 95°28'00"–95°36'00" E and 5°22'00"–5°28'00" N. Administratively, the sub-watershed is bordered by Indrapuri and Montasik Districts to the north, Seulimeum District to the east, Indrapuri District to the west, and Kuta Cot Glie District to the south (Figure 1). The total area analyzed covers 9,599.66 ha. The landscape is characterized by lowland to hilly topography and has experienced substantial land-use change over time, making it a suitable case for spatial analysis of land degradation.

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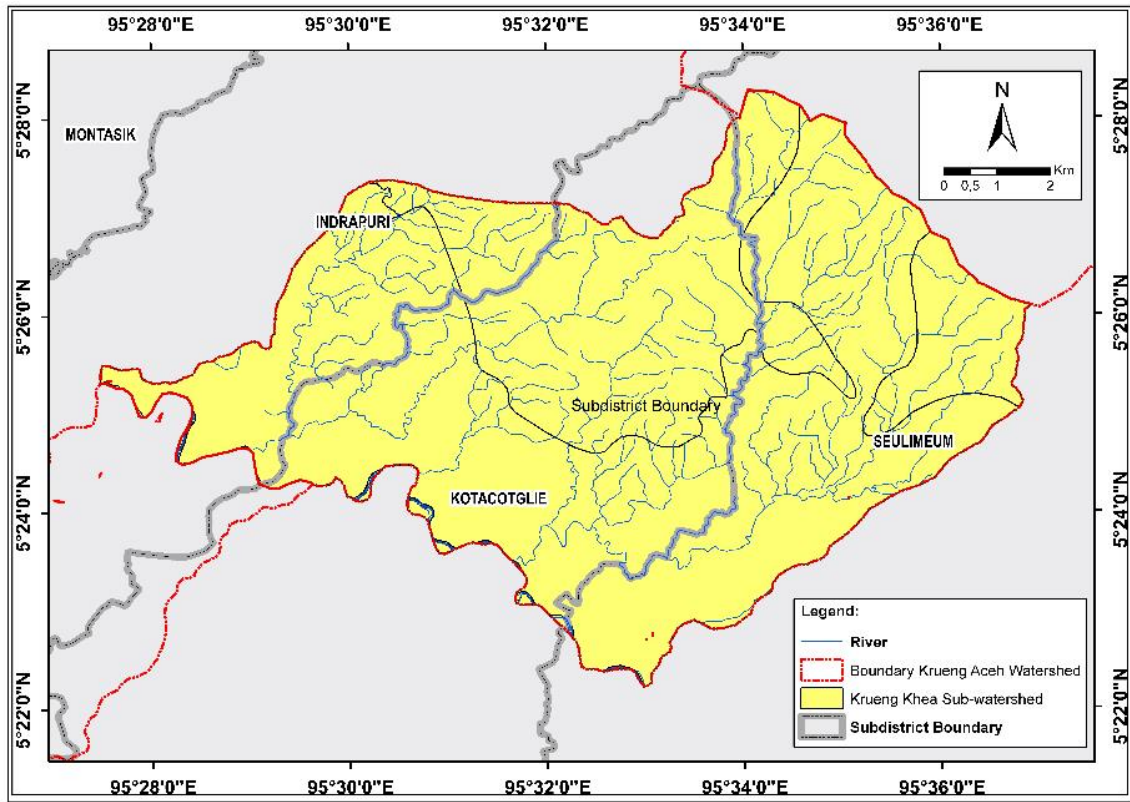


Figure 1. Study Site of The Krueng Khea Sub Watershed

Data sources and preprocessing

This study focused on the land-degradation component of a broader research framework, while the land-criticality assessment is excluded from its scope. Four key indicators based on the GLASOD were utilized. Land covers were interpreted from 2023 Landsat 8 imagery (path 131/row 56) and verified through field observations conducted in 2024. Rainfall data were compiled from regional records and subsequently classified into an annual rainfall categories from Agency for Meteorology, Climatology and Geophysics in Aceh Province. Soil data were obtained from existing soil maps, while slope classes were generated from topographic data using DEMNAS. Prior to analysis, all spatial datasets underwent several preprocessing steps, including projection to a uniform coordinate system, clipping to the Krueng Khea Sub-watershed boundary, verification of attribute consistency, and harmonization of classification schemes. All processes were conducted using ArcGIS 10.3 to ensure consistency in spatial resolution, mapping units, and legend structure.

