Jurnal Kejuruteraan 38(1) 2026: 101-113
https://doi.org/10.17576/jkukm-2026-38(1)-10

Enhancing Percut Watershed Sustainability in North Sumatra: The Role of Monitoring and Evaluation

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Received 3 June 2025, Received in revised form 9 October 2025
Accepted 9 November 2025, Available online 30 January 2026

ABSTRACT

The Percut Watershed is vital in supporting the region's ecological and socio-economic systems. However, the watershed has been increasingly impacted by rapid urbanization, deforestation, pollution, and unregulated land use, leading to environmental degradation and decreased water quality. This study aims to assess the current state of the Percut Watershed and evaluate the effectiveness of ongoing management practices. The research utilizes a combination of water quality analysis, land-use mapping through Geographic Information Systems (GIS), and stakeholder engagement to monitor key environmental indicators. The research results show that the Percut Watershed has a restored classification where the total value of the watershed carrying capacity reaches 101.75 (including the "moderate" criteria). Criteria that need attention are critical land and flood vulnerability. The land parameters in the Percut Watershed are considered quite good, with the erosion index in the Percut Watershed also having a moderate value; this is because, apart from natural topographic factors, there is also a mismatch in land use with existing land capabilities. The condition of the water system in the Percut Watershed is considered quite good because the flow regime coefficient value is low, which indicates the land's ability to hold and store water is quite good high annual flow coefficient value. The use of regional space in the Percut Watershed is still good. Attention needs to be paid, especially to cultivated areas that are topographically less suitable for agricultural cultivation. Effective monitoring and evaluation are crucial for addressing these challenges and ensuring the sustainable management of the watershed.

Keywords: Percut Watershed; monitoring and evaluation; sustainable watershed management; environmental conservation; water quality

INTRODUCTION

Watershed management in Indonesia aims to coordinate, integrate, synchronise, synergise, and increase the carrying capacity of watershed areas. This is in accordance with Government Regulation of the Republic of Indonesia Number 37 of 2012 concerning Watershed Management. The process of watershed management involves planning, implementation, funding, monitoring, and evaluation. The first stage in developing Watershed planning is to gather data on watershed performance indicators related to the watershed.

Several studies on watershed management, employing various approaches in different regions, have emphasized the importance of sustainability in this field. Various studies on watershed management have highlighted the importance of sustainability in this field using different approaches across regions (Butt et al. 2015; Flotemersch et al. 2016; Lane et al. 2023; Miralles-Wilhelm et al. 2023; Narendra et al. 2021; Perdinan et al. 2024; Singh et al. 2023; Sulistyaningsih et al. 2021; Wanf et al. 2016). One of the watersheds in North Sumatra Province, Indonesia, which deserves attention because of its uniqueness is the Percut Watershed. The total area of the Percut Watershed is 37,251.44 Hectare (Ha). The Percut Watershed is classified as a watershed that needs to be restored to its carrying capacity. This watershed is in the Wampu Sei Ular Watershed Management Center, North Sumatra Province. The Percut Watershed management plan can be used as a guideline for all stakeholders in overcoming and resolving Percut Watershed management problems and, at the same time, preserving watershed functions in supporting the dynamics of life by involving all stakeholders to support sustainable development and sustainable watershed management, especially in North Sumatra Province.

One of the regional watersheds in North Sumatra Province is the Percut Watershed. This watershed plays a crucial role in preserving natural resources and the environment. Its strategic location makes it vulnerable to damage. Therefore, monitoring and evaluation of the Percut watershed is vital.

Watershed management is a multidimensional approach that aims to maintain the function of watershed ecosystems while supporting the socio-economic needs of the community. Previous research has shown that anthropogenic pressures (urbanisation, deforestation, and inappropriate land use) significantly threaten watershed sustainability (Lal, 2014). One key approach to watershed management is monitoring water quality. According to Yotova et al. (2021), analysing water quality parameters (pH and dissolved oxygen (DO), as well as pollutant concentrations) can help identify environmental pressures impacting watershed sustainability.

In an integrated watershed management program, a community-based approach involving stakeholders is crucial. These stakeholders include representatives from government agencies, academia, community leaders, industry, and the media, collectively known as the pentahelix. This is consistent with research conducted by Asdak & Munawir (2017), and Wang et al. (2016).

Previous studies have identified several significant issues, such as water pollution due to domestic waste and environmentally unfriendly agricultural activities (Machairiyah et al. 2020), watershed management. Environmental Monitoring and Assessment (Ogato et al. 2020), Impact of land conversion on watershed ecosystem services (Mengistu & Assefa, 2022) as well as about sustainable watershed management (Mengistu & Assefa, 2022). However, in the context of the Percut Watershed, comprehensive studies that combine water quality analysis, GIS, and stakeholder engagement to support sustainable watershed management still need to be completed (El Mouatassime et al. 2019). Therefore, this study aims to assess the current ecological conditions of the Percut Watershed and evaluate the effectiveness of ongoing management practices to support sustainable watershed management with the objectives of environmental conservation and community development.

METHODOLOGY

LOCATION AND AREA OF RESEARCH SITE

The area of Percut Watershed is 37,251.44 Ha and covers two regencies (Deliserdang Regency and Karo Regency) and Medan City. Most of the Percut Watershed area is in Deli Serdang Regency.

