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Interaction between Understory Riparian Vegetation, Land Use and Water Quality in the Upper Ranoyapo River, South Minahasa, Indonesia

Ratna Siahaan[1,*], Ficky M. Oroh[2], Yosia N. Wijaya[3], Daniel H. Tulis[4], Charles E. Mongi[5]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, University of Sam Ratulangi, Indonesia
[2]Department of Civil Engineering, Faculty of Engineering, University of Sam Ratulangi, Indonesia
[3]Department of Environmental Engineering, Faculty of Engineering, University of Sam Ratulangi, Indonesia
[4]Department of Urban and Regional Planning Engineering, Faculty of Engineering, University of Sam Ratulangi, Indonesia
[5]Department of Mathematics, Faculty of Mathematics and Natural Sciences, University of Sam Ratulangi, Indonesia

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Abstract Clean water is an essential need for humans. Human activities in the watershed can reduce river water quality. Riparian, a transitional ecosystem, functions in controlling river water quality due to its ability to absorb material from the land before entering the river. The upstream watershed functions as a water and land management. The study aims to analyse the interaction between land cover, riparian vegetation types, and the water quality of the upstream Ranoyapo River. The survey method was conducted at two stations by placing 30 locations for sampling vegetation and river water. The results show land demands and uses in the Ranoyapo Watershed. Most are forests and mixed gardens (86.07%), namely 9,247 Ha (37.13%) of forest and 12,186.25 Ha (48.94%) of mixed gardens. The rest are settlements, open land and water bodies. The diversity of riparian vegetation types and undergrowth is classified as moderate. The diversity of riparian vegetation reduces total phosphate in river water quality. The water quality parameters of the Ranoyapo River remain below the maximum allowable limits (compliant with Class 2 standards) for TDS, TSS, TN, TP, nitrate, nitrite, and turbidity. The pH parameter meets quality standards, and turbidity remains low. Land cover and land use are predominantly vegetative, with riparian land cover consisting of mixed gardens and moderate species diversity, contributing to good water quality in the Ranoyapo River, as it meets quality standards.

Keywords Water Quality, Riparian Vegetation, Ranoyapo Watershed, Land Cover, Riparian Ecology

1. Introduction

Clean water is one of the goals of sustainable development [1]. Water is a very important natural resource for humans, but less than 1.5% of fresh water is accessible [2]. Rivers play an important role for humans because they provide fresh water. River water is used by humans to meet various needs, including for households and agriculture. However, as human growth increases, clean river water is becoming increasingly scarce due to the entry of various pollutants into rivers. The ecological services and functions of rivers as providers of good quality water are apparently influenced by riparian zones [3-5]. Riparian zones are ecotones that connect river aquatic ecosystems with terrestrial ecosystems. Riparian zones are periodically affected by river floods [6], so these riparian zones have high diversity. Riparian zones have various ecological functions and services. One of them, riparian zones can maintain river water quality by absorbing or filtering runoff water that carries nutrients and sediment from the land before entering the river [3]. Riparian zones and rivers have a very strong connection. The use of riparian land will affect river water quality [4,5]. In fact, even though the riparian width is reduced, the riparian zones can still reduce pollutants that will enter the river [4]. Efforts to overcome water pollution include riparian conservation, which functions as a buffer and filter for runoff and pollutants from the land before entering the river. The Ranoyapo River is the main river in the Ranoyapo River Watershed. Changes in land use in the upstream riparian area, even in the Ranoyapo River Watershed, have an impact on the decline in the water quality of the Ranoyapo River, which can reduce the health of residents and the diversity of living things in the Wallacea Region, also, the diversity of riparian vegetation consisting of grass, shrubs, and trees [6].

The Ranoyapo River plays a vital role in the community as it provides clean water for both domestic and agricultural needs. The decline in river water quality impacts not only the community but also the wildlife that depends on the river's water. The Ranoyapo River is part of the Wallacea Region, which boasts high biodiversity and is generally endemic. In this regard, the decline in water quality not only reduces human quality of life but also threatens biodiversity, which has significant ecological functions and services. Changes in land cover in the riparian zone and/or the Ranoyapo watershed directly impact the water quality of the Ranoyapo River and its tributaries. This decline in quality is caused by sediment and nutrients from agricultural land carried by surface runoff into the river. The resulting losses include not only difficulties in accessing clean water but also the potential decline in biodiversity.