GLASOD-based land-degradation assessment

Land degradation was assessed using a GLASOD-based weighted overlay approach integrating four parameters: soil type, slope, annual rainfall, and land cover (Oldeman et al., 1990; Lynden and Oldeman, 1997). Each a weight reflecting its relative influence on land degradation parameter was assigned a a weight reflecting its relative influence on land degradation, with soil type weighted at 2, slope at 3, rainfall at 3, and land cover at 2.

Each class within the parameters was assigned a susceptibility score. Soil type scores were assigned as follows: Vertisols = 1, Oxisols = 2, Mollisols/Ultisols = 3,

Inceptisols/Entisols/Histosols = 4, and Andisols/Spodosols = 5. For classification compatibility within the study area, Chromic Luvisols were grouped with the Ultisol class (score 3) and Dystric Fluvisols with the Entisol/Inceptisol class (score 4). Slope classes were scored as follows: for 0-8% = 1, 8-15% = 2, 15-25% = 3, 25-45% = 4, and >45% = 5. Rainfall classes were 1 assigned score for <1,000 mm yr⁻¹, 2 for 1,000-2,000, 3 for 2,000-3,000, 4 for 3,000-4,000, and 5 for >4,000 mm yr⁻¹. Land-cover types were assigned according to surface protection: secondary forest and water body = 1; shrubland and grassland = 2; forest plantation, upland agriculture, mixed upland agriculture, and paddy field = 3; and settlement and open land = 5. This reclassification transformed the land-cover map into a degradation susceptibility layer that could be combined with the other GLASOD parameters.

The land-degradation index was calculated using the following equation

$$LD = ST(2) + SL(3) + RF(3) + LC(2)$$

where *LD* is land degradation, *ST* is soil type, *SL* is slope, *RF* is rainfall, and *LC* is land cover. The resulting total scores were reclassified into five degradation classes: very low (<15), low (15-24), moderate (25-34), high (35-44), and very high (45-50).

Furthermore, to ensure reproducibility, the analysis was implemented in ArcGIS ModelBuilder as a fixed geoprocessing sequence consisting of project/clip, reclassification, score calculation, overlay, calculation of the total weighted score (*LD_Total*), classification, dissolve by class, and area calculation. This workflow enabled efficient updates following field validation or data revision while minimizing manual errors .

Data analysis

The outputs were analyzed descriptively by calculating the area and percentage of each land-cover class, slope class, rainfall class, soil type, and degradation class. Additionally, cross-tabulation was performed to examine the distribution of degradation classes within the dominant land cover types, namely shrubland, mixed dryland agriculture, and grassland-across slope classes. Field observations were used to support interpretation of the spatial pattern and to confirm whether mapped moderate-to-high degradation zones corresponded to sparse vegetation cover, cultivated land on slopes, and exposed surface conditions. Land-cover interpretation was further supported by field verification conducted in 2024. Representative observation points were visited to assess the correspondence between the classified land-cover categories derived from Landsat 8 imagery and the actual conditions observed in the field. This verification process served as a quality-control measure to improve the reliability of the land-cover map used in the subsequent land-degradation assessment.

RESULTS AND DISCUSSION

Land Cover Characteristics

Shrubland was identified as the dominant land-cover class, covering 4,627.41 ha (48.20%) of the total study area. The second largest class was Mixed Upland Agriculture, occupying 1,435.94 ha (14.96%), followed by Grassland with 1,186.06 ha (12.36%) and Paddy Field with 1,050.57 ha (10.94%). Upland Agriculture covered 553.53 ha

(5.77%), while Open Land and Settlement occupied 348.91 ha (3.63%) and 252.45 ha (2.63%), respectively. Forest cover was very limited, consisting of only 13.57 ha (0.14%) of Secondary Dryland Forest and 59.45 ha (0.62%) of Forest Plantation. Water Body accounted for 71.78 ha (0.75%) of the sub-watershed area (Table 1 and Figure 2).

Table 1. Land-cover classes in the Krueng Khea Sub-watershed

Land-cover class	Area (ha)	Share (%)
Shrubland	4,627.41	48.20
Secondary Dryland Forest	13.57	0.14
Forest Plantation	59.45	0.62
Settlement	252.45	2.63
Upland Agriculture	553.53	5.77
Mixed Upland Agriculture	1,435.94	14.96
Grassland	1,186.06	12.36
Paddy Field	1,050.57	10.94
Open Land	348.91	3.63
Water Body	71.78	0.75
Total	9,599.66	100.00

Source: Data analyses (2024)

This distribution clearly indicates that the non-forest covers dominate the Krueng Khea Sub-watershed, with very limited permanent woody vegetation. Such a pattern reflects a landscape that has undergone substantial land-use transformation, most likely due to deforestation and agricultural expansion. Previous studies have consistently demonstrated that the decline of forest cover and the expansion of open cultivated land reduce infiltration capacity, increase runoff, and accelerate land degradation (Kuntoro *et al.*, 2018; Muis, 2019; Agbenorhevi *et al.*, 2024). Therefore, the current land-cover composition indicates a reduced capacity of the watershed to regulate water flow and protect soil resources.