The geographical location of the Percut Watershed is at 3° 10’ 40.87’’ to 3° 46’ 20.77’’ (north latitude) and 98° 32’01.20’’ to 98° 48’ 02.88’’ (east longitude) (Fig. 1). The Percut Watershed, located in one city and two regencies, namely: Medan City, Deli Serdang Regency, and Karo Regency with the following boundaries, namely: in North is Deli Watershed, in South is Simai Mai and Petani Watersheds, in West is Bekala Watershed, and in East is Batang Kuis and Belumai Watersheds.

METHOD OF COLLECTING DATA

The data collected in this study comprises primary and secondary data based on Ministry of Forestry (2014). Primary data were collected through surveys at predetermined locations using purposive sampling. The monitoring and evaluation (Ministry of Forestry, 2014) of Percut Watershed to support sustainable watershed management in North Sumatra are carried out by collecting data related to land conditions and water management conditions. The parameters measured are described as follows:

LAND CONDITIONS

1. Critical Land: Critical land data was obtained from secondary data from the results of critical land identification carried out by the Ministry of Forestry/Directorate General of Watershed Management and Social Forestry/Watershed Management Center, results of a 2013 review.
2. Vegetation Cover: Permanent vegetation cover data is obtained from secondary data, which is the result of high-resolution imagery/land cover identification sourced from the Ministry of Forestry/ Geospatial Information Agency/ National Institute of Aeronautics and Space and other parties, according to their respective authorities. The permanent vegetation analysed consists of perennial plants, such as forests, shrubs, bushes, and gardens.
3. Erosion Index: This data represents actual erosion data obtained from erosion calculations using the Universal Soil Loss Equation (USLE) method. The permissible erosion value is calculated using standard criteria for soil damage on dry land based on Government Regulation No. 150 of 2000 concerning Control of Soil Damage for Biomass Production.

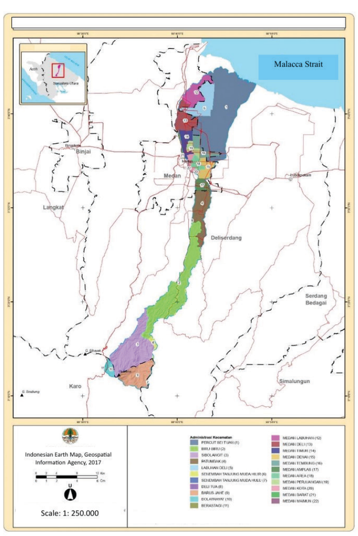

FIGURE 1. Map of research locations in the Percut Watershed

WATER SYSTEM CONDITIONS

1. The discharge data used is derived from predictions using the Manning formula and reconstruction of flooded cross-sections. Minimum data is obtained from direct measurements during the dry season.
2. Annual Flow Coefficient (AFC): AFC is obtained based on the flow thickness (Q), obtained from the discharge volume (Q, in m^3) observed in the watershed over a period of one year, or by dividing the calculated formula by the watershed area (ha or m^2) converted to mm. Annual rainfall thickness (P) is obtained from records at Rainfall Observation Stations (ROS) using Automatic Rainfall Recorders (ARR) and/or ombrometers.
3. Sediment Load: Obtained through an erosion prediction approach using the Sediment Delivery Ratio (SDR) formula.
4. Flood Data: This data is obtained from disaster reports from the Deli Serdang Regency Regional Disaster Management Agency and through direct observation.
5. Water Use Index: obtained using the annual per capita water availability by comparing the amount of water to the population.

DATA ANALYSIS

LAND CONDITIONS

1. Critical Land: Essential calculation of land area using the classification presented in Table 1. The calculation of the percentage of vegetation cover using value classification is presented in Table 2.
2. Erosion Index: The calculation of the permissible erosion value is based on the standard criteria for soil damage on dry land in accordance with Government Regulation No. 150 of 2000 concerning Control of Soil Damage for Biomass Production. The critical erosion threshold is calculated based on soil thickness (Table 3). Calculation of erosion index using value classification as stated in Table 4.

TABLE 1. Percentage of Critical Land Area Calculation in the Percut Watershed Based on Critical Land Weight, Value, and Classification

Sub Criteria	Weight	Parameter	Mark	Class	Score
Percentage of Critical Land (PCL)	20	Critical Land Area PCL = x100% watershed Area	PCL ≤ 5 5 < PCL ≤ 10 10 < PCL ≤ 15 15 < PCL ≤ 20 PLLK >20	Very low Low Medium High Very High	0.5 0.75 1 1.25 1.5

TABLE 2. Vegetation Cover Classification (Weights, Values, and score)

Sub Criteria	Weight	Parameter	Mark	Class	Score
Percentage of Vegetation Cover (PVC)	10	L V P PVC = x 100% Watershed Area	PVC > 80 60< PVC ≤ 80 40 < PVC ≤ 60 20 < PVC ≤ 40 PVC≤ 20	Very Good Good Average Bad Very Bad	0.5 0.75 1 1.25 1.5

TABLE 3. Critical Threshold of Erosion Based on Soil Thickness

Soil Thickness (Cm)	Critical Threshold of Erosion	
	ton/ha/year	mm/10 year
< 20	0.1<T≤1	0.2 <T≤1.3
20 - <50	1 < T ≤3	1.3 <T≤4
50 - <100	3 < T ≤7	4.0 <T≤9.0
100 – 150	7< T≤ 9	9.0<T≤12
>150	T >9	T>12

