
UTILIZATION OF SENTINEL-2 IMAGERY FOR WATER QUALITY ANALYSIS: A CASE STUDY OF SAGULING RESERVOIR

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Abstract

Water resources are essential for human life and are one of the main indicators of regional development success. Saguling Reservoir is one of the reservoirs located in West Java that plays a crucial role in various aspects of the lives of the surrounding community. This study aims to determine the distribution of Total Suspended Solids in Saguling Reservoir and to assess turbidity levels using the Normalized Difference Turbidity Index. This study utilizes the Total Suspended Solids (TSS) model by Huizeng Liu using Sentinel-2 imagery data. Based on the research findings, Saguling Reservoir has three classes of Total Suspended Solids (TSS): low (902.91 hectares), moderate (1830.47 hectares), and high (592.78 hectares). Meanwhile, the turbidity levels in Saguling Reservoir are very low (212.84 hectares), moderate (2649.94 hectares), and high (457 hectares).

Keywords: *Saguling Reservoir, Total Suspended Solids (TSS), Normalized Difference Turbidity Index (NDTI), Sentinel-2 imagery.*

1. Introduction

Water resources are crucial for human life and serve as a key indicator of regional development success. The dynamics of population growth and the accelerating rate of development have heightened the demand for water resources, including surface water (such

as lakes, reservoirs, and rivers), groundwater, and rainfall. Thus, achieving high-quality water resources, both in terms of quality and quantity, is an essential and inseparable component of development goals that must be continuously pursued.

Sustainable water resources have become a target within the Sustainable Development Goals (SDGs), specifically under Goal 6: "Clean Water and Sanitation." Target 6.6 of the SDGs states, "By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, groundwater, and lakes." Access to high-quality water resources supports the development of human resources. The SDGs help align development objectives with various targets to enhance the quality of life globally, for both current and future generations, by promoting the effective and efficient use of natural resources (Munir, 2023).

Saguling Reservoir is one of the reservoirs located in West Java that plays a crucial role in various aspects of people's lives. Saguling Reservoir is utilized as a hydroelectric power plant. This reservoir is also used to meet the water needs of the surrounding community, such as irrigation, the Perusahaan Daerah Air Minum (PDAM), and daily needs. Given its multifaceted role, the consistent monitoring of water quality is essential to ensure its suitability for various purposes and to protect the ecosystem. One of the methods to do this is by analyzing the distribution of Total Suspended Solids (TSS) and Normalized Difference Turbidity Index (NDTI).

The distribution of Total Suspended Solids (TSS) in a region is typically determined through field sampling followed by laboratory analysis. However, this method is often ineffective and inefficient due to its time-consuming nature, high costs, and limitations in terms of time and spatial coverage. To address these challenges, various remote sensing methods have been developed to observe TSS more effectively (Wirasatriya et al., 2023).

Turbidity in aquatic environments is fundamentally a factor that can influence the dynamics of underwater topography across varying depths, such as meandering river channels, gullies, levees, and can also affect the structure of sediment layering (Nasr-Azadani & Meiburg, 2014).

At present, many satellites with sufficiently high spatial resolution are being utilized in water quality monitoring studies. For example, the ratio between band 5 and band 4 from Sentinel 2A multispectral imagery has proven to provide an accurate estimation of chlorophyll-a and suspended sediments in water (Nguyen et al., 2020).

This study provides a comprehensive overview of the use of Sentinel satellites in monitoring inland waters. The Sentinel satellites discussed include Sentinel-1A/B, Sentinel-2A/B, and Sentinel-3A/B. Inland waters are surface water bodies on land, excluding oceans, such as lakes, reservoirs, rivers and ponds.

2. Materials and method

2.1 Research Location

This research was conducted at Saguling Reservoir. Saguling Reservoir is located in West Bandung Regency, West Java Province at an altitude of 643 m above sea level precisely at 6°54'45"S - 107°21'58"E. This reservoir is one of three reservoirs that stem the flow of the Citarum River, which is the largest river in West Java. The reservoir's inundation area is about 5,606 hectares with an initial storage volume of 875 million m^3 of water.

