Research Article **Open Acces**

Monitoring Spatiotemporal Changes of Limboto's Lake Condition Using Sentinel-2 MSI Images Based on Google Earth Engine (GEE)

Moh. Musi Amal I. Muzamil[1,2], Rahmat Asy'Ari [2,3,4,5], Muhammad Hisyam Fadhil [3,5,6], Moh. Zulfajrin[2,7], Yudi Setiawan[8,9]

[1] *Undergraduate Student, Department of Environmental Engenering, Institut Teknologi Yogyakarta, Bantul Regency, Yogyakarta, Indonesia*
[2] *SSRS Banggai Advanced Research Facility, SSRS Institute – SSRS Group, Banggai Regency, Central Sulawesi, Indonesia*
[3] *IPB Sustainable Science Research Students Association (IPB SSRS Association – Local Committee in IPB University), IPB University, Bogor, Indonesia*
[4] *SSRS EartInformatics Labs, SSRS Institute – SSRS Group, Bogor, Indonesia*
[5] *SSRS Indonesia Biodiversity Hub, SSRS Institute – SSRS Group, Bogor, Indonesia*
[6] *Undergraduate Student at Department of Agronomy and Horticulture, IPB University, Bogor Indonesia*
[7] *Computational Soil Science Research Group, IPB University, Bogor Regency 16680, Indonesia*
[8] *Center for Enviromental Reesearch, IPB university, Bogor Indonesia*
[9] *Department of Forest Resource Conservation and Ecotourism, IPB university, Bogor Indonesia*

* Correspondence: Musiamal66@gmail.com

Abstract: Lake Limboto is the largest lake in Gorontalo Province and is a critical lake prioritized for recovery (National Priority Lake). The criticality of Lake Limboto is influenced by various surrounding land use activities that affect the lake's water quality through runoff and possible pollution from domestic waste from surrounding settlements. Changes in the water quality of Lake Limboto are essential for spatial assessment using remote sensing data for efficient periodic monitoring. Spatiotemporal monitoring of Lake Limboto's condition was conducted using Sentinel-2 MSI (MultiSpectral Instrument) satellite imagery and involving the Random Forest (RF) machine learning classification method. RF classification was carried out by mapping water and non-water cover in the 2017 - 2023 timeframe and obtained a classification accuracy of 0.93 (kappa). Based on the monitoring of lake water conditions, the distribution of turbidity in 2017, 2019, 2021, and 2023. Lake water quality in 2017 with dirty water condition class had an area of 0.45 ha and decreased in 2019 (0.04 ha), 2021 (0.03 ha) and 2023 (0.03 ha). The increase in lake water quality and the expansion of water cover in Lake Limboto during the study period indicate the success of lake recovery. It is hoped that this research can be used as a basis for decision-making for protecting the Limboto Lake area.

Keyword: Limboto's Lake, GEE, Turbidity, Conservation.

INTRODUCTION

Julzarika & Dewi (2019) Lake Limboto is one of the largest lakes in Gorontalo Province, Indonesia. This lake has an important role in supporting the lives of surrounding communities, both as a source of clean water, a source of livelihood and as an ecosystem that supports biodiversity. However, like many other lakes in Indonesia, Lake Limboto is one of the largest lakes in Gorontalo province, Indonesia, and is included in the 15 national priority lakes program. The lake has a strategic role in ecology and economy, as it provides various benefits such as the hydrological role of water supply, biodiversity, and being an important recreation and fish farming site for the surrounding community (Alfianto & Cecilia 2017). However, Lake Limboto faces various threats and challenges related to environmental degradation and changes in ecosystem conditions. Environmental monitoring of Lake Limboto needs to be considered early because the degradation is caused mainly by land use change, such as the conversion of forest land to agricultural land and other land uses. Changes in Lake Limboto's water quality can be well monitored using remote sensing technology (Lihawa & Mahmud 2017).