TABLE 4. Classification of Erosion Index Values

Sub Criteria	Weight	Parameter	Mark	Class	Score
Erosion Index (Ei)	10	Ei = Actual Erosion / Tolerable Erosion	Ei ≤ 0.5	Very Low	0.5
			0.5 < Ei ≤ 1.0	Low	0.75
			1.0 < Ei ≤ 1.5	Medium	1
			1.5 < Ei ≤ 2.0	High	1.25
			> 2.0	Very High	1.5

WATER SYSTEM CONDITIONS

1. The Flow Regime Coefficient (FRC) is the ratio of Qmax to Qmin, which is the absolute discharge (Q) from SPAS observations or formula calculations. For areas without river water during the dry season, the FRC value is the ratio of Qmax to Qa. Qmax is the absolute maximum discharge, and Qa is the primary discharge (Qa = 0.25 x monthly average Q). The FRC calculation using the value classification is presented in Table 5.
2. Annual Flow Coefficient (AFC) is the ratio between the thickness of the yearly flow (Q, mm) and the thickness of the annual rainfall (P, mm) in a River Basin (what percentage of rainfall becomes flow (runoff) in the watershed. To calculate the AFC, use the value classification presented in Table 6.
3. Sediment load is obtained based on an approach based on erosion prediction results. The formula used is:

$$SL = A \times SDR \quad (1)$$

where:
SL = sediment load (tons/ha/year)
A = erosion value (tons/ha/year)
SDR = sediment delivery ratio

The total erosion value is determined using the USLE formula. The SDR is calculated using the value classification (Table 7).

4. Flood frequency calculations use the value classification presented in Table 8.

TABLE 5. Classification Values of Flow Regime Coefficients based on Weight and Value

Sub Criteria	Weight	Parameter	Mark	Class	Score
Flow Regime Coefficient (FRC)	5	Wet Areas: FRC = Q max/ Q min	FRC ≤ 20	Very Low	0.5
			20< FRC ≤ 50	Low	0.75
			50 < FRC ≤ 80	Medium	1
			80 < FRC ≤ 110	High	1.25
			FRC > 110		1.5
		Dry Areas: FRC = Q max/Qa	FRC ≤ 5	Very High	0.5
			10 < FRC ≤ 15	Very Low	0.75
			15 < FRC ≤ 20	Medium	1
			FRC > 20	High	1.25

TABLE 6. Classification of Annual Flow Coefficients based on Sub-Criteria, Weights and Values

Sub Criteria	Weight	Parameter	Mark	Class	Score
Flow Regime Coefficient (AFC)	5	Wet Areas: AFC = Q max/ Q min	AFC ≤ 20	Very Low	0.5
			20< AFC ≤ 50	Low	0.75
			50 < AFC ≤ 80	Medium	1
		Dry Areas: AFC = Q max/Qa	80 < AFC ≤ 110	High	1.25
			AFC > 110	Very High	1.5
			AFC ≤ 5	Very High	0.5
			10 < AFC ≤ 15	Very Low	0.75
			15 < AFC ≤ 20	Medium	1
			AFC > 20	High	1.25

TABLE 7. Sediment Load Classification by Weight and Value

Sub Criteria	Weight	Parameter	Mark	Class	Score
SL	4	Qs = k x Cs x Q	SL ≤ 5	Very low	0.5
			5 < SL ≤ 10	Low	0.75
		SL = A x SDR	10 < SL ≤ 15	Medium	1
			15 < SL ≤ 20	High	1.25
			SL >20	Very high	1.5

TABLE 8. Flood Classification Class and Score

Sub Criteria	Weight	Parameter	Mark	Class	Score
Flood	2	Frequency of occurrence	Never	Very low	0.5
		Flood	1 time in 5 years	Low	0.75
			1 time in 2 years	Medium	1
			1 time per year	high	1.25
			More than 1 time in 1 year	Very high	1.5

5. The Water Utilisation Index (WUI) is an indicator for water management in watersheds. The WUI is crucial for mitigating annual droughts in the watershed. The water utilisation index in the Percut Watershed is calculated using a comparison method between water demand and water availability. The water utilisation index in the Percut Watershed is calculated using the following formula:

$$WUI = \frac{\text{water needs } (m^3)}{\text{water supply } (m^3)} \quad (2)$$

Description:
Water requirement (m^3) = the amount of water consumed for land use/needs during one year (annually) for example for agriculture, households, industry, etc. WUI calculations use value classifications as in Table 9.

TABLE 9. Weights and Values for Water Utilization Index Classification

Sub Criteria	Parameter	Mark	Class
Water Usage Index (WUI)	$WUI = \frac{\text{water needs } (m^3)}{\text{water supply } (m^3)}$	WUI ≤ 0.25	Very Low
		0.25 < WUI ≤ 0.50	Low
		0.50 < WUI ≤ 0.75	Medium
		0.75 < WUI ≤ 1.00	High
		WUI > 1.00	Very High

6. Water Quality: Water quality monitoring provides factual information on the current water quality status, past trends, and predictions of future environmental changes. Basic information generated from monitoring activities can serve as a reference for preparing environmental plans, evaluating and controlling ecological impacts, as well as for spatial planning, business or activity location permits, and determining water and wastewater quality standards. River water sampling in the Percut watershed was carried out at 6 locations with 10 test parameters, such as: pH, BOD, COD, TSS, TDS, DO, NH_4, NO_3, NO_2, and P_Total.