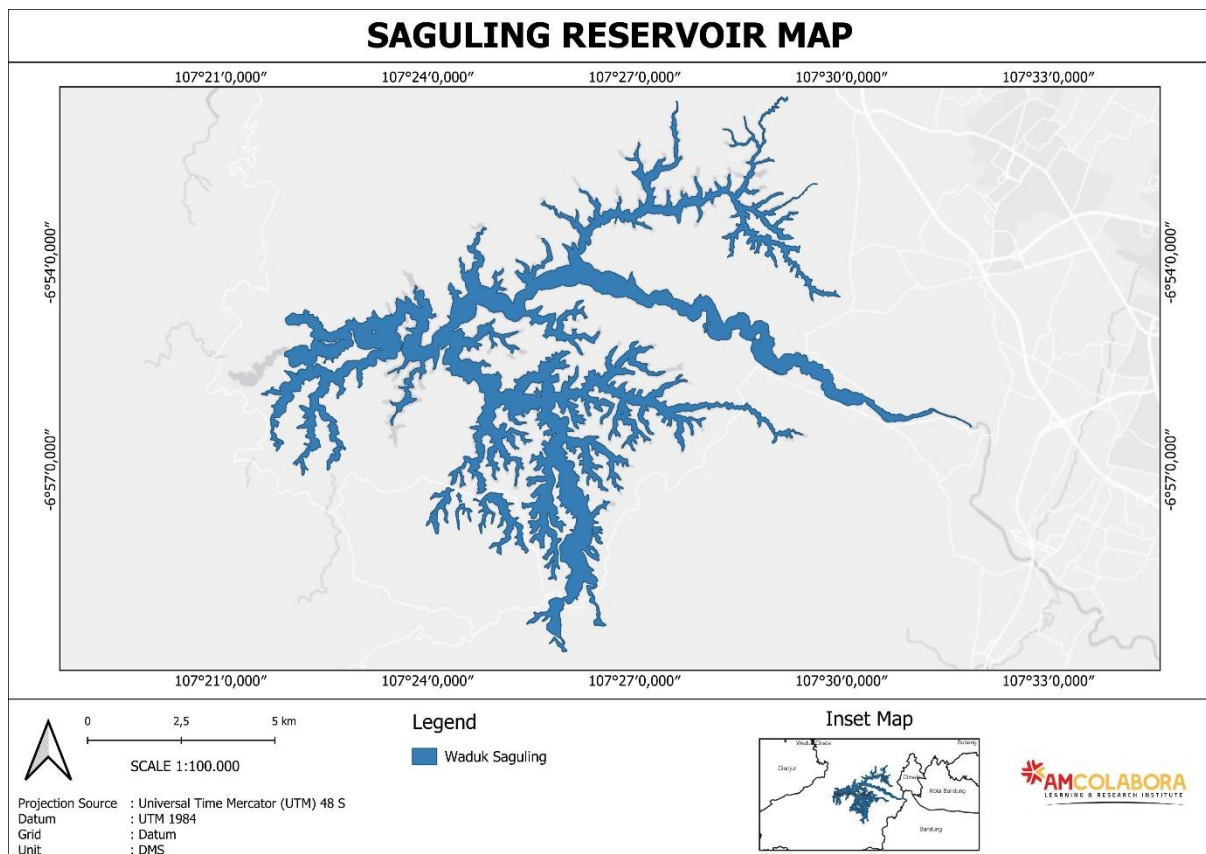


Figure 1. Saguling Reservoir Map

2.2 Tools and Materials

This research used several tools for data processing and materials consisting of imagery and spatial data. The tools and materials used are presented in Table 1 and Table 2. All available data were used in mapping TSS in Saguling reservoir.

Table 1. Tools used in the research

Instrument Name	Function
QGIS 3.34	Spatial data processing and map creation
Microsoft Excel	Processing results in the form of area

Tabel 2. Data used in the research

Data	Source
Shapefile of Saguling Reservoir	GADM
Total Suspended Solids	Sentinel-2
Normalized Difference Turbidity Index (NDTI)	Sentinel-2

2.3 Data Processing and Analysis Phases

2.3.1 Sentinel 2 MSI Atmospheric Correction

The Sentinel 2 MSI features a 290 km field of view and offers 12-bit radiometric quantization. It includes 13 spectral bands that cover the visible, near infrared, and SWIR regions. The spatial resolution varies with four bands at 10 meters, six bands at 20 meters, and three bands at 60 meters (Drusch et al., 2012).

