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Spatiotemporal Land Use Dynamics and Their Implications for Watershed Quality in the Minraleng Sub-Watershed, Indonesia

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Land use change is a key indicator of environmental dynamics in watershed ecosystems, particularly in areas experiencing increasing land use changed. This study aims to analyze spatiotemporal land use changes and assess watershed quality based on permanent vegetation cover in the Minraleng Sub-Watershed, Indonesia. Sentinel-2 Level-2A satellite imagery from 2017, 2020, and 2023 was processed and analyzed using a GIS-based overlay approach. Image preprocessing included radiometric correction, band combination, clipping, and on-screen digitization, followed by ground validation using GPS. Classification accuracy was evaluated using confusion matrix and kappa statistics. The results indicate that the Minraleng Sub-Watershed is predominantly covered by primary dryland forest. Forest cover declined by 0.95% between 2017 and 2020 but slightly increased by 0.16% from 2020 to 2023. Watershed quality based on Permanent Vegetation Cover (PVC) remained in the good category, with values of 61% in 2017, 60% in 2020, and 61% in 2023. Classification accuracy was high, with kappa values ranging from 92.25% to 96.43%. These findings provide important insights for sustainable watershed management and strategies to mitigate land degradation risks. Despite the fact that PVC is still classified as being in a good category, the continuous decline in forest cover indicates a growing threat to watershed sustainability, especially in terms of maintaining hydrological functions, regulating streamflow, and preserving the ecological integrity of the watershed.

Keywords: Land use change; sentinel-2; spatiotemporal analysis; watershed quality; minraleng sub-watershed

1. Introduction

Land use is a fundamental component of terrestrial ecosystems that plays a critical role in sustaining ecological processes and supporting human livelihoods. However, land use is inherently dynamic and continuously undergoes changes driven by both natural processes and anthropogenic activities (Ye et al., 2024); (Regasa et al., 2021). The conversion of natural vegetation, particularly forests, into built-up areas, agricultural land, and infrastructure can disrupt ecosystem balance and accelerate environmental degradation, including soil erosion, biodiversity loss, and hydrological alterations (Fauzi et al., 2016); (Meli et al., 2024).

Rapid population growth and increasing socio-economic demands are widely recognized as the primary drivers of land use change (Assede et al., 2023). Expanding human activities, such as urbanization, agricultural intensification, and infrastructure development, require substantial land

resources, often leading to the conversion of forests, grasslands, and wetlands into other land use types. Such transformations significantly influence watershed hydrology by increasing surface runoff, reducing infiltration capacity, and altering natural water flow regimes (Dash et al., 2024); (Kunle et al., 2023); (Kubangun et al., 2016).
Land use change is a complex and dynamic process involving interactions between human systems and the natural environment, with direct implications for soil, water, and atmospheric systems (Koomen et al., 2007). Similar findings have been reported by Soma et al. (2023), who emphasized that land use dynamics strongly influence watershed quality, particularly through changes in vegetation cover and hydrological response.
The Minraleng Sub-Watershed, located in the upstream area of the Walanae Watershed across Pangkajene, Maros, and Bone Regencies, covers approximately 50,957.07 ha and plays an important role in maintaining regional hydrological stability. Despite its ecological significance, comprehensive studies assessing spatiotemporal land use dynamics and their implications for watershed quality in this area remain limited.
Therefore, this study aims to analyze spatiotemporal land use changes in the Minraleng Sub-Watershed and evaluate watershed quality based on permanent vegetation cover using multi-temporal satellite imagery and GIS-based analysis. The findings are expected to provide scientific insights to support sustainable watershed management and land use planning.

2. Method

1) Study Area

Study Area. This study was conducted over a period of seven months, from January to July 2024. The research was carried out in the Minraleng Sub-Watershed, which covers an area of approximately 50,957.07 ha and is administratively located in Maros Regency, South Sulawesi Province, Indonesia. The Minraleng Sub-Watershed forms part of the upstream area of the Walanae Watershed and plays a critical role in regional hydrological regulation. Spatial data processing and analysis were conducted at the Watershed Management Laboratory, Faculty of Forestry, Hasanuddin University. The location of the study area is presented in Figure 1