RESULTS AND DISCUSSION

CRITICAL LAND CONDITIONS

The critical land area in the Percut Watershed is approximately 6,602.78 ha (17.72% of the total area of the Percut Watershed), with categories of very critical, critical, somewhat critical and potentially critical (Table 10). The factors causing the large area of potential critical land in the Percut Watershed area come from land use, namely from dryland agriculture and plantations. The same thing also occurs in several other areas based on previous research (Butt et al. 2015; Narendra et al. 2021). The upstream part of the Watershed has a steep-very steep topography/slope with thin and rocky soil solum (Lane et al. 2023). Land cover in areas with critical conditions is dominated by plantations and some are also used as mixed agricultural land that is less suitable for the topographic conditions of the land in the upstream part. Land use for agriculture in the upstream part that does not pay attention to topographic aspects in land management can affect the high value of erosion and affect the condition of critical land. With a critical land percentage of 17.72% in the Percut Watershed, the essential conditions of land in the Percut Watershed are included in the high category with a score of 1.25 for calculating the watershed carrying capacity.

TABLE 10. Critical Land Values and Scores in the Percut Watershed

No	Critical Land Category	Area (Ha)	Watershed Area (Ha)	Critical Land Value	Score
1.	Very Critical	1,349.31	37,251.44	17.72	1.25
2.	Critical	5,253.48			
	Total	6,602.78			High

VEGETATION COVERAGE

Land cover conditions in the Percut Watershed vary widely. Plantations, settlements, and rice fields dominate land use in the Percut Watershed. Land cover data for the Percut Watershed was obtained through interpretation of Landsat ETM imagery from the 2020 coverage period, compiled with field observations at several selected locations. Land cover data in several watersheds in North Sumatra Province also show similar conditions (Rahmawaty et al. 2021; Rahmawaty et al. 2022). The interpretation results show that plantations are the dominant land cover with an area of 12,359.93 Ha, then followed by settlements with an area of 10,673.72 Ha, and rice fields with an area of 3,346.98 Ha (Table 11). However, the increasing area of shrub land cover, dry land agriculture and dry fields indicates that the current forest cover can change (be converted) to other uses.

TABLE 11. Land cover in the Percut Watershed

Watershed	Territoriality	Land Cover	Area (Ha)	%
Percut		Primary Dryland Forest	4,296.17	11.53%
		Secondary Dryland Forest	898.22	2.41%
		Settlements	29.86	0.08%
		Plantations	4,262.46	11.44%
		Dryland Farming	318.84	0.86%
		Mixed Dryland Farming	222.00	0.60%
		Rice Fields	246.00	0.66%
		Shrubs	807.46	2.17%
	Middle	Settlement	1,367.25	3.67%
		Plantation	4,319.42	11.60%
		Dryland Farming	22.50	0.06%
		Rice Fields	716.13	1.92%
	Downstream	Water Body	98.46	0.26%
		Swamp Thicket	64.96	0.17%
		Secondary Mangrove Forest	188.13	0.51%
		Settlements	9.276.61	24.90%
		Plantations	3.778.05	10.14%
		Dry Land Farming	1,899.14	5.10%
		Rice Fields	2,384.85	6.40%
		Fish Ponds	1,966.06	5.28%
		Open Land	88.88	0.24%

Source: Ministry of Environment and Forestry (2020).

Based on the technical guidelines for Watershed Performance Monitoring and Evaluation (Regulation No. 61 of 2014), permanent vegetation cover includes forests, shrubs, and plantations. The area of vegetated land in the Percut Watershed reaches 18,550.05 Ha (49.80% of the watershed area). Based on its vegetation cover parameters, the Percut Watershed is in the moderate category with a score of 1 for calculating the percentage of watershed vegetation cover area (Table 12).

EROSION INDEX

Erosion is the process of transporting topsoil that has a pretty good level of soil fertility, so that erosion can affect soil productivity (Asdak, 2017). Erosion can be calculated using the USLE formula. This formula takes into account several factors, including erosion, soil erodibility, slope gradient, land cover, and conservation measures (Asdak, 2017; Narendra et al. 2021). The watershed plays a crucial role in human life because it is where many human activities occur. The magnitude of erosion in the Percut watershed varies from very light to very high. Erosion with a very light class covers a total area of approximately 24,568.92 ha. The light class is approximately 2,402.31 ha. The moderate class is approximately 1,877.52 ha. The high class is approximately 7,821.85 ha, and the very high class is approximately 580.84 ha (Tables 13 and 14).