Previous research has examined the relationship between riparian zone quality and river water quality. Research in China [3], Portugal [4], and Argentina [5] indicates that riparian zones influence river water quality. Land use/cover in the riparian zone and the watershed are inseparable in maintaining river water quality. Based on this, this study is about the interaction of land use/cover types in the riparian and Ranoyapo River watershed on the water quality of the upper Ranoyapo River.

2. Materials and Methods

2.1. Land Cover and Use of the Ranoyapo Watershed

Land classification uses data from Google Earth Engine (GEE) [7,8]. GEE imagery data, along with data from Splash Planet and the 2014-2034 South Minahasa Spatial Plan (RTRW) will be processed using ArcGIS. The resulting land classification includes forest, mixed plantations, open land, settlements, and water bodies. Coordinate points will be obtained for the supervised classification method.

Data collection was conducted using Landsat 8 satellite imagery for 2025. Land use information will be validated and adjusted based on direct field observations at the research site to ensure the accuracy of the current data. Classification is conducted in accordance with SNI 7645:2010 concerning Land Cover Classification. This stage concludes with a thematic map layout, which serves as the final spatial visualization.

2.2. Understory Vegetation Analysis

The research locations were selected using a purposive sampling method. Two stations were predetermined: before and after the Ranoyapo dam, both located in the upstream part of the river. At each station, the research site was divided into three replicates, spread zigzag along the left, right, and left banks of the river. The total number of observation points was 30, consisting of 2 stations, 3 replicates, and 5 land cover types. The lateral interconnection of riparian vegetation to river water quality was represented by the determination of research locations according to predetermined quadrat plots. Riparian vegetation samples were collected and identified digitally and/or manually using literature.

Understory vegetation was collected using 1 m x 1 m quadrat plots for grasses, and 2 m x 2 m for seedlings and herbs [9]. Seedlings are plants ranging from seedlings/sprouts to a height of 1.5 m [10]. Herbs are plants with wet, non-woody stems that can reach a height of up to 2 m [11]. The diversity of riparian understory plant species was calculated using the Shannon – Wiener species diversity index (H').

2.3. Water Quality of the Upper Ranoyapo River

Water sampling at the same location as vegetation analysis. Water sampling at each location point. A total of 5 L of water was put into a 5 L plastic jerry can with a total of 30 sampling points. Next, the samples were taken to the BSPJI Laboratory (Industrial Standardization and Service Center) in Manado. Sampling was carried out 3 times, namely in July, August and September 2025. The sampling period was specifically selected to represent the crucial transition from the dry season to the early rainy season. This period is critical for observing the "first flush" phenomenon, where surface runoff typically carries the highest load of accumulated pollutants from the land into the river, thereby testing the buffering capacity of the riparian zone [12]. The water will be tested using standard methods at the BSPJI laboratory for seven (7) parameters that will be tested ex situ (TDS, TSS, Nitrate, Nitrite, Total N, Total P, and turbidity), and one (1) parameter will be tested in situ (pH).

2.4. Data Analysis

To determine the interaction between riparian vegetation and water quality, a Pearson Product-Moment Correlation analysis was conducted using R-Studio software (Version 2026.01.0 Build 392). This analysis aims to measure the strength and direction of the linear relationship between the Shannon-Wiener Diversity Index (H') of understory vegetation and key water quality parameters (TDS, TSS, Nitrate, Nitrite, Total Nitrogen, Total Phosphate, and turbidity). Additionally, a descriptive analysis was performed to link land use patterns (percentage of forest vs. mixed gardens) with spatial variations in water quality.

3. Results and Discussions

3.1. Description of Research Location

The research was conducted at two stations: Station I in Kinamang Village and Station II in Kinamang Satu Village, Maesaan District, South Minahasa Regency, North Sulawesi Province. A total of 30 observation points were divided into two stations. Five locations were designated as substations, each of which was observed three times. Thus, a total of 15 observation points were observed at each station. Station I was located before the dam, and Station II was located after the dam (Figure 1).

3.2. Land Cover and Use of the Upper Ranoyapo Watershed

The land cover and use classification of the upstream Ranoyapo Watershed in 2025 (Figure 2) includes 9,247 hectares (37.13%), mixed plantations (12,186.25 hectares) (48.94%), settlements (1,459.14 hectares) (5.86%), open land (669.98 hectares), and water bodies (1,338.85 hectares) (5.38%). The land cover and use patterns in the upstream Ranoyapo Watershed are already becoming concerning. Nearly 50% of the upstream Ranoyapo Watershed has been converted into mixed plantations. This can degrade environmental quality. However, the vegetative character of the upstream Ranoyapo Watershed remains substantial, a combination of forest and mixed plantations.