The changes of lake conditions exerts a considerable influence on ecosystems and environmental sustainability. In order to understand these changes accurately and efficiently, a monitoring method is needed to provide consistent and detailed data (Julzarika & Dewi 2019). The Sentinel-2 satellite, operated by the European Space Agency (ESA), provides optical data with high spatial resolution and global coverage. Sentinel-2 imagery can observe changes in vegetation, water quality, and surface morphology, resulting in imagery with high spatial and temporal resolution (NASA 2021). These water quality parameters are employed to ascertain the extent of changes that have occurred to the condition of Lake Limboto's water bodies based on GEE (Liu *et al.* 2017). High turbidity (mg/l) can be indicated by elevated TSS values in the water. TSS is defined as a solid substance comprising both organic and inorganic matter suspended in water areas (Jiyah 2017). TSS concentration plays a role in determining the environmental quality of a water body. A positive correlation exists between the concentration of TSS and the turbidity of the water (Kamajaya 2021). High turbidity and TSS values can increase the potential of water siltation due to settling sedimentary materials in the waters. Information related to the distribution of TSS can be utilized to predict siltation resulting from sedimentation (Anwar 2020). The indices employed for monitoring lake conditions are the Normalized Water Difference Index (NDWI) and the Normalized Difference Turbidity Index (NDTI), which are utilized for monitoring water conditions. Using technologies such as Google Earth Engine (GEE), Sentinel-2 image data processing and analysis becomes more efficient (Lahay *et al.* 2021).

METHOD

Study Case

Administratively, the case study was conducted at Lake Limboto in Gorontalo Regency, Gorontalo Province, at 25 meters above sea level (above sea level) and about 20 km from the coast, surrounded by limestone mountains. The lake area has decreased from year to year due to siltation process. The lake area in 2005 was approximately 2,985 hectares. Lake Limboto is a shallow and polymictic lake located at a low altitude (Lahay 2022). (Figure 1).

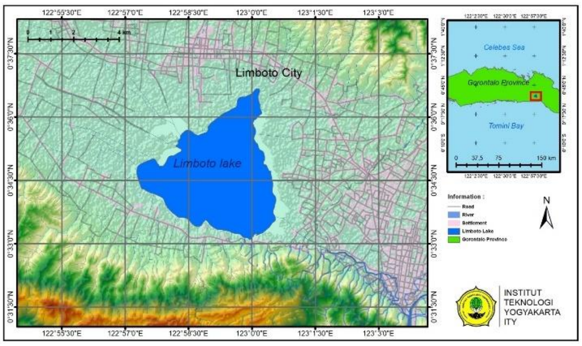


Figure 1. Study area

Data and Data Source

This study used Sentinel-2 satellite imagery as the main data in detecting the condition of Lake Limboto. Water quality is detected from remote sensing data using the Normalized Difference Index (NDTI and NDWI) method, where NDTI is used to estimate the distribution of TSS (mg/l) in the Lake Limboto water body. This method was developed (Ouma *et al.* 2020) and can extract turbidity parameters by looking at brightness variations in a water body (Julzarika & Dewi 2019). This method is based on the blue and green bands of Sentinel-2, which are closely related to surface water information.

The downloadable imagery is a finished product projected into WGS84, generated using GEE. Radiometric measurements of each image pixel are provided in units of Surface Reflectance (SR) (ESA 2015). Thus, the GEE platform has geometrically and radiometrically corrected the image product (Oktaviani *et al.* 2017). This method is used in satellite image analysis by utilizing optical parameters such as reflectance values. This method involves processing and analyzing satellite images using specialized algorithms and techniques to estimate water turbidity from optical data collected by satellites. (Oktaviani *et al.* 2017).