TABLE 12. Area of vegetation cover in the Percut Watershed

No	Type of Land Use	Area (Ha)	Watershed Area (Ha)	Vegetation Cover (%)	Score
1.	Primary dryland forest	4,296.17			
2.	Secondary dryland forest	898.22	37,251.44	49.80	1
3.	Secondary mangrove forest	188.13			
4.	Plantation	12,359.93			
5.	Shrubs	807.46			
	Total	18,550.05			Moderate

TABLE 13. Erosion level in the Percut Watershed

Area	Erosion Value	Class	Area (Ha)	%
Upstream	<=15	Very Low	571.40	1.53%
	>15-60	Low	1,219.26	3.27%
	>60-180	Medium	1,208.91	3.25%
	>180-480	High	7,577.60	20.34%
	>480	Very High	503.84	1.35%
Middle	<=15	Very Low	4,252.39	11.42%
	>15-60	Low	1,183.05	3.18%
	>60-180	Medium	668.61	1.79%
	>180-480	High	244.25	0.66%
	>480	Very High	77.00	0.21%
Downstream	<=15	Very Low	19,745.13	53.01%
Total			37,251.44	

TABLE 14. Erosion Index Values and Scores in Percut Watershed

No.	Parameter	Erosion Value (Ton/Ha/Year)	Erosion Index	Score
1.	Actual erosion based on USLE	29.97	1.39	1
2.	Erosion of tolerance	21.50		Moderate

Land erosion monitoring was conducted using the erosion index value in the Percut watershed, which is the ratio between actual erosion and permitted erosion. The calculation results showed that the erosion index was approximately 1.39, categorising it as moderate with a score of 1.

WATER SYSTEM CONDITIONS

FLOW REGIME COEFFICIENT (FRC)

In this study, it is essential to calculate the magnitude of river discharge over time. Likewise, river discharge must be closely monitored. Monitoring by measuring the highest (maximum) discharge is carried out during the rainy season, and at the lowest (minimum) discharge during the dry season. The FRC value is the ratio between the Qmax and Qmin values, which are the absolute discharge (Q) from SPAS observations. The calculation formula is presented in Table 15.

The FRC value obtained is categorised as low, with a value of 5.65 and a score of 0.75. From these figures, it can be concluded that the Percut Watershed shows a small range of runoff values during the rainy season. Conversely, during the dry season, the water discharge is quite large. This condition indicates that the land absorption capacity in the Percut Watershed is sufficiently capable of retaining and storing rainwater, and most of the runoff does not enter the river, but is instead discharged into the sea (Khomsiati et al. 2021). Based on the findings, it can be concluded that water availability in the Percut Watershed during the dry season is still quite adequate. This condition should be closely monitored in the future to prevent water shortages during the dry season.

ANNUAL FLOW COEFFICIENT

The annual flow coefficient (AFC) is the ratio of yearly runoff to annual rainfall in a watershed. The monthly water balance calculation method was used to calculate the AFC in the Percut watershed. The computed data showed a score of 1.25 (high category). The values and scores for the Percut watershed are presented in Table 16.

TABLE 15. Value and Scores of the Percut Watershed Flow Regime Coefficient

No	Measurement Location	Qmin (M^3/Sec)	Qmax (M^3/Sec)	Frc	Score
1.	Percut Tembung	12.85	72.60	5.65	0.75

Source: Sumatra River Basin Center II North Sumatra Province (2023)

TABLE 16. Values and Scores of the Annual Flow Coefficient of the Percut Watershed

Parameter	Total
Rainfall (mm)	3,365.4
Run-off (mm)	1,600
AFC	0.48
Score	1.25

SEDIMENT LOAD

One crucial aspect to understand in this study is the sediment conditions occurring in the Pertcut Watershed. By understanding the sediment, the amount of soil material in the form of mud carried by the river flow due to the upstream erosion process, which is then deposited somewhere downstream, can be determined by considering the sedimentation rate of suspended particles, which is lower than the transport rate (Asdak, 2017). During this sedimentation process, only a portion of the sediment carried by the river flow is transported out of the river (Riyanto et al. 2020). Meanwhile, the rest settle at specific locations along the river's flow during its journey.

Sediment load is calculated using the USLE erosion approach multiplied by the sediment conductivity value. Sedimentation in the Percut watershed also occurs primarily in flat river channels. In addition to sedimentation in the form of gravel, sand, and soil, rock fragments, tree trunks and branches, bamboo clumps, and remains of buildings and household utensils were also found. Sedimentation in the form of soil, sand, and gravel is generally found in almost all river channels, especially during low tide. Meanwhile, fragments of rocks, tree trunks and branches, bamboo clumps, building remains, and household equipment can be found in several areas that have experienced landslides or flash floods. Sediment in the form of soil and fine sand deposits is generally found in the downstream regions of watersheds or river estuaries.

In this study, sediment load calculations were performed using an erosion value approach. The sediment load was then multiplied by the sediment conductivity (SDR) value. The sediment conductivity value for the Percut Watershed, covering an area of 37,251.44 Ha (at the outlet measured to determine the minimum discharge), was 11.5%. According to the calculation results, the sediment load in the Percut Watershed was 3.45 tons/ha/year. Based on the obtained value, it can be stated that the Percut Watershed falls into the very low category, with a score of 0.5 for the calculation of the Watershed Carrying Capacity (Table 17). To increase the carrying capacity of the Percut Watershed, efforts focused on soil and water conservation, community empowerment and participation, and control of land cover changes are necessary.