Sentinel 2 MSI L1C product provides the top of atmosphere reflectance (ρ_{TOA}), which is assumed to be the sum of Rayleigh reflectance (ρ_r), aerosol reflectance (ρ_a) and water-leaving reflectance (ρ_w):

$$\rho_{TOA} = \rho_r + \rho_a + t \cdot \rho_w$$

where t is the two-way diffuse atmospheric transmittance.

The reflectance due to Rayleigh scattering was calculated using the 6S radiative transfer code. For each spectral band, the diffuse atmospheric transmission (t) was also determined. Mid-latitude summer atmospheric conditions were applied, and average values of the solar

zenith and azimuth angles as well as sensor zenith and azimuth angles across the entire granule were computed to account for the sun-sensor geometry. Cloud and land screening was performed using a threshold on reflectance centered at 1610 nm. Pixels were categorized as non-water if the Rayleigh-corrected reflectance ($\rho_c = \rho_{TOA} - \rho_r$) of band B11 exceeded 0.0215 (Vanhellemont & Ruddick, 2015).

2.3.2 Total Suspended Solid Algorithm

Huizeng Liu modeled Total Suspended Solids (TSS) using Sentinel-2 imagery data from Lake Poyang. The research involved the development of nine algorithms utilizing bands 1 through 8a. The results indicated that band 7 (Visible and Near Infrared/VNIR) produced the highest accuracy, with a coefficient of determination of 0.93, surpassing the other bands (Liu et al., 2017). The following presents Liu's 2017 algorithm:

$$TSS \left(\frac{mg}{L}\right) = 2950 \times \lambda_{71,357}$$

where: λ_7 is reflectance band 7

2.3.3 Normalized Difference Turbidity Index (NDTI)

NDTI was initially designed to characterize water turbidity. It increases as water bodies become turbid and exhibit spectral reflectance similar to bare soil, thereby demonstrating a negative association with the presence of water. The NDTI is calculated using the digital counts of the red and green bands of the electromagnetic spectrum as follows:

$$NDTI = \frac{(RED - GREEN)}{(RED + GREEN)}$$

By applying this NDTI model to imagery in QGIS software, a turbidity cover map was generated and simplified for presentation. Low, moderate, and high turbidity values were assigned to the image and subsequently converted into a GIS environment. This turbidity map encodes each turbidity category with a unique pixel value (Mondal & Bandyopadhyay, 2014).

2.3.3 Classification

The classification of TSS based on concentration in water is divided into three categories. A TSS concentration ranging from 0 to 40 mg/l is categorized as low, indicating minimal turbidity and good water quality. The medium category includes TSS concentrations between 40.1 and 80 mg/l, which suggests increased turbidity and potential impacts on aquatic ecosystems. Meanwhile, high TSS concentrations, ranging from 80.1 to 120 mg/l, indicate significant turbidity levels that can have negative effects on aquatic organisms and result in an overall decline in water quality.

Table 3. TSS Rank Values

TSS Concentration (mg/l)	Class
0 – 40	Low
40,1 – 80	Medium
80,1 – 120	High

Source : (Pangihutan Sinaga et al., 2022)

The classification of NDTI illustrates the turbidity levels of water. NDTI value ranging from 0.028 to 0.0078 indicates very low turbidity, where the water is clear with minimal suspended particles; a value between 0.0078 and 0.35 represents moderate turbidity, where the water begins to show signs of cloudiness; and a value from 0.35 to 0.10 signifies high turbidity, where the water is highly turbid, as shown in Table 4.

Table 4. NDTI Rank Values

NDTI Value	Class
0.028 to 0.078	Very low turbidity
0.078 to 0.35	Moderate turbidity
0.35 to 0.10	Represent high turbidity

Source: (Mondal & Bandyopadhyay, 2014)

The research flowchart is presented in Figure 2.