Tabel 1. Envolved Index

Metode	Formula	Referensi
Normalized Difference Water Index	(Green-Swir)/(Green + Swir)	(Xu. 2006)
Normalized Difference Turbidity Index	(Blue-Green)/(Blue+Green)	(Ouma *at al.* 2017)

Remote Sensing and GEE

This study employs the TSS standard from Michigan, then entered into the regression modeling equation to see the turbidity on Sentinel-2 MSI, so that the TSS standard is obtained which states that if the TSS is less than 20 mg/l, it is considered clear water, if the TSS is 40-80 mg/l, it is considered turbid water, while if it is more than 150 mg/l, it is considered dirty water. The results of this classification have an impressive representation rate of 80%.

$$y = 367.82x2 - 976.42x + 649.13$$

Information :

y = Turbidity

Tabel 2. Standarisasi TSS (mg/l)

Golongan	TSS (mg/l)	Klasifikasi air
1	< 20	Clear
2	40 < TSS ≤ 80	Cloudy
3	> 150	Dirty

Random Forest Algorithm

Rahmawati & Asy'ari (2021) research uses Random Forest Algorithm which is a machine learning that is used for classifying large amounts of data sets because its function can be used for many dimensions with various scales and high performance. This classification is done through combining water in the decision water by training the dataset of available data. Mondal *et al.* (2019) Random Forest works by building several decision waters and combining them to get a more stable and accurate prediction. The 'water' built by Random Forest is a collection of decision water usually trained by bagging method. The general idea of the bagging method is the combination of learning models to improve the overall result. Random Forest is used for regression and classification problems with large data sets. Random forest is an algorithm implemented in various ways including analysis in this research.

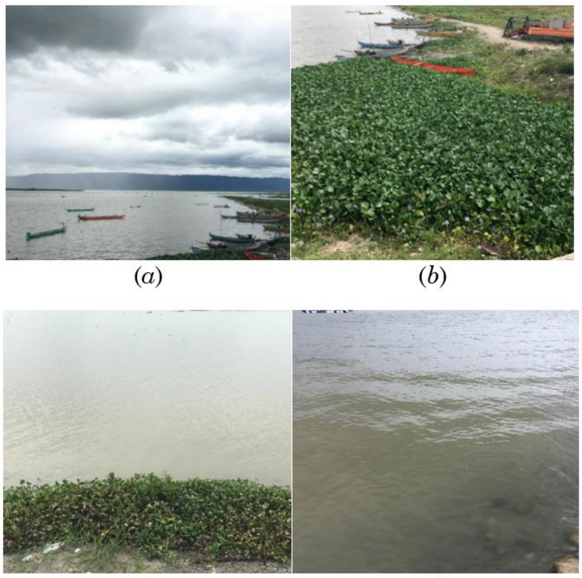
Acuration Analysis

Story & Congalton (1986) explain that accuracy analysis is one of the final steps to test the accuracy of the classification process. In this study, the accuracy analysis method is seen from the Kappa Statistic value. with a presentation using a confusion matrix table. A total of 200 validation points were involved in this analysis, consisting of water (100 points) and non-water (100 points). The validation data will be tested and compared with the turbidity classification results, so that be able to obtain information on the accuracy of this method. With the equation;

$$Kappa = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{ii} (X_{i+} \times X_{+i})}{N^2 \sum_{i=1}^{r} X_{ii} (X_{i+} \times X_{+i})}$$

Tabel 3. Kappa value

Nilai Kappa	Keterangan
< 0,00	Very bad
0,00 – 0,20	Bad
0,21 – 0,40	Moderate
0,41 – 0,60	Good enough
0,61 – 0,80	Very good
0,81 – 1,00	Perfect



(a) (b) (c) (d)

Figure 2. Limboto's Lake Condition

RESULTS AND DISCUSSION

Limboto's Lake Condition

Lake Limboto, as an ecological entity, has become a focus of research in the context of conservation and ecosystem understanding in Gorontalo. With its rich biodiversity and significant ecological role, the lake holds the potential for valuable information on freshwater ecosystem dynamics. As an area rich in biodiversity, Lake Limboto faces challenges from various sources, including the influence of human activities and climate change. By adopting an ecological