Watershed environmental services have four types of functions: provisioning services, regulating services, support services, and cultural services [13]. The upstream watershed functions as a soil and water conservation area [14]. Forests can regulate water management, allowing rainfall to infiltrate the ground and avoid surface runoff. The impact of rainfall flowing onto the surface causes bank erosion, increased river discharge, and flooding.

The upper Ranoyapo watershed can store water during the rainy season. This storage capacity is due to forest vegetation, which moderates the flow velocity during the rainy season. Rainfall that is not stored in the ground increases the flow velocity, leading to bank erosion [15].

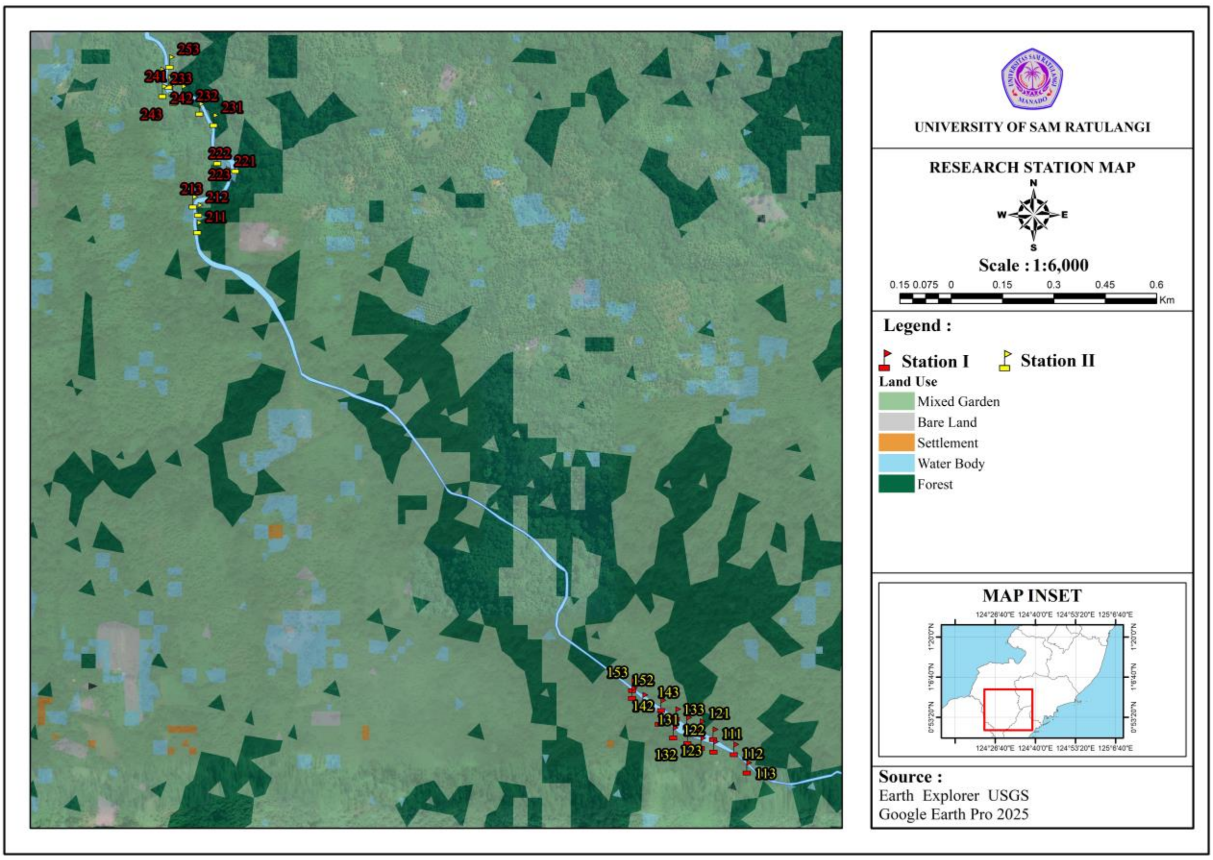

Figure 1. Research location

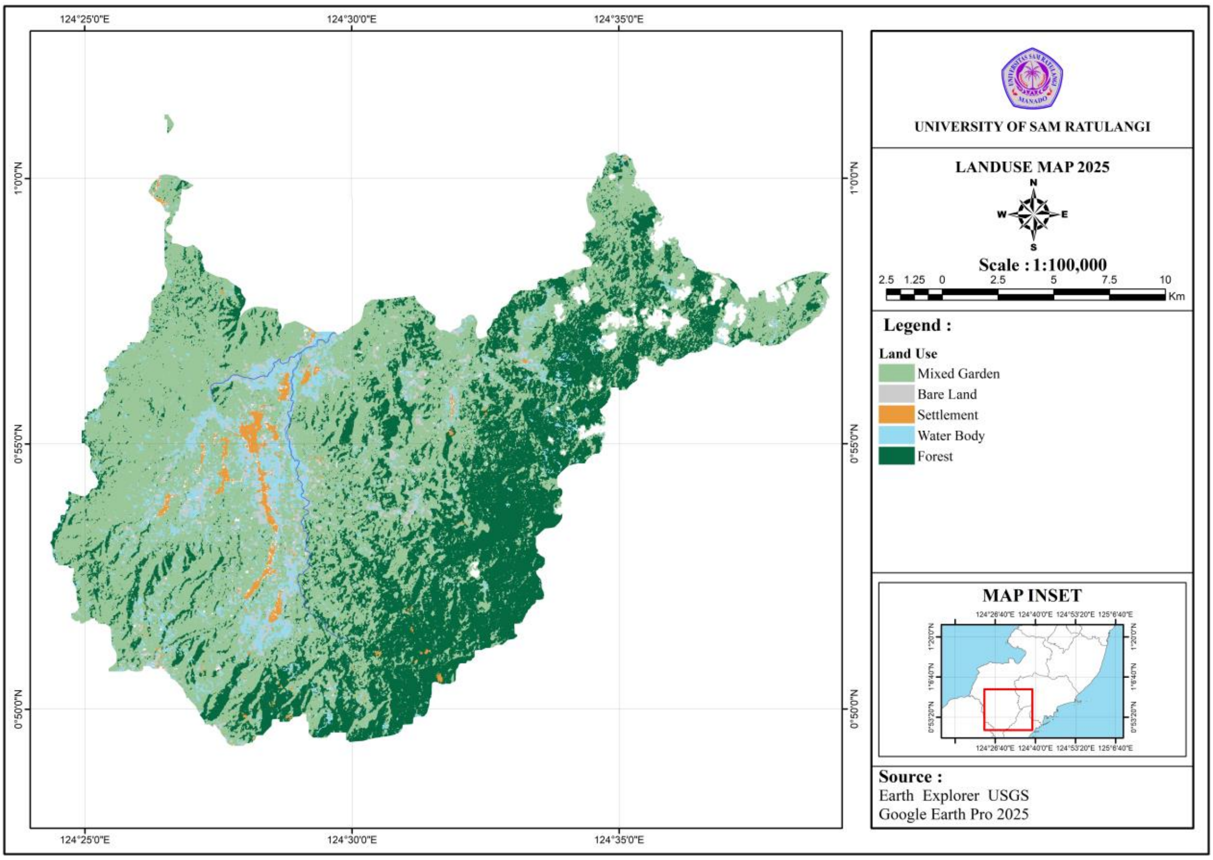

Figure 2. Land Cover and Use of the Upper Ranoyapo Watershed

3.3. Width of the Riparian Zone

The width of the riparian zone was determined using the flood trace method. Measurements began from the farthest boundary affected by the flood to land. The width of the riparian zone was 0.8 m - 7.2 m (Table 1). This is because riparian zones are defined based on the riparian definition, namely the zone between a river ecosystem and a terrestrial ecosystem that is periodically affected by river flooding [16].

Table 1. Width of the Riparian Zone of Upper Ranoyapo River

Parameter	Station I				
	SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
Riparian width (m)	2.5	3.0	0.8	6.1	4.8
Parameter	Station II				
	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
Riparian width (m)	7.2	6.8	5.4	4.1	4.9

The width of the riparian zone in the upstream area is approximately 0 m - 55 m [16,17]. The upstream area has varied topography, with some areas never being inundated by river water, even during peak floods [18]. The slope class reaches more than 15%, thus preventing river overflow.

Land cover and use in the riparian zone are dominated by mixed gardens. Farmers utilize the riparian zone with woody plants such as sugar palm. Mixed gardens are a form of agroforestry. Mixed gardens are crucial for maintaining biodiversity and soil conservation [19]. Mixed gardens provide ecosystem services including reducing runoff, increasing the rate of water infiltration into the soil, controlling bank erosion, maintaining soil fertility and regulating water [20].