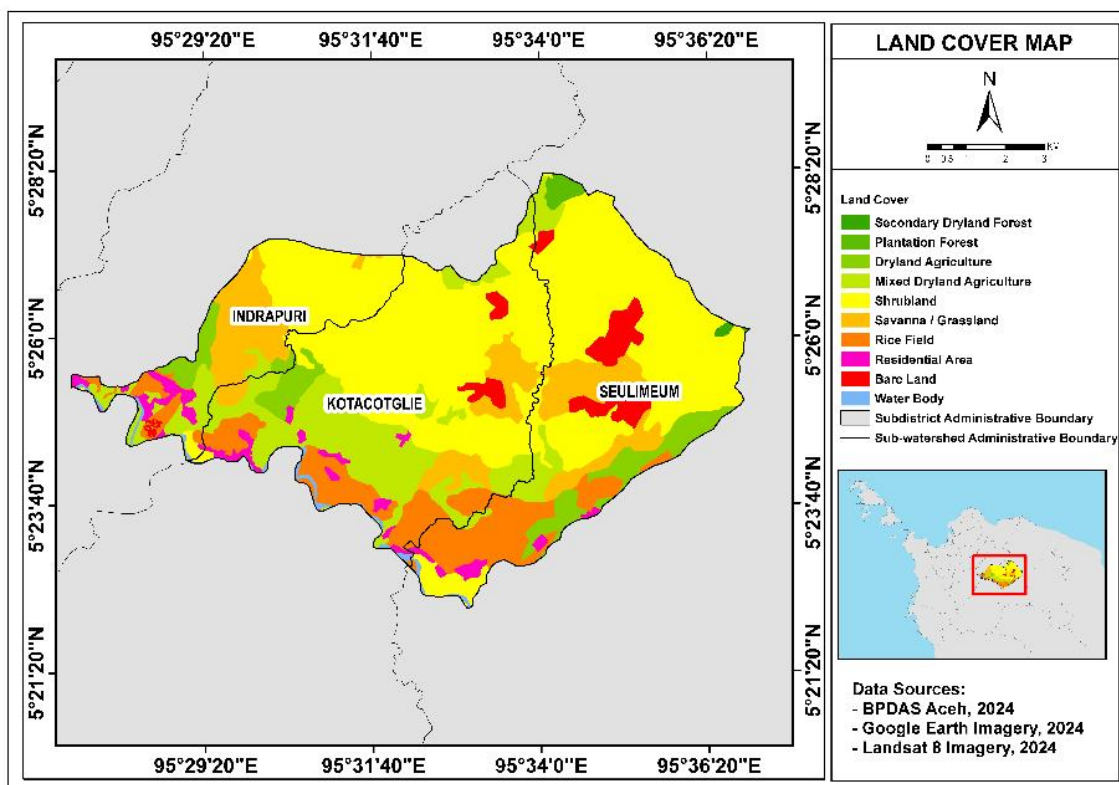


Figure 2. Land cover in Krueng Khee Sub-Watershed

Slope, Rainfall, and Soil Characteristics

Topographic analysis revealed that 71% of the sub-watershed consists of flat to gently slope (0–15%), while the remaining 29% is characterized by slopes greater than 15% (Table 2). Rainfall distribution was spatially uniform within the moderate class of 2,000–3,000 mm per year (Table 3). In terms of soil characteristics, the area is dominated by Chromic Luvisols (70.94%), followed by Dystric Fluvisols (29.06%) (Table 4).