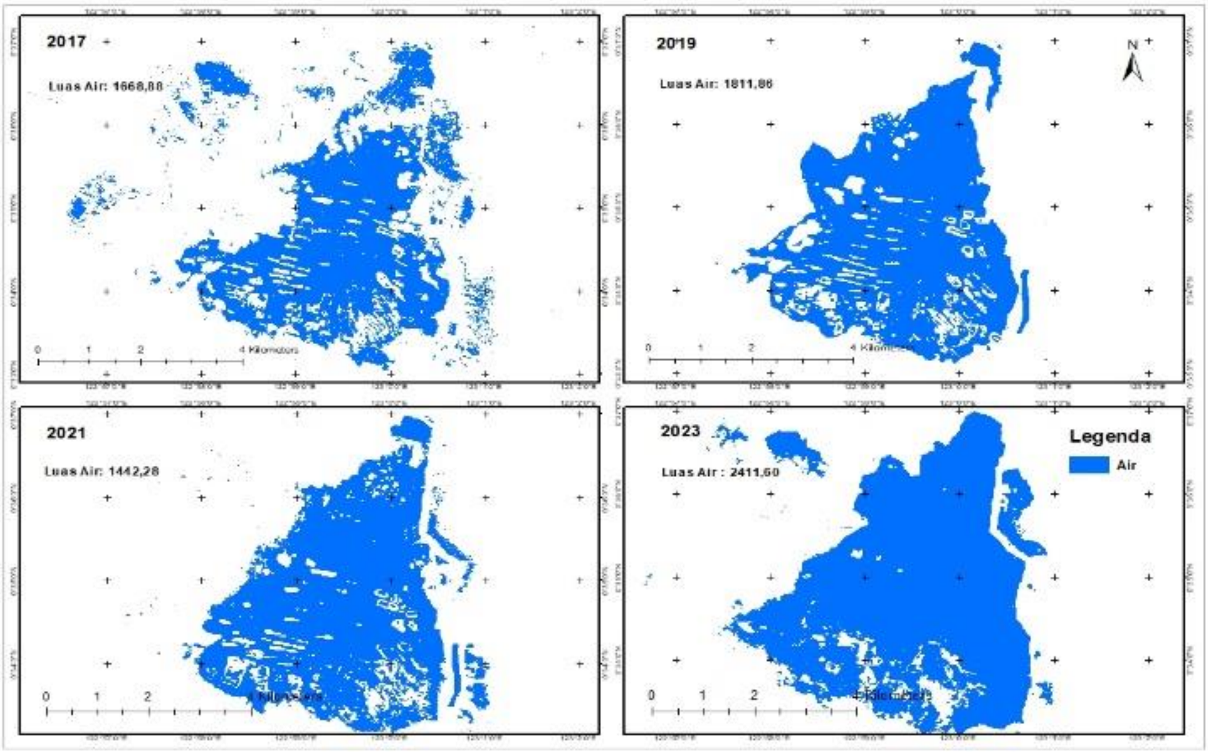


Figure 3. Water spatial distribution

approach, we will trace the passage of time and engage in the analysis of historical and environmental data to identify past changes. This in-depth understanding is expected to provide a solid scientific basis prior to the substantive analysis, namely the spatiotemporal analysis of Lake Limboto conditions via Sentinel-2 MSI.

Administratively, Limboto Lake is located in Limboto Sub-district, Gorontalo Regency, Gorontalo Province. The lake is divided into two administrative regions, with 70% in Gorontalo Regency and 30% in Gorontalo Province. Currently, Lake Limboto, which is the estuary of 23 rivers, is facing an alarming condition due to significant shrinkage and siltation, threatening its future existence. The siltation is mainly caused by the accumulation of total suspended solids or pollutants in the water body, threatening the sustainability of Lake Limboto. Historical data from BALIHRISTI shows that in 1932, the average depth of Lake Limboto was 30 meters, with an area of 7,000 hectares. However, by 1961, the depth had reduced to 10 meters, with the area shrinking to 4,250 hectares.

The decrease in the lake's water surface area results in a decline in its function as a water reservoir and habitat for aquatic biota, potentially leading to flooding and loss of endemic organisms. Siltation in Lake Limboto is mainly caused by erosion and sedimentation due to agricultural practices that do not pay attention to soil and water conservation, as well as deforestation in upstream areas, especially in the Limboto watershed. In addition, unsustainable fishing practices and uncontrolled growth of aquatic plant populations, such as water hyacinth, have also contributed to a decrease in the lake's water capacity and excessive evapotranspiration. Since 1991, the lake has narrowed by almost 4,000 hectares, shrinking from an initial 7,000 hectares to 3,644.5 hectares in 2017 (Umar *et al.* 2018). In a recent study conducted in 2023, the lake area further decreased to 2,411.6 hectares.