3.4. Diversity of Understory Riparian Vegetation

The species richness of understory vegetation in the riparian zone at both stations totaled 32 species: 18 species at Station I and 27 species at Station II. Species diversity at both stations was moderate, as indicated by the Shannon-Wiener Diversity Index (H') of 1.58, 1.83, 1.51, 1.61, 2.42, 1.89, 1.99, 2.16, 1.51, and 1.76 at Stations SRU11, SRU12, SRU13, SRU14, SRU15, SRU21, SRU22, SRU23, SRU24, and SRU 25, respectively (Table 2). The understory vegetation diversity of the Ranoyapo River is moderate.

Table 2. Abundance and Biodiversity of Riparian Vegetation Index

No	Species	Family	Stations									
			SRU11	SRU12	SRU13	SRU14	SRU15	SRU21	SRU22	SRU23	SRU24	SRU25
1	*Alpinia* sp	Zingibe-raceae	0	0	0	0	49	3	0	0	0	23
2	*Alsophila glaucifolia* R.M.Tryon	Cyathe-aceae	0	0	0	2	3	0	0	0	0	0
3	*Arenga pinnata* (Wurmb) Merr	Arecaceae	0	0	1	2	7	0	0	2	0	1
4	*Asplenium nidus* L	Aspleniaceae	0	0	0	0	0	1	0	0	0	0
5	*Bauhinia purpurea* L	Fabaceae	0	0	0	0	0	0	0	1	0	0
6	*Begonia* sp	Begoniaceae	1	0	0	0	0	0	0	0	0	0
7	*Cenchrus purpureus* (Schumach.) Morrone	Poaceae	0	0	0	0	0	1	0	0	0	0
8	*Cocos nucifera* L.	Arecaceae	0	0	0	0	0	1	0	0	0	0
9	*Cyperus kyllingia* Endl	Cyperaceae,	0	0	0	0	0	0	3	0	0	0
10	*Diplazium esculentum* (Retz.) Sw.	Athyriaceae	14	23	5	3	9	6	13	1	0	0
11	*Diplazium* Sw.	Athyriaceae	0	8	0	0	0	0	0	0	0	0
12	*Drymaria cordata* (L.) Willd. ex Schult	Caryophyll-aceae.	0	0	0	0	0	0	24	2	0	0
13	*Elatostema stewardii* Merr.	Urticaceae	56	20	68	104	106	104	0	113	43	5
14	*Ficus ampelos* Burm.f	Moraceae	0	0	0	1	2	0	0	13	0	0
15	*Ficus lepicarpa* Blume	Moraceae	0	0	0	3	2	0	0	13	0	0
16	*Ficus septica* Burm.f.	Moraceae	5	10	1	1	13	1	0	1	0	0
17	*Ficus wassa* Roxb.	Moraceae	0	0	1	0	0	0	0	0	0	0
18	*Hellenia speciosa* (J. Koenig) S. R. Dutta	Costaceae	0	0	4	0	1	0	0	1	2	0
19	*Heterogonium sp*	Polypo-diaceae	0	0	0	0	8	0	0	0	2	1
20	*Homalomena* sp	Araceae	0	14	14	0	9	0	0	10	0	0
21	*Hyptis capitata* Jacq.	Lamiaceae	84	0	0	0	1	144	87	0	0	0
22	***Ichnanthus vicinus (F.M.Bailey) Merr.***	Poaceae	0	0	0	0	0	0	0	0	1	0
23	*Manihot esculenta* Crantz	Euphor-biaceae	0	0	0	0	0	0	7	0	0	0
24	*Medinilla* sp	Melastom-ataceae	0	0	0	0	0	0	0	3	2	0
25	*Musa paradisiaca* L.	Musaceae	0	0	0	0	0	0	2	0	0	0
26	*Pandanus amaryllifolius* Roxb. ex Lindl.	Pandanaceae	0	0	0	0	0	0	0	0	0	9
27	*Paspalum conjugatum* P.J. Bergius	Poaceae	0	0	0	0	0	0	14	0	0	0
28	*Phrynium pubinerve* Blume	Marantaceae	0	0	0	0	0	5	0	2	0	9
29	*Piper aduncum* L.	Piperaceae	24	5	0	1	7	0	0	1	0	1
30	*Piper* sp	Piperaceae	0	1	0	0	1	6	10	0	5	0
31	*Selaginella doederleinii* (Hieron.) H.S.Kung.	Selagine-llaceae	0	0	0	8	51	0	23	93	86	0
32	*Solanum torvum* Sw.	Solanaceae	0	0	0	0	0	1	0	0	0	0
	Total		184	81	94	125	269	273	183	256	141	49
	H'		1.58	1.83	1.51	1.61	2.40	1.89	1.99	2,16	1,51	1,76

The understory vegetation diversity of the riparian zone is influenced by human activities along the river. The upstream riparian zone of the Ranoyapo River has been utilized by residents for agricultural purposes, including plantations. The agricultural practices at the study site do not clear the plantation floor, allowing a variety of natural plants to grow. The dominant understory vegetation in the upstream area consists of grasses and shrubs. This understory vegetation is wild plants found in agricultural land and is often considered a weed by farmers growing crops in the riparian zone [18].