Table 2. Slope classes in the Krueng Khea Sub-watershed

Slope class	Area (ha)	Share (%)
0–8% (flat)	4,279.59	45.00
8–15% (gentle)	2,515.33	26.00
15–25% (moderately steep)	1,710.73	18.00
25–45% (steep)	984.73	10.00
>45% (very steep)	109.28	1.00
Total	9,599.66	100.00

Table 3. Annual rainfall class in the Krueng Khea Sub-watershed

Rainfall class	Range (mm yr ⁻¹)	Area (ha)	Share (%)
Moderate	2,000–3,000	9,599.66	100.00
Total		9,599.66	100.00

Table 4. Soil types in the Krueng Khea Sub-watershed

Soil type	Area (ha)	Share (%)
Dystric Fluvisols	2,789.78	29.06
Chromic Luvisols	6,809.88	70.94
Total	9,599.66	100.00

Source : FAO–UNESCO Soil Map (2007) 1:3,000,000

These findings indicate that rainfall variability is not a major differentiating factor within the study area; instead, land covers and topography play a more significant role in controlling hydrological processes and land degradation risk. Although most of the area is relatively flat terrain, the presence of nearly one-third of the landscape on slopes exceeding 15% is particularly important, as these positions are more sensitive to runoff and erosion when vegetation cover is sparse (Arsyad, 2010; Kardhana *et al.*, 2024).

ChromicLuvisol, commonly found in upland areas, are moderately developed soils that can be prone to erosion under intensive land use. Meanwhile, Dystric Fluvisols typically occur in alluvial lowlands and are more influenced by sediment deposition processes. This toposequence plays a key role in determining the spatial variability of land degradation. Similar patterns have been reported in humid tropical watersheds, where the interaction between slope, soil properties, and land use pressure governs the extent and intensity of degradation (Barchia *et al.*, 2019).

Spatial Distribution of Land Degradation

The spatial analysis of land degradation (Table 5; Figure 30) shows that moderate degradation is the dominant class, covering 7,684.17 ha or 80.05% of the sub-watershed. Low degradation accounts for 1,592.19 ha (16.59%), while high degradation is relatively limited at 323.30 ha (3.37%). No areas were classified as very low or very high degradation. This distribution suggests that the Krueng Khea Sub-watershed is generally under sustained but not yet critical environmental pressure. The dominance of moderate degradation indicates that degradation processes are already widespread, although they have not yet reached irreversible levels. This stage is often described as a “threshold condition,” where ecosystems still retain some resilience but are at risk of further deterioration if no intervention is undertaken.

Table 5. Land-degradation classes in the Krueng Khea Sub-watershed

Degradation class	Area (ha)	Share (%)
Very low	0.00	0.00
Low	1,592.19	16.59
Moderate	7,684.17	80.05
High	323.30	3.37
Very high	0.00	0.00
Total	9,599.66	100.00

Importantly, the moderately degraded land represents a strategic target for rehabilitation efforts. Early intervention at this stage is typically more cost-effective and has a higher probability of success compared to restoring severely degraded land. Similar findings in other Indonesian watersheds show that areas tend to accumulate in the moderate degradation class before transitioning into higher severity levels when unsustainable land-use practices persist (Wahyuningrum and Putra, 2019; Wiwoho *et al.*, 2024).

Relationship of Land Cover and Slope to Degradation

The relationship between land cover, slope, and degradation level (Table 6) highlights that slope is a critical controlling factor that amplifies the impact of land cover on land degradation. Low degradation level in shrubland, mixed dryland agriculture, and grassland was concentrated on flat terrain (0–8%). However, moderate degradation become dominant on slope 8–45%, especially in shrubland. High degradation is confined almost exclusively to very steep slopes (>45%), where shrubland is the predominant cover type.