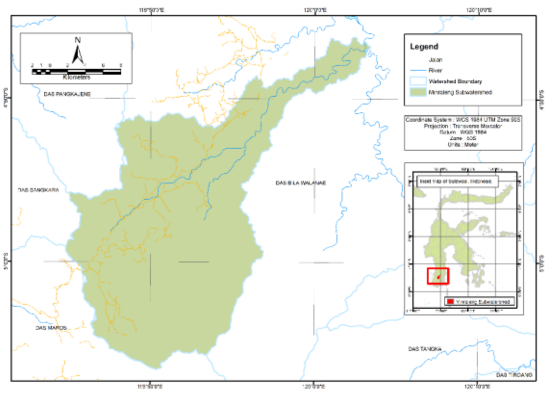

Figure 1. Map of the Research Location

2) Data and Materials

The tools used in this study included a laptop, GIS software (Arc Map 10.4), a Global Positioning System (GPS) receiver, a digital camera, and standard field equipment. The materials consisted of Sentinel-2 Level-2A satellite imagery for the years 2017, 2020, and 2023, as well as Digital Elevation Model (DEM) data. A three year study period was adopted to capture the effects of rapid population growth and the escalating occurrence of flood events in the Minraleng Sub-Watershed over recent years. The research methodology comprised several stages, including data preparation, determination of the study area, data collection, image interpretation through radiometric correction, band combination, clipping, and on-screen digitization, field verification, accuracy assessment, and land use change analysis.
The data used in this study consisted of primary and secondary data. Primary data were obtained through field observations and analysis, including land use information and administrative data of the Minraleng Sub-Watershed. Secondary data were acquired from existing sources, including spatial datasets of administrative boundaries. The data sources are described as follows:

1) Land use data were derived from Sentinel-2 Level-2A satellite imagery for 2017, 2020, and 2023 which was downloaded from https://scihub.copernicus/ through image interpretation based on the Indonesian National Standard for land use classification (SNI 7645:2014). Classification accuracy was assessed using a confusion matrix, including Overall Accuracy (OA) and the Kappa coefficient. The classification results were considered acceptable when the overall accuracy exceeded 80% (Julzarika et al., 2015). Field verification data were used to validate the classification results, and the comparison between classified data and ground observations was summarized in a percentage-based accuracy table.
2) The administrative and the road network data obtained from the Geospatial Information Agency website (https://tanahair.indonesia.go.id/portal-web/). This information was employed to facilitate field surveys and observations.

3) Data Analysis

Land use change analysis was conducted using a spatiotemporal overlay approach by comparing classified land use maps for 2017, 2020, and 2023. This approach enabled the identification and quantification of transitions between land use classes over time. The results of land use changes were summarized in tabular form to clearly present the magnitude and direction of changes. In addition, potential driving factors and environmental implications of land use change were qualitatively analyzed.
Watershed quality is commonly assessed using a range of indicators, including land criteria. One of the key parameters within the land criterion is the slassification of permanent vegetative cover, which reflects the extent and condition of long-term vegetation cover within the watershed.

The results of the percentage of vegetation cover, then the data is organized into categories to assess the quality of the watershed, following the provisions set out in the Regulation of the Minister of Forestry of the Republic of Indonesia: P.61/Menhut-II/2014 on monitoring and evaluation of watershed management.

Table 1. Classes of Percentage of Vegetation Cover

Nilai	Class
PVC > 80%	Very Good
60 < PVC ≤ 80 %	Good
40 < PVC ≤ 60 %	Medium
20 < PVC ≤ 40 %	Bad
PVC ≤ 20%	Very Bad

The analysis of permanent vegetation cover focused on land use types classified as perennial vegetation, including forests, shrubs, and plantations, as defined in the Regulation of the Minister of Forestry of the Republic of Indonesia (P.61/Menhut-II/2014). These vegetation types are characterized by minimal disturbance and are not subject to regular harvesting. Spatial analysis was performed to calculate the area of each permanent vegetation class derived from land use maps. The total area of permanently vegetated land was then aggregated to estimate the percentage of vegetation cover across the watershed. The percentage of Permanent Vegetation Cover (PVC) was calculated using the following equation:

$$PVC = \frac{LVP}{watershed\ area} \times 100\%$$

Where:
PVC = Percentage of Vegetation Cover (%)
LVP = Area of Permanently Vegetated Land (ha)
Watershed Area = Targeted watershed area (ha)

3. Result and Discussion

1) Slope

Topographic conditions in Minraleng Sub-Watershed can be identified by the category of slope. The slope data was obtained through analysis of the National DEM (Digital Elevation Model). Classification of slope and its area distribution can be seen in Table 2.