3.5. Water Quality of the Upper Ranoyapo River

The water quality of the Upper Ranoyapo River was determined over three months of observation and testing, namely July, August, and September. There were 30 sampling points evenly distributed across the two stations. In general, the results of the Ranoyapo River water quality showed that the quality still met the quality standards for river water and similar Class 2, according to the requirements of Government Regulation Number 22 of 2021, Appendix VI [21]. The water quality of the Upper Ranoyapo River is classified as good because it meets the quality standards (Tables 3-5). This is because human activity in the upstream area is still minimal, so the environmental burden on the waters of the Upper Ranoyapo River is still low.

3.5.1. Total Dissolved Solids (TDS)

The TDS parameter remains below the quality standard (Table 3). This TDS parameter is a river water quality parameter. TDS concentration can degrade the taste of drinking water. TDS is produced by organic molecules released during the growth and breakdown of biological materials, such as roots and microbes, in rivers. Another factor is the influx of soil particles and sediment into the river [22].

TDS concentrations in July were higher than in August and September due to the continued influence of rainfall (Table 3). Meanwhile, TDS concentrations in September were higher than in August due to the onset of the rainy season. Rainfall increased TDS concentrations at both stations, although they remained below the quality standard. The release of soil particles, which increased the concentration of dissolved solids in river water, was influenced by the vegetative characteristics of the upstream Ranoyapo watershed, which is still dominated by vegetative structures.

Table 3. TDS concentration in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	1,000	mg/L	114.667	73.333	136,667	136,000	133,333
August	1,000	mg/L	52.000	57.333	41,333	62,667	54,667
September	1,000	mg/L	81.333	64.000	45,333	57,333	74,667
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	1,000	mg/L	100.000	92.667	176,000	198,667	140,667
August	1,000	mg/L	56.000	66.667	53,333	54,667	59,333
September	1,000	mg/L	82.000	133.333	165,333	188,000	172,667

* Class 2, app VI

Table 4. TSS concentration in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	50	mg/L	2.333	2.333	2.667	2.667	2.333
August	50	mg/L	0.933	1.267	0.967	0.367	1.333
September	50	mg/L	0.500	0.300	0.667	0.283	1.067
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	50	mg/L	2.000	3.333	2.000	2.767	2.133
August	50	mg/L	0.900	1.200	0.867	0.667	0.567
September	50	mg/L	5.000	2.667	2.333	2.000	2.000

* Class 2, app VI

3.5.2. Total Suspended Solids (TSS)

TSS concentrations remained below the quality standards for July, August, and September 2025. TSS concentrations in July were higher than in August and September (Table 4). Differences in water quality between Station I (upstream) and Station II (downstream) were analysed by considering confounding factors such as topography and tributary inflows. As noted in the results, TSS concentrations in September were higher at Station II (5.0 mg/L) compared to Station I (0.5 mg/L). This increase is not necessarily due to land use failure in the riparian zone, but rather due to the natural influx from tributaries that join the main river between the two stations. These tributaries carry additional sediment loads from sub-catchments. However, despite this tributary input, the overall water quality at Station II remains within acceptable limits (<50 mg/L), indicating that the riparian vegetation along the main channel still performs an effective buffering function.

The amount of TSS below the quality standards in the river ensures the river's ecological functions continue to function properly. TSS is not toxic, but in large quantities it can increase turbidity. The quality of TSS was still below the quality standards, resulting in low turbidity, even though there are no quality standards. Turbidity is a river water quality indicator that indicates the presence of biotic elements such as plankton and microbes, as well as abiotic elements in the water [22].

3.5.3. Nitrate

Nitrate concentrations in July, August, and September were relatively similar (Table 5). Nitrate concentrations were still below the quality standard (<0.2 mg/L). The source of nitrate in the river comes from fertilizer use during agricultural activities [23,24]. Land cover and use, which are largely vegetative, cause nitrate concentrations to fall below the quality standard.