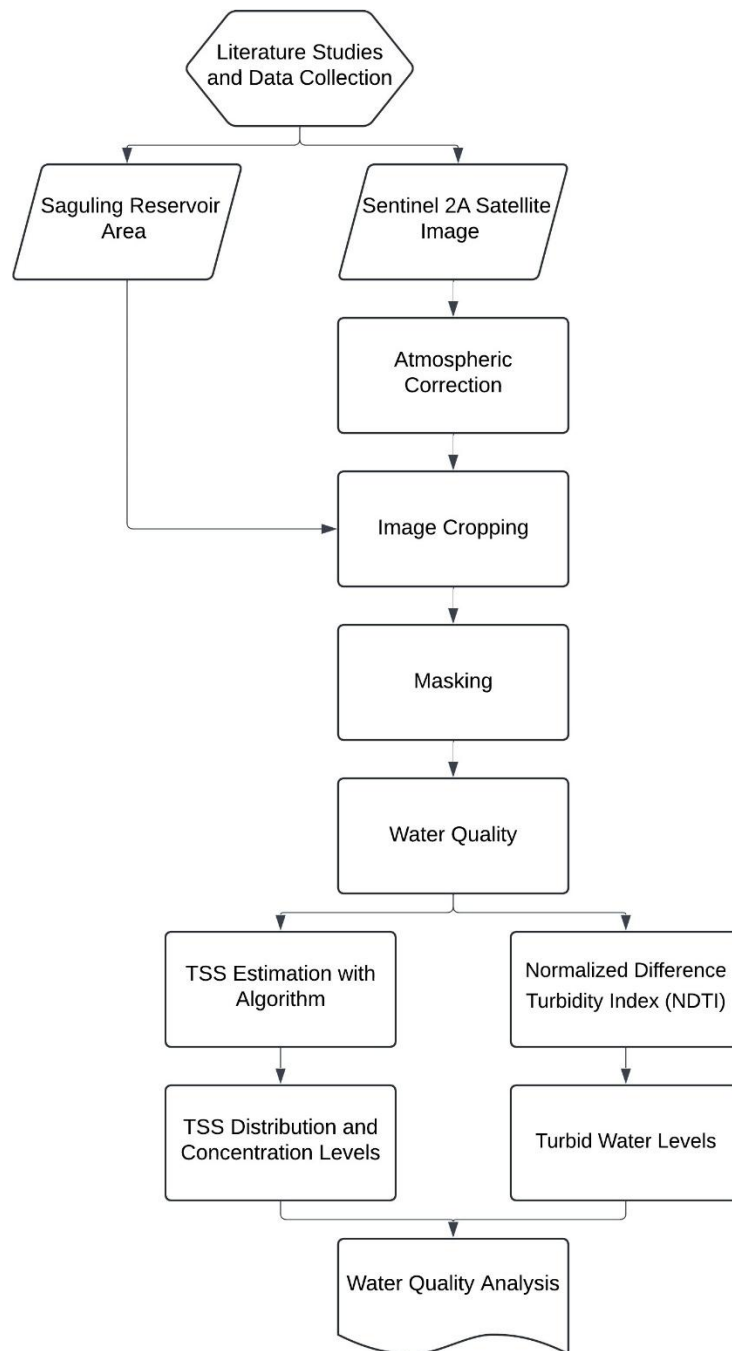


Figure 2. Research Flowchart

3. Results and Discussion

3.1. Atmospheric Correction

Satellite imagery obtained directly from the Sentinel-2 sensor typically contains various disturbances caused by atmospheric conditions. Influences such as aerosols, water vapor, and other atmospheric gases can distort the image data, altering the true reflectance of the Earth's surface. Uncorrected atmospheric imagery tends to have higher reflectance values than the actual conditions, which can affect data interpretation, such as land cover identification,

vegetation analysis, and water quality assessment. Therefore, raw Sentinel-2 imagery before atmospheric correction is often not sufficiently accurate for scientific analysis requiring precise reflectance data.

After undergoing atmospheric correction, Sentinel-2 imagery has the atmospheric disturbances removed or minimized. This correction process calibrates the reflectance data by accounting for atmospheric factors such as aerosols, water vapor, and other gases. The result is imagery with more accurate surface reflectance, closely representing actual field conditions. Consequently, atmospherically corrected imagery is more reliable for precise analyses, such as land cover mapping, vegetation health monitoring, and environmental change observation. The following is a comparison of the atmospheric correction results of Sentinel-2 imagery at the study site, as shown in Figure 3.