Table 2. Slope of the Minraleng Sub-Watershed

Slope (%)	Description	Area (ha)
0-8	Flat	14,131.86
8-15	Ramps	17,914.73
15-25	Somewhat Steep	12,603.25
25-40	Steep	5,257.41
>40	Very steep	1,050.58
	Total	**50,957.07**

2) Land Use 2017

Based on image interpretation, the distribution of land use in the Minraleng Sub-Watershed in 2017 is on the Table 3.

Table 3. Distribution of Land use in the Minraleng Sub Watershed in 2017

Land use	Area (ha)	Percentage (%)
Primary Dryland Forest	15,381.78	30.19
Secondary Dryland Forest	13,983.84	27.44
Open Land	184.51	0.36
Settlements	1,085.32	2.13
Dryland Agriculture	797.16	1.56
Mixed Dryland Farming	10,055.86	19.73
Rice Field	7,159.97	14.05
Shrubs	1,666.85	3.27
Water Body	641.76	1.26
Total	**50,957.07**	**100**

3) Land Use 2020

Based on image interpretation, the distribution of land use in the Minraleng Sub-Watershed in 2020 is on the Table 4.

Table 4. Distribution of Land Use in the Minraleng Sub-Watershed in 2020

Land use	Area (ha)	Percentage (%)
Primary Dryland Forest	14,899.25	29.24
Secondary Dryland Forest	14,243.25	27.95
Open Land	83.14	0.16
Settlements	1,083.53	2.13
Dryland Agriculture	798.66	1.57

Land use	Area (ha)	Percentage (%)
Mixed Dryland Farming	10,223.27	20.06
Rice Field	7,389.97	14.5
Total	**50,957.07**	**100**

4) Land use 2023
Based on image interpretation, the distribution of land use in the Minraleng Sub Watershed in 2023 is on the Table 5.

Table 5. Distribution of Land Use in the Minraleng Sub Watershed in 2023

Land use	Area (ha)	Percentage (%)
Primary Dryland Forest	14,815.69	29.07
Secondary Dryland Forest	14,198.06	27.86
Open Land	79.35	0.16
Settlements	1,077.71	2.11
Dryland Agriculture	702.91	1.38
Mixed Dryland Farming	10,200.16	20.02
Rice Field	7,213.55	14.16
Shrubs	2,014.64	3.95
Water Body	654.98	1.29
Total	50,957.07	100

5) Land Use Change 2017-2020
Land use dynamics in the Minraleng Sub-Watershed during the 2017-2020 period exhibited notable fluctuations across several land use classes, reflecting ongoing land use adjustments driven by local socio-economic activities. Primary dryland forest experienced a decline of 482.53 ha (0.95%), which can be attributed to its conversion into secondary dryland forest due to community activities in and around forest areas. In contrast, secondary dryland forest increased by 259.41 ha (0.51%), indicating a process of forest degradation and transition from primary to secondary vegetation. Open land showed a reduction of 101.37 ha, primarily due to its conversion into agricultural land uses, including dryland agriculture and mixed dryland agriculture. Dryland agriculture increased slightly by 1.50 ha, while mixed dryland agriculture expanded more significantly by 167.41 ha (0.33%), largely driven by the utilization of previously open land and shrub areas for cultivation. The settlement class decreased marginally by 1.79 ha, with some areas converted into rice fields. Based on field observations, several houses were found to be abandoned following the migration of local residents to other regions for work and economic reasons.
Meanwhile, rice fields increased by 29.99 ha (0.45%), indicating a shift toward irrigated agricultural practices. Shrubland decreased by 72.99 ha (0.14%), reflecting its conversion into agricultural land, particularly mixed dryland agriculture and rice fields. Water bodies exhibited only a minor change, with an increase of 0.37 ha, suggesting relatively stable hydrological surface conditions during the study period. Overall, the observed land use changes indicate a gradual transition from natural and semi-natural vegetation to more intensive agricultural land uses. This trend may have implications for watershed functions, particularly in terms of reduced vegetation cover, increased surface runoff, and a higher risk of soil erosion and land degradation.