3.5.4. Nitrite

Nitrite concentrations are still below the quality standard (Table 6). The source of nitrite in the river comes from the use of fertilizers from agricultural activities [25]. Nitrite concentrations are still below the quality standard because the upstream Ranoyapo watershed is mostly vegetative.

3.5.5. Total Nitrogen

Total Nitrogen concentration is still below the quality standard (Table 7). The source of Total Nitrogen (TN) in the river comes from the use of fertilizers from agricultural activities [26]. Land cover and use in the upstream Ranoyapo watershed, which is mostly vegetative, causes nitrite concentrations to be below the quality standard.

Table 5. Nitrate concentration in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	10	mg/L	0.20	0.20	0.20	0.20	0.20
August	10	mg/L	0.20	0.20	0.20	0.20	0.20
September	10	mg/L	0.20	0.20	0.20	0.20	0.20
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	10	mg/L	0.20	0.20	0.20	0.20	0.20
August	10	mg/L	0.30	0.20	0.20	0.20	0.20
September	10	mg/L	0.20	0.20	0.20	0.20	0.20

* Class 2, app VI

Table 6. Nitrite Concentration in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	0.06	mg/L	0.001	0.0009	0.0009	0.0009	0.0010
August	0.06	mg/L	0.001	0.0015	0.0013	0.0010	0.0009
September	0.06	mg/L	0.001	0.0009	0.0010	0,0013	0.0010
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	0.06	mg/L	0.0010	0.0013	0.0013	0.0010	0.0010
August	0.06	mg/L	0.0030	0.0013	0.0010	0.0010	0.0017
September	0.06	mg/L	0.0009	0.0009	0.0013	0.0009	0.0009

* Class 2, app VI

Table 7. Total Nitrogen Concentration in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	15	mg/L	1.267	1.103	1.293	1.400	1.267
August	15	mg/L	1.833	0.977	0.710	1.400	1.060
September	15	mg/L	1.557	1.353	1.500	1.633	1.700
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	15	mg/L	4.967	1.867	1.933	1.900	2.033
August	15	mg/L	0.990	1.433	1.177	1.200	1.167
September	15	mg/L	1.767	1.200	1.700	1.600	1.867

* Class 2, app VI

3.5.6. Total Phosphate

Total Phosphate concentration is still below the quality standard (Table 8). Sources of Total Phosphate (TP) in rivers come from natural rock weathering activities [27], fertilizer use from agricultural activities, and organic material weathering [28]. Land cover and use in the upstream Ranoyapo watershed, which is mostly vegetative, cause TP concentrations to be below the quality standard. Forests prevent bank erosion due to high river currents, which will reduce TP concentrations in rivers [28].

3.5.7. Turbidity

Turbidity measures water clarity by determining how much light penetrates the water (Table 9). Materials that can make water cloudy include sediment, dissolved organic matter, and fertilizer use from agricultural activities. Turbid water will increase sediment, which can disrupt the habitat of aquatic animals in the river [29]. The turbidity level of the Ranoyapo River water is still good, as indicated by a value of less than 10 NTU. A value of less than 10 NTU indicates low turbidity [29].

3.5.8. pH

The pH value still meets the quality standards (6-9) (Table 10). Test results indicate a pH value of around 7, which indicates the optimum pH for river water. This pH value can support various life forms in the river.

3.6. Correlation between Vegetation Diversity and Water Quality

Statistical analysis reveals a significant interaction between understory vegetation diversity and average water quality parameters. The Pearson correlation test (Table 11) showed a strong negative correlation between the Diversity Index (H') and Total Phosphat (TP) ($r = -0.8917$, $p < 0.05$). This indicates that locations with higher understory diversity tend to have lower TP concentrations. The diversity of riparian vegetation can retain TP before it enters the river body.

3.7. Interaction of Land Use, Riparian Vegetation, and Water Quality

Land cover and use in the upper Ranoyapo Watershed are generally mixed forests and gardens with a land cover percentage of 86.07%, namely 9,247 Ha (37.13%) of forest and 12,186.25 Ha (48.94%) of mixed gardens. The riparian zone width of 0.8 m - 7.2 m is inhabited by various types of riparian vegetation. The water quality of the upper Ranoyapo River is classified as good because it still meets quality standards. Land use in the form of forests and mixed gardens has trees that can regulate water management.