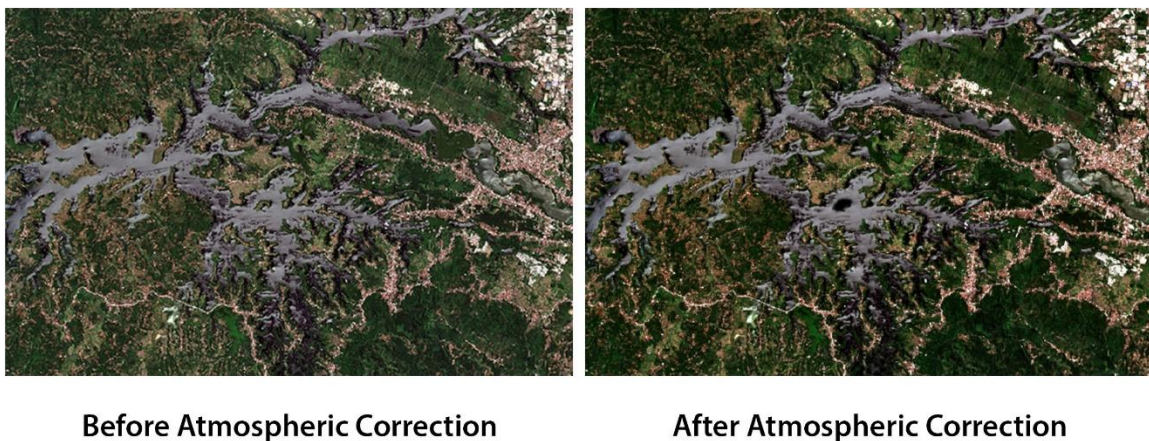


Figure 3. Atmospheric Correction Sentinel-2

3.2. TSS Distribution and Concentration Levels

The distribution of Total Suspended Solids (TSS) in the Saguling Reservoir is uneven, with areas exhibiting low (0-40 mg/l), moderate (40.1-80 mg/l), and high (80.1-120 mg/l) TSS concentrations. The largest portion of the reservoir, covering 1.830,47 hectares, falls within the moderate TSS concentration range, indicating that most of the reservoir's area experiences medium TSS levels. Despite the smaller extent of high TSS concentration areas, their presence suggests that certain sections of the reservoir are subject to significant pollution levels.

Table 5. TSS Concentration in Saguling Reservoir, along with its Area

No.	TSS Concentration (mg/l)	Area (Ha)
1	0 – 40	902,91
2	40,1 – 80	1.830,47
3	80,1 – 120	592,78

Source: Result of TSS Distribution and Concentration Levels Processing, Saguling Reservoir, 2024

The spatial distribution TSS Concentration in Saguling Reservoir can be seen in Figure 4.