Spatial Condition of Lake Limboto

Based on Figure 4, applying the algorithm in the GEE environment to process Sentinel-2 images has produced four spatial and temporal variations. Extraction of the spatial distribution of water surface area from 2017 to 2023. The blue-colored area on the map represents the waterlogged area in the year of observation. The most dynamically changing area is the northwestern part of Lake Limboto. This indicates some activities that affect the water cover of Lake Limboto. Spatial changes in the water cover of Lake Limboto are caused by accumulated erosion and sedimentation from the flow of rivers into the lake, and environmentally unfriendly aquaculture activities and the expansion of water hyacinth populations. The siltation and shrinkage of Lake Limboto.

Figure 3. Water grafic distribution

The graph (Figure 5.) shows a very low trend of water cover in 2017. Then there was an increase in the trend in 2019, and again fell in 2021, then again rose in 2023. Water Resources Research and Development Center results show that Lake Limboto is one of the lakes experiencing heavy sedimentation and a significant reduction in lake area of 2.5 meters per year. In 2017 the water surface area was 1668.88 ha, in 2019 the water surface area increased to 1811.96 ha, in 2021 it decreased to 1442.28 ha. And in 2023 the water surface area increased significantly to 2411.60 ha.

Turbidity Distribution

Turbidity and brightness values in Lake Limboto were obtained without making corrections first, because the images obtained have been corrected at the surveillance reflectance (SR) level automatically based on cloud computing using the random forest algorithm (NASA 2021). turbidity values are visualized using NDTI, then the image product is entered into a regression equation model to calculate turbidity in Sentinel-2 MSI. To get the best image at the desired time, with Based on Figure 5, changes in surface area due to the accumulation of sedimentation can be monitored with remote sensing data, the satellite image used is Sentinel-2. where Sentinel-2 images with 2017 acquisition data show the distribution of sediment or turbidity that is so bright in the northeast and southwest areas. Where the concentration with an increasing trend shows a high accumulation of sediment. In 2019 there was a concentration of particulate matter in the middle of the lake that was so bright. 2021 the brightness level dimmed, which reduced the turbidity concentration in