FLOOD

Flooding is generally defined as a high river water discharge or a water discharge in a river that is relatively greater than normal due to continuous rainfall upstream or in a specific location, so that the water cannot be accommodated by the existing river channel, causing the water to overflow and inundate the surrounding area. Based on data from the Deli Serdang Regency Regional Disaster Management Agency, in 2021, there were two floods in the Percut Watershed (specifically in Percut Sei Tuan Sub-district and Babalan Sub-district in 2022). Meanwhile, floods in 2023 occurred twice in Percut Sei Tuan, Patumbak, and Biru-Biru Sub-districts (Table 18).

TABLE 17. Sediment Load Value and Score of the Percut Watershed

Description	Unit	Mark
Watershed area	Ha	37,251.44
Erosion	Ton/ha/year	29.97
SDR	%	11.5
Sediment	Ton/ha/year	3.45
Score		0.5

TABLE 18. Flood Occurrence in Percut Watershed

No	Year	Number of Occurrences	Types of Floods	Category	Score
1.	2021	2	Flood Inundation	Very high	1.5
2.	2022	2	Flood Inundation	Very high	1.5
3.	2023	4	Flood Inundation	Very high	1.5

WATER USAGE INDEX

The water demand in the Percut Watershed is approximately 12,399,800 m³ (primarily for agriculture and households), and the water availability in the Percut Watershed is approximately 16,084,000 m³. From the calculation results, the Water Use Index (WUI) value is 0.77 (high category) with a score of 1.25 (Table 19).

The Water Use Index (WUI) is defined as the ratio between water demand and water availability in a watershed. Water use monitoring is conducted to determine the amount of water demand compared to the quantity of water available in the Percut Watershed. A watershed is considered good if the amount of water used in the watershed is still below its potential, so that the watershed still produces water for downstream areas.

Conversely, it is considered poor if the volume of water used is greater than its potential, resulting in little or no water produced by the watershed for downstream areas.

A high WUI value can indicate the risk of future water shortages without proper management (Yang & Chen, 2023). Sustainable water management strategies are crucial to ensuring the sustainability of water resources, according to Bhattarai & Parajuli (2023). Sustainable water management planning needs to be improved to maintain ecosystem balance and ensure adequate water availability (Li et al. 2022).

WATER QUALITY

The results of the Percut Watershed water quality testing can be seen in Table 20.

TABLE 19. Water use index in Percut Watershed

No	Water Needs (M³/ Year)	Water Supply (M³/ Year)	WUI	Category
1.	12,399,800	16,084,000	0.77	high

Source: Sumatra Watershed Center II (2023)

TABLE 20. Results of Surface Water Quality Testing (River Water) in the Percut Watershed

SAMPLE LOCATION	PARAMETER[1)]									
	pH	BOD	COD	TSS	TDS	DO	NH_4	NO_3	NO_2	P-total
		mg/Ltr								
Sibiru-biru Village	7.75 (A)	1.4 (a)	1.20 (a)	25 (a)	133 (A)	7.61 (c)	0.023 (A)	0.40 (A)	0.003 (A)	0.583 (e)
Patumbak Village	7.75 (A)	1.4 (a)	5.00 (a)	45 (b)	63 (A)	7.49 (c)	0.039 (A)	0.44 (A)	0.019 (A)	0.666 (e)
Lantasan Village	7.63 (A)	1.1 (a)	2.90 (a)	35 (b)	50 (A)	4.95 (c)	0.033 (A)	0.62 (A)	0.153 (A)	0.771 (e)
Amplas Village	7.05 (A)	4.2 (a)	2.75 (a)	55 (b)	167 (A)	1.25 (d)	0.018 (A)	0.38 (A)	0.029 (A)	0.821 (e)
Tembung Village	7.14 (A)	1.9 (a)	1.70 (a)	105 (b)	150 (A)	4.39 (c)	0.040 (A)	1.68 (A)	0.928 (A)	1.046 (e)
Sampali Village	7.58 (A)	2.9 (a)	18.80 (a)	85 (b)	167 (A)	0.72 (d)	0.025 (A)	0.72 (A)	0.002 (A)	1.613 (e)

Description:

Analysis results conducted at the PT. Socfin Indonesia Laboratory.

(A) Safe values/contents; (a) exceed the maximum limits required by the Regulation of the Minister of Health of the Republic of Indonesia Number:

492/*Menkes/Per*/IV/2010 concerning Drinking Water Quality Requirements.
(B) Safe values/contents; (b) exceed the maximum limits required by the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number: P.68/Menlhk-Setjen/2016 concerning Domestic Waste Water Quality Standards.
(c) Above the minimum threshold required by the Regulation of the Minister of Health of the Republic of Indonesia Number: 2 of 2023 concerning Environmental Health Implementation Regulations.
(d) and (e) Above the maximum threshold permitted by the Regulation of the Minister of Health of the Republic of Indonesia Number: 2 of 2023.

River water quality in the Percut Watershed indicates mild pollution. Various parameters (pH, TDS, NO_3, NO_2, and NH_4) indicate conditions that meet the drinking water quality standards required by the Minister of Health Regulation No. 492/*Menkes/PER*/IV/2010. However, TSS, DO, and P-total parameters exceed the maximum limits stipulated in the Regulation Number 2 (2023) as mention before. Therefore, water quality monitoring and supervision are essential for determining appropriate pollution management and control strategies to maintain the water quality status of the Percut Watershed according to its intended use. River water quality data also reflect the importance of monitoring and management to prevent pollution. Conservation and monitoring efforts need to be increased to maintain adequate water quality (Chaminé & Gómez-Gesteira, 2019). Continuous monitoring is necessary to determine best practices in water management (Faksomboon, 2022).