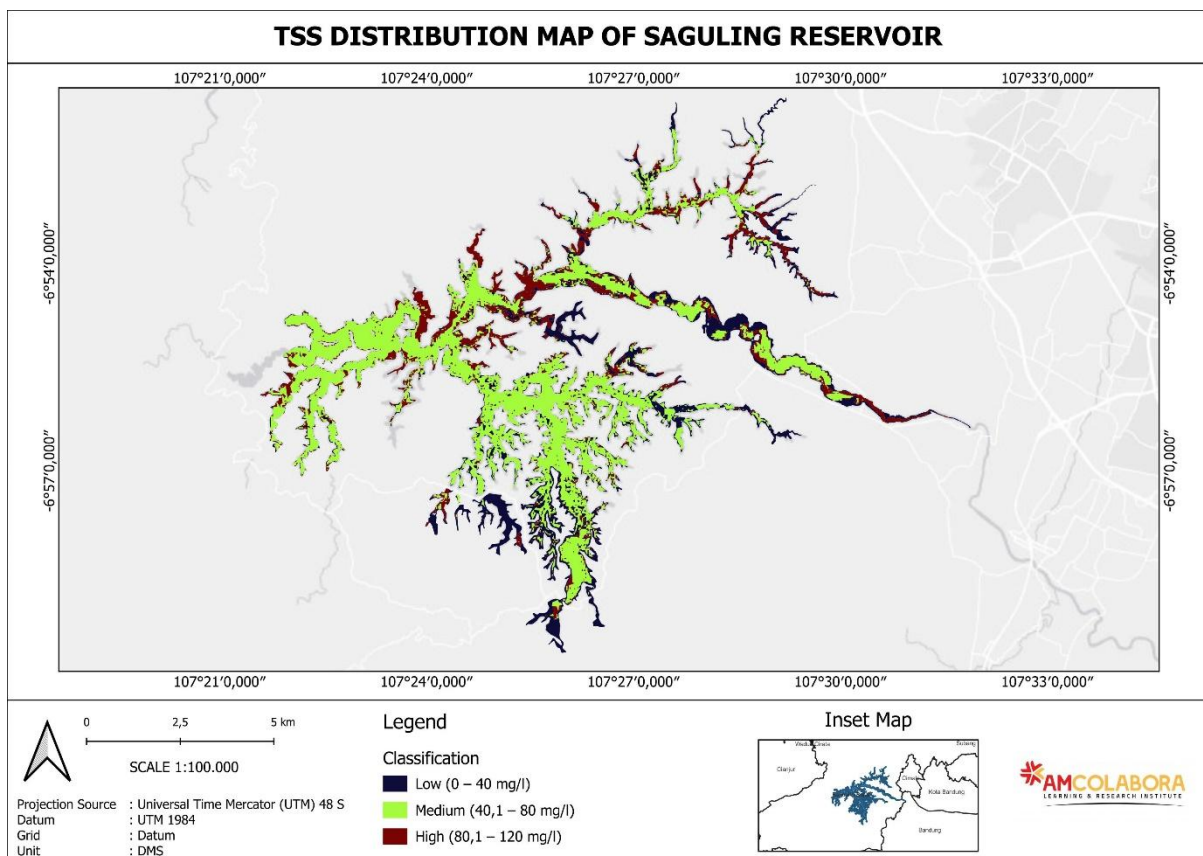


Figure 4. TSS Distribution Map of Saguling Reservoir

3.3. Normalized Difference Turbidity Index (NDTI)

Saguling Reservoir turbidity shows an uneven distribution. Most of the reservoir area (2.643,94 hectares) has moderate turbidity, indicating generally acceptable water quality. However, the presence of areas with very low (212,84 hectares) and high (457 hectares) turbidity indicates significant variations in water quality at various points.

Table 6. NDTI Rank Values in Saguling Reservoir, along with its Area

Water Turbidity Class	Area (Ha)
Very low turbidity	212,84
Moderate turbidity	2643,94
Represent high turbidity	457

Source: Result of Normalized Difference Turbidity Index Processing, Saguling Reservoir, 2024