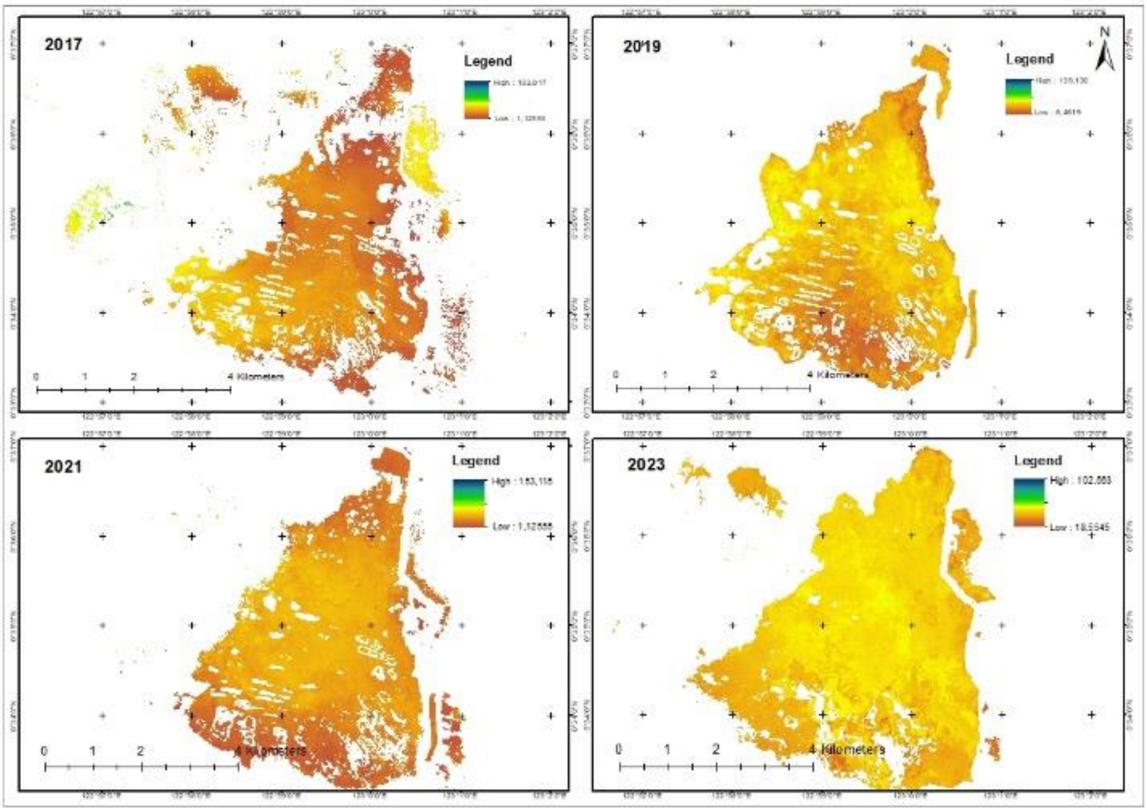


Figure 5. Turbidity spatial distribution

the lake. And in 2023 it rose again, by looking at the brightness trend of the turbidity distribution.

The brightness algorithm developed (Ouma *et al.* 2020) for viewing turbidity levels in water bodies utilizes the closest representative reflectance value by testing all bands for water monitoring, then combining them. The combination of existing bands is then seen for its error rate. The resulting image product was then entered into the existing regression equation, the results of which are shown in Figure 5 below. The distribution of turbidity visualized in brightness levels provides an understanding to easily see patterns, sources, and turbidity models, which can provide preferences to save the environment.

Turbidity Classification

From the image classification results above (Figure 6) The distribution of turbidity in a water body is shown. The Sentinel-2 image with the acquisition in 2017 shows the distribution of suspended particles in the southern area of the lake with a clear area of 719.65 ha, turbid 948.33 ha, and dirty 0.45 ha. Then in 2019 the clear area was 55.86 ha, turbid 1755.96 ha, and dirty 0.04 ha. In 2021 the water surface area was clear 436.29 ha, turbid 1441.96 ha, and dirty 0.03 ha. And in 2023 the clear water surface area reached 0.04 ha, turbid 2411.53 ha, and dirty 0.03 ha.

Accuracy Assesment

The brightness algorithm developed (Ouma *et al.* 2020) for viewing turbidity in water bodies utilizes the closest representative reflectance value by testing all bands for water monitoring, and then combining them. The combination of the existing bands is then seen for its error rate. The resulting image product was then entered into the existing regression equation, the results of which are shown in Figure 5 below. The distribution of turbidity visualized in brightness levels provides an understanding to easily see patterns, sources, and turbidity models, which can provide preferences to save the environment.

Based on Figure 6, the water classification results provide information on the spatial distribution of turbidity. However, the classification results sometimes do not match the actual situation. This is one part of the role of accuracy analysis where the classification results are compared with the representation data and the error rate like Root Mean Square Error (RMSE), where the