Rainfall can infiltrate the soil, reducing surface runoff and current velocity, thus controlling riverbank erosion. Furthermore, natural vegetation can promote water purification [30]. Agricultural activity remains low, resulting in relatively low fertilizer use and low inputs into water bodies. However, distinct anthropogenic pressures still exist. Although settlement expansion and agricultural activities are present in the watershed, their impact on water quality remains mitigated. Our analysis suggests that the "mixed garden" land use type acts as an effective semi-natural buffer. Unlike intensive monoculture agriculture, which typically spikes nitrate levels, the mixed gardens in Ranoyapo (covering 48.94% of the area) maintain a complex root structure from understory species like *Paspalum conjugatum* and *Diplazium esculentum*. This explains why, despite anthropogenic pressure, parameters such as nitrate and phosphate remain below Class 2 quality standards. The interaction is evident: the functional diversity of the riparian understory effectively intercepts agricultural runoff before it reaches the main river body. The entry of pollutants into rivers can be controlled laterally by riparian vegetation, as riparian vegetation is closest to the river body.

Table 8. Total Phosphate Concentration in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	0.2	mg/L	0.027	0.050	0.050	0.040	0.023
August	0.2	mg/L	0.047	0.020	0.023	0.020	0.013
September	0.2	mg/L	0.023	0.020	0.017	0.033	0.011
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	0.2	mg/L	0.030	0.029	0.012	0.032	0.017
August	0.2	mg/L	0.040	0.023	0.020	0.027	0.033
September	0.2	mg/L	0.017	0.030	0.020	0.030	0.030

* Class 2, app VI

Table 9. Turbidity Values in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	-	NTU	0.023	0.083	0.067	0.180	0.083
August	-	NTU	0.093	0.107	0.047	0.120	0.070
September	-	NTU	0.087	0.120	0.073	0.143	0.130
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	-	NTU	0.233	0.267	0.333	0.367	0.367
August	-	NTU	0.167	0.160	0.167	0.233	0.267
September	-	NTU	0.233	0.267	0.933	0.433	0.433

* Class 2, app VI

Table 10. pH Values in the Upper Ranoyapo River in July – September 2025

Time	Requirement*	Unit	Stations				
			SRU 11	SRU 12	SRU 13	SRU 14	SRU 15
July	6-9	-	7.3	7.5	7.5	7.3	6.9
August	6-9	-	6.9	7.1	7.4	7.5	7.3
September	6-9	-	7.4	7.2	7.3	7.3	7.1
Time	Requirement*	Unit	SRU 21	SRU 22	SRU 23	SRU 24	SRU 25
July	6-9	-	7.9	7.9	7.6	7.8	7.6
August	6-9	-	7.5	7.6	7.4	7.5	7.5
September	6-9	-	7.5	7.5	7.6	7.7	7.3

* Class 2, app VI

Table 11. Pearson Correlation Matrix between Vegetation Index (H') and Water Quality Parameters

Parameters	Correlation (r)	Significance (p)
TDS	0.0069	0.9848
TSS	0.3127	0.379
Nitrite	-0.2436	0.4976
TN	0.0713	0.8448
TP	-0.8917	0.0005271*
Turbidity	0.1828	0.6131

*Note: Correlation is significant at the 0.05 level

The riparian zone closure consists of mixed gardens that allow for the presence of trees and understory vegetation such as grasses, herbs, and shrubs. The diversity of riparian understory vegetation is moderate, indicating a low impact from human activity. The water quality of the upper Ranoyapo River is affected by the riparian zone closure. The riparian understory vegetation can absorb fertilizer residues from agricultural activities.

4. Conclusions

Land cover and use in the upper Ranoyapo watershed are generally forest and mixed gardens, with a land cover percentage of 86.07%, consisting of 9,247 hectares (37.13%) of forest and 12,186.25 hectares (48.94%). Water quality in the upper Ranoyapo River is considered good, meeting quality standards. Land use, both forest and mixed gardens, includes trees that regulate water flow. Rainfall infiltrates the soil, reducing surface runoff and current velocity, thus controlling riverbank erosion. Agricultural activity remains low, resulting in relatively low fertilizer use and low inputs to the water body.

The riparian zone consists of mixed gardens, allowing for the presence of trees and understory vegetation such as grasses, herbs, and shrubs. The diversity of riparian understory vegetation is moderate, reflecting the diverse riparian understory vegetation in the Ranoyapo River riparian zone. The diversity of riparian vegetation tends to reduce total phosphate thus affecting river water quality. Water quality in the upper Ranoyapo River is influenced by riparian zone cover. Riparian understory vegetation can absorb fertilizer residues from agricultural activities.

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