6) Land Use Change 2020-2023
Land use dynamics in the Minraleng Sub-Watershed during the 2020–2023 period showed continued fluctuations, with an overall tendency toward a decline in productive land uses compared to the 2017–2020 period. These changes reflect ongoing adjustments in land use practices driven by local socio-economic considerations. Primary dryland forest decreased by 83.56 ha (0.16%), while secondary dryland forest declined by 45.19 ha (0.09%). Unlike the previous period, the reduction in primary forest was not primarily associated with conversion to secondary forest, but rather to shrubland, indicating a shift toward less managed or transitional vegetation types. Open land exhibited only a minor decrease of 3.79 ha (0.01%), suggesting relatively stable conditions or prior conversion into other land use classes. Settlement areas decreased by 5.82 ha, with some areas transitioning into shrubland, reflecting possible land abandonment or changes in land tenure and utilization. Dryland agriculture showed a notable decline of 95.75 ha, likely influenced by changes in farming practices and land use preferences. In some cases, land was either left fallow, converted to grassland for livestock, or allowed to revert to shrub vegetation. Similarly, mixed dryland agriculture decreased by 23.11 ha, indicating reduced intensity or shifts in land management strategies.
Rice fields experienced a significant decrease of 176.42 ha, partly due to conversion into shrubland

and water bodies. Meanwhile, shrubland increased substantially by 420.78 ha, suggesting widespread land abandonment or reduced agricultural activity. Water bodies also increased by 12.85 ha, likely associated with the expansion of irrigation infrastructure or surface water accumulation in low-lying areas. Overall, the 2020–2023 period is characterized by a transition from actively managed agricultural land toward more passive land use types such as shrubland. This trend may indicate declining land productivity or changing livelihood strategies, with potential implications for watershed stability, including increased erosion risk and altered hydrological responses.

7) Characteristics of Land Use Change

The characteristics of land use change in the Minraleng Sub-Watershed were further analyzed by integrating land use transitions with slope classes to better understand spatial patterns and associated environmental risks. During the 2017-2020 period, several significant land use transitions were observed across different slope classes. The conversion of primary dryland forest to secondary dryland forest was most prominent in moderately steep areas, covering 155.89 ha, indicating forest degradation in ecologically sensitive zones. Similarly, conversion from primary forest to open land occurred on steep slopes (2.01 ha), which poses a high risk of soil erosion and land degradation due to the loss of vegetation cover. The transition from primary dryland forest to dryland agriculture (2.36 ha) and rice fields (69.16 ha) was predominantly observed on gentle slopes, suggesting that these areas are more suitable for agricultural expansion. However, such changes may alter hydrological processes if not properly managed.

Secondary dryland forest conversion to open land (4.33 ha) and agricultural land, particularly mixed dryland agriculture (60.66 ha) and dryland agriculture (3.04 ha), was mainly identified on moderately steep slopes. These transitions increase the vulnerability of land to erosion and highlight the need for sustainable land management practices such as agroforestry systems. Shrubland conversion to mixed dryland agriculture (6.06 ha) also occurred on moderately steep slopes, further emphasizing the expansion of cultivation into marginal lands. In the 2020–2023 period, land use transitions continued to exhibit clear spatial patterns associated with slope. Secondary dryland forest remained dominant on gentle slopes, with an area of 77.62 ha, indicating its role in maintaining ecological stability and carbon sequestration. However, several conversions from forest to non-forest land uses were observed in steeper areas. For example, the conversion of primary dryland forest to dryland agriculture (0.68 ha) and secondary forest to rice fields (2.25 ha) occurred on moderately steep slopes, which may increase erosion risk and reduce land suitability for agriculture. A substantial transition from secondary dryland forest to shrubland was recorded, covering 160.11 ha on moderately steep slopes. This pattern suggests land abandonment or degradation processes, where productive land is no longer actively managed. Notably, several conversions from forest to non-forest land uses occurred in steep slope areas, including transitions to open land, agricultural land, shrubland, and water bodies.

The largest conversion was from secondary dryland forest to dryland agriculture, covering 27.15 ha in steep slope areas. Such changes are environmentally critical, as steep slopes are highly susceptible to soil erosion, landslides, and hydrological instability. The conversion of forested land in these areas significantly reduces slope stability and increases the risk of land degradation. The integration of land use change and slope analysis highlights that land conversion is not only driven by socio-economic factors but also constrained by topographic conditions. The expansion of agriculture and other land uses into moderately steep and steep areas indicates increasing pressure on marginal lands.