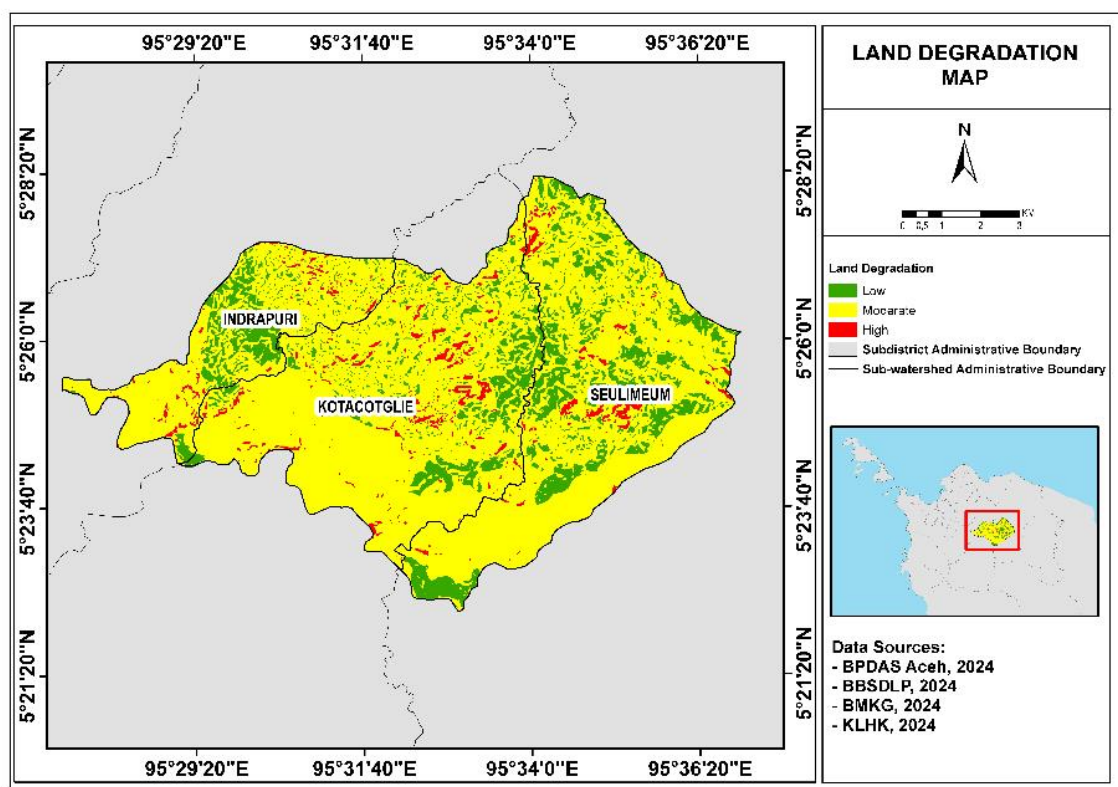


Figure 3. Land degradation map in Kreung Khee Sub-Watershed

Table 6. Distribution of degradation classes across dominant land-cover types and slope classes (ha)

Land cover and class	0–8%	8–15%	15–25%	25–45%	>45%
Shrubland – low	948.99	0.00	0.00	0.00	0.00
Shrubland – moderate	0.00	1,275.79	1,371.08	924.18	0.00
Shrubland – high	0.00	0.00	0.00	0.00	107.37
Mixed dryland agriculture – low	950.76	368.29	0.00	23.61	0.00
Mixed dryland agriculture – moderate	0.00	0.00	92.02	0.00	1.26
Mixed dryland agriculture – high	0.00	0.00	0.00	0.00	0.00
Grassland – low	608.89	0.00	0.00	0.00	0.00
Grassland – moderate	0.00	425.37	130.18	21.25	0.00
Grassland – high	0.00	0.00	0.00	0.00	0.37

These results show that lands cover alone is insufficient to explain degradation patterns, instead, its effectiveness is strongly influenced by topographic conditions. Shrubland may provide partial protection against erosion on gentle slopes but become ineffective on steeper slopes due to insufficient canopy density and root reinforcement. Similarly, mixed dryland agriculture and grassland also became more vulnerable as slope increased, which is consistent with the widely reported role of cultivated and sparsely covered land in accelerating degradation on sloping watersheds (Arsyad, 2010; Barchia *et al.*, 2019).

Slope-based prioritization is a key principle in land rehabilitation planning. Moderately degraded shrubland and agricultural areas on slopes of 8–25% should be prioritized for early intervention using measures such as agroforestry, contour planting, and soil conservation to maintain land productivity. In contrast, steeper areas (>25%) require stricter vegetative and mechanical conservation approaches, including reforestation and terracing, to prevent further degradation and support long-term watershed stability. This differentiated approach provides a practical basis for sustainable land management under varying topographic conditions.

CONCLUSIONS

Land degradation in the Krueng Khea Sub-watershed is dominated by the moderate class, covering 80.05% of the total area, followed by low (16.59%) and high (3.37%) degradation, with no areas classified as very low or very high. The spatial distribution of degradation is primarily influenced by land-cover composition and slope. Shrubland, mixed dryland agriculture, and grassland dominate the landscape, and degradation intensifies as these land-cover types occur on slopes exceeding 8%, particularly above 15%.

These findings indicate that the sub-watershed is under considerable but still manageable environmental pressure. Therefore, land rehabilitation efforts should prioritize moderately degraded areas, especially on gentle to moderately steep slopes (8–25%), through appropriate vegetative and soil conservation measures. In contrast, steeper areas (>25%) require stricter land-use control and more intensive conservation practices. Integrating the degradation map into local land-use planning and watershed management programs is essential to ensure targeted and effective intervention

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