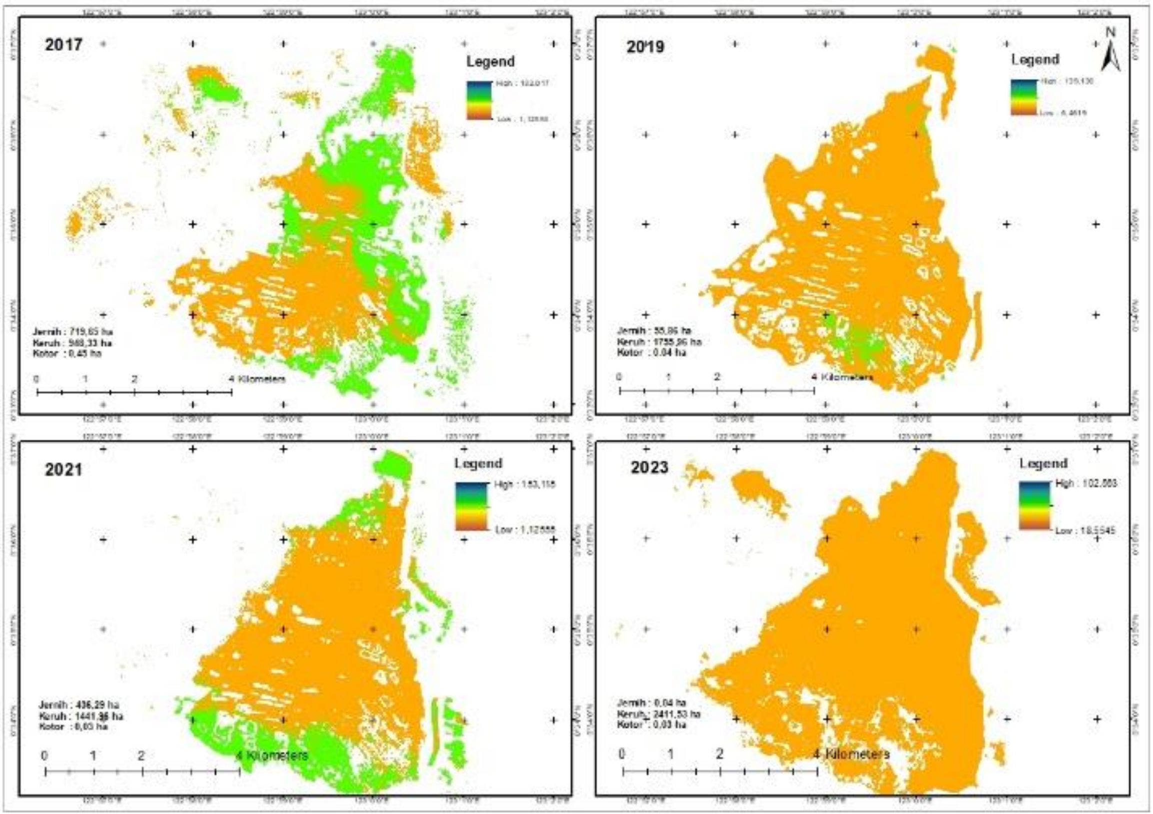


Figure 6. Turbidity classification

turbidity index is entered into the equation to achieve 80% accuracy. After the modeling was completed, based on the results obtained, Kappa Statistic's showed the average value of image classification reached 0.99. So that the value obtained shows the classification results with almost perfect accuracy. Based on the accuracy assessment obtained, 200 validation data provide accuracy information from the turbidity classification results. This index helps the turbidity classification with an impressive rate of 80%. In addition, the images used with various advantages such as a spatial resolution of 10-60 meters help the RF algorithm in carrying out the classification process and can reduce identification errors. The concept in this study, using the GEE platform, proved to be an alternative for mapping turbidity distribution locally.

CONCLUSIONS

Remote sensing data can be used to identify changes in the condition of Lake Limboto through a normalized index algorithm, in this case the MNDWI-NDTI data classification. Figure 4.1 shows the upward trend of water cover from 2017 1668.88 ha to 2019 1811.86 ha, but decreased in 2021 1442.28 ha, and then increased significantly in 2023 2411.60 ha. Using the TSS standardization (Michigan Gov. DEQ), turbidity in 2017 - 2023 is in the range of 20 mg/l - 50 mg/l, which is in the turbid class category. Then the data classification results in Figure 4.4, show the distribution of turbidity each year, which is decreasing yearly. Conservation efforts are needed to maintain Lake Limboto's sustainability, starting from monitoring and supervision, ecosystem management, habitat protection, pollution control, habitat restoration, education and collective awareness of the regional community and involving all related parties and all levels of society.

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