8) Land use Change Analysis

- Primary Dryland Forest

Primary dryland forest showed a continuous decline over the study period, decreasing from 15.381,78 ha (2017) to 14.899,25 ha (2020) and further to 14.815,69 ha (2023). The reduction during 2017–2020 was primarily associated with conversion to secondary dryland forest, indicating forest degradation processes. In the 2020–2023 period, the decline was more closely linked to expansion of shrubland, suggesting a shift toward less productive or unmanaged land use. These changes are strongly influenced by anthropogenic pressures, particularly local dependence on forest resources. Activities such as small-scale logging and land clearing for subsistence needs contribute to the gradual degradation of primary forest. Similar findings have been reported by Dewi et al. (2023), highlighting illegal logging as a key driver of forest degradation. From an ecological perspective, the loss of primary forest reduces canopy density and structural complexity, which are essential for regulating hydrological processes. Dense forest vegetation plays a critical role in enhancing infiltration, reducing surface runoff, and protecting soil from erosion through canopy interception and litter layers.

- Secondary Dryland Forest

Secondary dryland forest increased from 13.983,78 ha (2017) to 14.243,25 ha (2020), reflecting the transition from primary forest. However, it slightly declined to 14.198.06 ha (2023) due to conversion into shrubland and agricultural land. The decrease in secondary forest is primarily driven by agricultural expansion, particularly mixed dryland agriculture. Socio-economic factors, including population growth and livelihood dependence on farming, play a major role in this process (Adamidou et al., 2026). Continuous land clearing for agriculture can reduce soil organic matter, disrupt soil biota, and degrade soil structure, ultimately lowering infiltration capacity and increasing surface runoff, which may lead to flooding and landslides (Simanjuntak, 2005).

- Open Land

Open land decreased significantly from 184.51 ha (2017) to 83.14 ha (2020) and further to 79.35 ha (2023). This reduction is mainly attributed to conversion into agricultural land, particularly dryland and mixed farming systems. Open land in the study area includes both natural features (e.g., rock outcrops) and anthropogenically cleared land. The declining trend indicates increasing land utilization driven by population growth and infrastructure demands, consistent with findings by Badoa et al. (2018).

- Settlements

Settlement areas showed a decreasing trend during both periods, although population growth continued. This pattern suggests spatial reorganization of settlements rather than an actual decline in population. Some settlement areas were converted into agricultural land or other land use types. Changes in settlement areas have important hydrological implications. The expansion or redistribution of built-up areas can reduce infiltration capacity and increase surface runoff, potentially contributing to flooding within the watershed. Conversely, when residential areas decrease and are replaced by vegetative cover, the extend of impervious surfaces is reduced, resulting in the opposite effect (Purwantara, 2015).

- Dryland Agriculture

Dryland agriculture slightly increased from 797.16 ha (2017) to 798.66 ha (2020), but declined significantly to 702.91 ha (2023). The increase in the earlier period was driven by conversion from open land, while the subsequent decline was largely due to conversion into shrubland. This trend reflects changing agricultural practices and land use strategies, where some areas are abandoned, left fallow, or repurposed for livestock grazing. The variability in crop types—such as maize (*Zea mays*), cassava (*Manihot esculenta*), and chili (*Capsicum annuum*)—also indicates adaptive strategies to seasonal and economic conditions.

- Mixed Dryland Farming

Mixed dryland agriculture expanded from 10,055.86 ha (2017) to 10,223.27 ha (2020), followed by a slight decrease to 10,200.16 ha (2023). Despite fluctuations, the overall change was relatively stable. This land use type is dominated by multi-species cropping systems, including perennial and annual crops such as corn (*Zea mays*), banana (*Musa paradisiaca*), pepper (*Paper nigrum*), coffee (*Coffea arabica*), porang (*Amorphophallus muelleri*), elephant grass (*Cenchrus purpureus*), coconut (*Cocus nucifera*), aren palm (*Arenga pinnata*) and various multipurpose tree species (MPTS) such as cashew (*Anacardium occidentele*), durian (*Durio zibethinus*), and mango (*Mangifera indica*). The relative stability of this class suggests its importance as a sustainable land use system that balances productivity and ecological functions