CONCLUSION

Based on several land parameters in the Percut Watershed, it can be assessed as quite good, with an erosion index that also has a moderate value. This is due to the natural topography and the mismatch between land use and existing land capacity. Water management in the Percut Watershed is considered quite good, due to the low Flow Regime Coefficient, which indicates the land's ability to retain and store water. Meanwhile, the high Annual Flow Coefficient is due to the presence of water structures in the Percut Watershed that can store water for periodic distribution.

ACKNOWLEDGEMENT

We would like to thank USU for financial support through research grant Number: 13388/UN5.1.R//PPM//2023. dated August 28. 2023. Thank to Wampu Sei Ular Watershed Management Center. Ministry of Environment and Forestry. Medan. North Sumatra. Indonesia and North Sumatra provincial planning. research and development agency. Medan. North Sumatra. Indonesia for providing support and facilitating activities in the field.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Asdak, C. & M. Munawir. 2017. Integrated water resources conservation management for a sustainable food security. *KnE Life Sciences* 2(6). https://doi.org/10.18502/kls.v2i6.1045

Bauer, M., B. Jáchymová, J. Krása, K. Bynum, J. S. Schwartz & T. Dostál. 2024. Sustainable watershed management: Assessing the impact of data precision on sediment transport in the Oostanaula Creek Watershed, Tennessee. *Sustainability (Switzerland)* 16(6). https://doi.org/10.3390/su16062332

Bhattarai, S. & P. B. Parajuli. 2023. Best management practices affect water quality in coastal watersheds. *Sustainability (Switzerland)* 15(5). https://doi.org/10.3390/su15054045

Butt, A., R. Shabbir, S. S. Ahmad & N. Aziz. 2015. Land use change mapping and analysis using remote sensing and GIS: A case study of Simly Watershed, Islamabad, Pakistan. *Egyptian Journal of Remote Sensing and Space Science* 18(2). https://doi.org/10.1016/j.ejrs.2015.07.003

Cai, Y. & L. Zhang. 2018. Editorial: Multi-scale ecological indicators for supporting sustainable watershed management. *Ecological Indicators* 92. https://doi.org/10.1016/j.ecolind.2018.05.079

Chaminé, H. I. & M. Gómez-Gesteira. 2019. Sustainable resource management: Water practice issues. *Sustainable Water Resources Management* 5(1).

Cruz, R. V. O. 1999. Integrated land use planning and sustainable watershed management. *Journal of Philippine Development* 26(47).

Davenport, M. A. & E. Seekamp. 2013. A multilevel community capacity model for sustainable watershed management. *Society and Natural Resources* 26(9).

El Mouatassime, S. et al. 2019. Modelling of soil erosion processes and runoff for sustainable watershed management: Case study Oued El Abid Watershed, Morocco. *Agriculture and Forestry* 65(4). https://doi.org/10.17707/AgricultForest.65.4.22

Flotemersch, J. E., S. G. Leibowitz, R. A. Hill, J. L. Stoddard, M. C. Thoms & R. E. Tharme. 2016. A watershed integrity definition and assessment approach to support strategic management of watersheds. *River Research and Applications* 32(7). https://doi.org/10.1002/rra.2978

Faksomboon, B. 2022. Development of a hydrodynamic model for regulating water drainage of reservoir and water resources management. Lamtakong Watershed of Thailand. *Nakhara: Journal of Environmental Design and Planning. 21*(3).https://doi.org/10.1080/08941920.2012.729650

Khan, H. F., Y. C. E. Yang, H. Xie & C. Ringler. 2017. A coupled modeling framework for sustainable watershed management in transboundary river basins. *Hydrology and Earth System Sciences* 21(12). https://doi.org/10.5194/hess-21-6275-2017

Khomsiati, N. L., N. Suryoputro, A. Yulistyorini, G. Idfi & N. E. B. Alias. 2021. The effect of forest area change in tropical islands towards baseflow and streamflow. *IOP Conference Series: Earth and Environmental Science* 847(1): 012032. https://doi.org/10.1088/1755-1315/847/1/012032

Lal, R. 2014. Soil conservation and ecosystem services. *International Soil and Water Conservation Research* 2(3). https://doi.org/10.1016/S2095-6339(15)30021-6

Lane, C. R., I. F. Creed, H. E. Golden et al. 2023. Vulnerable waters are essential to watershed resilience. *Ecosystems* 26(1). https://doi.org/10.1007/s10021-021-00737-2

Li, P., D. Wang, W. Li & L. Liu. 2022. Sustainable water resources development and management in large river basins: An introduction. *Environmental Earth Sciences* 81(6).