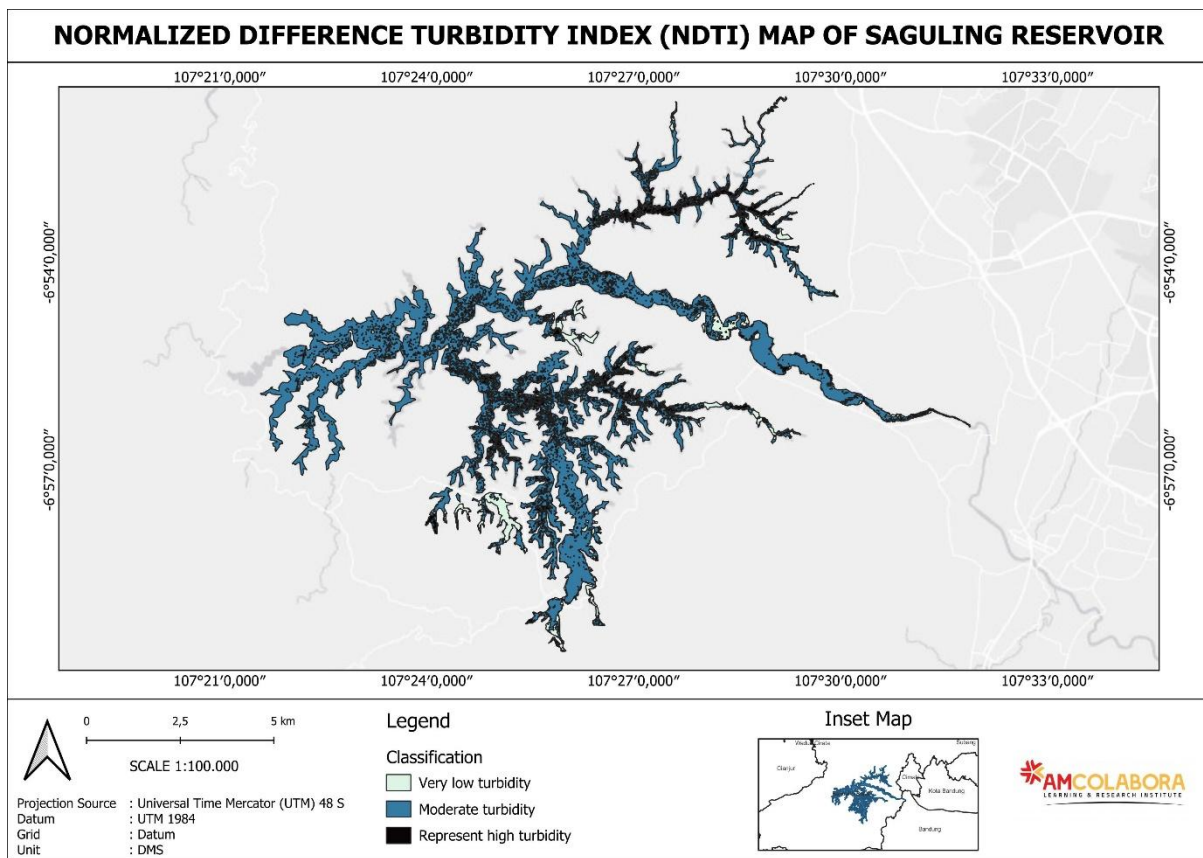


Figure 5. Normalized Difference Turbidity Index (NDTI) Map of Saguling Reservoir

4. DISCUSSION

Analysis of Total Suspended Solids (TSS) and Normalized Difference Turbidity Index (NDTI) in Saguling Reservoir indicates a spatial correlation. Satellite imagery reveals a non-uniform distribution of both parameters, with high TSS values often coinciding with high NDTI. This visual correlation suggests that increased suspended solids directly contribute to higher turbidity.

Generally, a moderate Total Suspended Solid (TSS) value indicates that the amount of suspended solid particles in the water is within a range that is neither too low nor too high. These particles can be soil, mud, plankton, or other organic matter. Meanwhile, a moderate Normalized Difference Turbidity Index (NDTI) value indicates the level of water turbidity. A moderate NDTI value signifies that the water is neither too clear nor too turbid.

Saguling Reservoir exhibits non-uniform distribution of Total Suspended Solids (TSS) and Normalized Difference Turbidity Index (NDTI) values. The water quality of Saguling Reservoir, dominated by moderate TSS and NDTI values, can be considered fairly good. The water quality in Saguling Reservoir is still suitable for agriculture and fisheries. However, for consumption, the water needs to be treated to remove solid particles. Additionally, water with moderate TSS values supports the life of various aquatic organisms because the level of light penetration into the water is still quite good and the amount of solid particles is not excessive.

5. Conclusion

Saguling Reservoir plays a vital role for the surrounding community, thus requiring water quality monitoring. Key parameters for assessing water quality in Saguling Reservoir include Total Suspended Solids (TSS) and Normalized Difference Turbidity Index (NDTI). Total Suspended Solids (TSS) in Saguling Reservoir are distributed as follows: 902.91 hectares at low concentration, 1,830.47 hectares at moderate concentration, and 592.78 hectares at high concentration. This indicates a relatively high amount of suspended solid particles in the water, which can include soil, mud, plankton, and other organic matter. Meanwhile, the Normalized Difference Turbidity Index (NDTI) in Saguling Reservoir is distributed as follows: 212.84 hectares at low turbidity, 2,643.94 hectares at moderate turbidity, and 457 hectares at high turbidity. This indicates that the water turbidity tends to be moderate to high. Therefore, it can be concluded that the water quality in Saguling Reservoir is still fairly good, but it requires further treatment before consumption.

Despite the findings, it is imperative to conduct further research to obtain a more comprehensive understanding of the water quality in Saguling Reservoir. The distribution of Total Suspended Solids (TSS) and Normalized Difference Turbidity Index (NDTI) is influenced by a multitude of factors including land use change, domestic and industrial waste, and hydrological conditions. To achieve a more accurate assessment, future studies should involve in situ sampling, comparisons of satellite imagery acquired at different times, and the application of various TSS algorithms.

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