- Rice fields

Rice fields increased from 7,159.97 ha (2017) to 7,389.97 ha (2020), then decreased to 7,213.55 ha (2023). The increase was driven by conversion from open land, while the decline was associated with conversion into water bodies and other land uses. Changes in rice field area are closely linked to water availability and irrigation practices. Expansion of rice fields increases water demand and may alter watershed hydrology by reducing river discharge due to increased water retention and evapotranspiration (Amaliah et al., 2020; Utari, 2023). Shrubland decreased from 1,666.85 ha (2017) to 1,593.86 ha (2020) but increased significantly in 2023 by 2,014.64 ha. This substantial increase indicates land abandonment or reduced agricultural activity. Shrubland plays a transitional ecological role by providing ground cover, reducing runoff, and supporting biodiversity. However, its expansion at the expense of productive land may indicate declining land productivity or shifting livelihood strategies.

- Water Body

Water bodies increased gradually from 641.76 ha (2017) to 642.13 ha (2020) and further to 654.98 ha (2023). This increase may be linked to land clearing and reduced infiltration capacity, resulting in higher surface water accumulation. Additionally, the expansion of irrigation systems to support agriculture contributes to the increase in water bodies. While beneficial for agricultural productivity, these changes may alter natural hydrological regimes within the watershed.

9) Watershed Quality Based on Permanent Vegetation Cover

Watershed quality in the Minraleng Sub-Watershed was assessed using the Permanent Vegetation Cover (PVC) indicator, following the Regulation of the Minister of Forestry of the Republic of Indonesia (P.61/Menhut-II/2014). The PVC values were calculated based on the proportion of land use classified as permanent vegetation, including primary dryland forest and secondary dryland forest, for the years 2017, 2020, and 2023. The results (Table 6) indicate that the percentage of permanent vegetation cover remained relatively stable over the study period, with values of 61% (2017), 60% (2020), and 61% (2023).

Table 6. Percentage value of vegetation cover in Minraleng Sub-Watershed

Permanent Vegetation (Ha)							
Year	**Primary Dryland Forest (Ha)**	**Secondary Dryland Forest (Ha)**	**Shrubs (Ha)**	**Permanent Vegetation Area (Ha)**	**Watershed Area (Ha)**	**PVC Value**	**Class**
2017	15,381.78	13,983.84	1,666.85	31,032.47		0.61	GOOD
2020	14,899.25	14,243.25	1,593.86	30,736.36	50,957.07	0.6	GOOD
2023	14,815.69	14,198.06	2,014.64	31,028.39		0.61	GOOD

A reduction in permanent vegetation cover can significantly affect watershed functions, particularly by increasing surface runoff, reducing infiltration capacity, and elevating the risk of soil erosion and sedimentation. These findings are consistent with Pratama and Yuwono (2016), who reported that forest conversion alters hydrological characteristics, including reduced dry-season flow and increased runoff during the rainy season. A similar conclusion was also reported by Soma et al. (2023), emphasizing that changes in vegetation cover directly influence watershed hydrological responses. Therefore, maintaining and restoring permanent vegetation is essential to ensure watershed sustainability. Strategic efforts such as forest conservation, reforestation, and sustainable land use management are necessary to mitigate degradation risks and preserve hydrological functions. These measures are critical for supporting ecosystem stability and sustaining the livelihoods of communities dependent on watershed resources

4. Conclusion

This study demonstrates that land use dynamics in the Minraleng Sub-Watershed are characterized by a gradual transition from primary dryland forest to secondary vegetation, followed by expansion of shrubland and agricultural land. The most significant change occurred during 2017–2020, marked by the conversion of primary forest into secondary forest, while the 2020–2023 period showed continued forest decline associated with increasing shrubland. Despite these changes, watershed quality based on Permanent Vegetation Cover (PVC) remained relatively stable within the "good" category, with values ranging from 60% to 61%. However, the observed reduction in forest cover indicates emerging risks of watershed degradation, including increased surface runoff, erosion, and sedimentation. These findings highlight the importance of sustaining permanent vegetation through conservation and adaptive land management strategies to maintain hydrological functions and ensure long-term watershed sustainability under growing anthropogenic pressure.

5. Author Contributions

The experimental design was devised by Second author. Wrote the paper by first author and Second author. Collected data by Second author and third author. Performed analysis by first author and third author. The data was interpreted in the result and discussion by Second author and fourth author.

6. Competing Interests

The authors are free of conflict of interest.

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