Machairiyah, Z. Nasution & B. Slamet. 2020. Study of river water quality in various land cover of Percut Watershed at Deli Serdang Regency. *IOP Conference Series: Earth and Environmental Science* 454(1): 012085. https://doi.org/10.1088/1755-1315/454/1/012085

Mengistu, F. & E. Assefa. 2022. Local perception of watershed degradation in the upper Gibe Basin, southwest Ethiopia: Implications to sustainable watershed management strategies. *International Journal of River Basin Management* 20(2). https://doi.org/10.1080/15715124.2020.1870990

Ministry of Forestry. 2014. *Regulation of Minister of Forestry Number P.61 2014 concerning Monitoring and Evaluation of Watershed Management.* Ministry of Forestry. https://jdih.menlhk.go.id/kiosk/files/P.61%20(3).pdf

Miralles-Wilhelm. F., Matthews. J. H., Karres. N., Abell. R., Dalton. J., Kang. S. T., Liu. J., Maendly. R., Matthews. N., McDonald. R., Muñoz-Castillo. R., Ochoa-Tocachi. B. F., Pradhan. N., Rodriguez. D., Vigerstøl. K., & van Wesenbeeck, B. 2023. Emerging themes and future directions in watershed resilience research. *Water Security* 18. https://doi.org/10.1016/j.wasec.2022.100132

Narendra. B. H., Siregar. C. A., Dharmawan. I. W. S., Sukmana. A., Pratiwi. Pramono. I. B., Basuki. T. M., Nugroho. H. Y. S. H., Supangat. A. B., Purwanto. Setiawan. O., Nandini. R., Ulya. N. A., Arifanti. V. B., & Yuwati, T. W. 2021. A review on sustainability of watershed management in Indonesia. *Sustainability (Switzerland)* 13(19). https://doi.org/10.3390/su131911125

Ogato, G. S., A. Bantider, K. Abebe & D. Geneletti. 2020. Geographic information system (GIS)-based multicriteria analysis of flooding hazard and risk in Ambo Town and its watershed, West Shoa Zone, Oromia Regional State, Ethiopia. *Journal of Hydrology: Regional Studies* 27. https://doi.org/10.1016/j.ejrh.2019.100659

Pathak, S. S. & S. Batalia. 2022. Sustainable watershed management. https://doi.org/10.4018/978-1-7998-8434-7.ch012

Perdinan Tjahjono, R. E. P., Infrawan, D. Y. D., Aprilia, S., Adi, R. F., Basit, R. A., Wibowo, A., Kardono. & Wijanarko, K. 2024. Translation of international frameworks and national policies on climate change, land degradation, and biodiversity to develop integrated risk assessment for watershed management in Indonesia. *Watershed Ecology and the Environment* 6. https://doi.org/10.1016/j.wsee.2023.10.001

Rahmawaty, A. Rauf, M. M. Harahap & H. Kurniawan. 2022. Land cover change impact analysis: An integration of remote sensing, GIS and DPSIR framework to deal with degraded land in Lepan Watershed, North Sumatra, Indonesia. *Biodiversitas* 23(6): 3000–3011. https://doi.org/10.13057/biodiv/d230627

Rahmawaty, M. M. Harahap, H. Kurniawan & A. Rauf. 2021. Land use changes monitoring over a period of ten years in Panjang Island, Pangkalan Susu, Langkat, North Sumatra. *IOP Conference Series: Earth and Environmental Science* 782(3): 032008. https://doi.org/10.1088/1755-1315/782/3/032008

Riyanto, R. B., T. Hardono & A. Sentani. 2020. Determination mining zone of non-metal mineral and rock based on sediment inflow and outflow in the Bodri River, Kendal Regency. *Pondasi* 23(2). https://doi.org/10.30659/pondasi.v23i2.11210

Rodriguez, B. C. et al. 2024. Drivers and impacts of land use and land cover changes on ecosystem services provided by the watersheds in the Philippines: A systematic literature review. *International Forestry Review* 25(4). https://doi.org/10.1505/146554823838028201

Sudriani, Y., V. Sebestyen & J. Abonyi. 2023. Surface water monitoring systems: The importance of integrating information sources for sustainable watershed management. *IEEE Access* 11. https://doi.org/10.1109/ACCESS.2023.3263802

Singh, M. C., S. Satpute & V. Prasad. 2023. Remote sensing and GIS-based watershed prioritization for land and water conservation planning and management. *Water Science and Technology* 88(1). https://doi.org/10.2166/wst.2023.207

Sulistyaningsih, T., A. Nurmandi, M. Kamil et al. 2021. Formulating sustainable watershed governance model: A meta-analysis of watershed governance. *Academic Journal of Interdisciplinary Studies* 10(2). https://doi.org/10.36941/ajis-2021-0041

Suwarno, J., H. Kartodiharjo, B. Pramudya & S. Rachman. 2011. Policy development of sustainable watershed management of Upper Ciliwung, Bogor Regency. *Jurnal Analisis Kebijakan Kehutanan* 8(2).

Wang, G., S. Mang, H. Cai et al. 2016. Integrated watershed management: Evolution, development and emerging trends. *Journal of Forestry Research* 27(5). https://doi.org/10.1007/s11676-016-0293-3

Yang, X. & Z. Chen. 2023. A hybrid approach based on Monte Carlo simulation–VIKOR method for water quality assessment. *Ecological Indicators* 150. https://doi.org/10.1016/j.ecolind.2023.110202

Yotova, G., M. Varbanov, E. Tcherkezova & S. Tsakovski. 2021. Water quality assessment of a river catchment by the composite water quality index and self-organizing maps. *Ecological Indicators* 120. https://doi.org/10.1016/j.ecolind.2020.106872