EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(7), 152–166 https://doi.org/10.12912/27197050/205088 ISSN 2719–7050, License CC-BY 4.0 Received: 2025.04.29 Accepted: 2025.05.30 Published: 2025.06.15

Analysis of total suspended matter and chlorophyll-a in southeast Bali using Sentinel-2 satellite imagery data

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ABSTRACT

Remote sensing data from Sentinel 2 satellite imagery is widely used in environmental quality analysis regarding water quality data, where two of the parameters that exist in analyzing water quality are the parameters of the water quality including chlorophyll-a and total suspended matter (TSM). This research focuses on the southeast Bali region, which is a region with high biodiversity and is vulnerable to environmental change. Thus, this research can provide important information about environmental conditions in the region. The Sentinel-2 satellite imagery data used in this study is data at level 1C. Sentinel-2B level 1C satellite image data, namely data recording on October 10th 2018, November 8th 2020. Sentinel-2A level 1C, namely data recording on November 3rd 2022. The highest chlorophyll value is found in the rainy season, namely in the recording data November 8th, 2020 with a chlorophyll-a value of 43.65 mg/m³. The highest TSM value is found during the transitional season from the dry season to the rainy season, namely in the recording data on October 10th 2018 with a TSM value of 42.77 mg/L. Despite these elevated values, TSM concentrations above 25 mg/L are generally considered to have limited impact on fisheries, suggesting that current sediment conditions are not likely to pose a significant threat to fishery activities in the region.

Keywords: chlorophyll-a, remote sensing, sentinel-2 and total suspended matter.

INTRODUCTION

Remote sensing is a method for obtaining information about objects on the earth's surface by utilizing satellite imagery data as the main medium for conducting data analysis (Virdis et al., 2022). According to (Subiyanto et al., 2018),(Bonansea et al., 2019), the advantages of choosing a remote sensing method include analysis that can be carried out over a large area, does not require a lot of effort and cost in field investigations and some satellite imagery data is used. can be downloaded officially and for free with a high enough resolution. The satellite imagery data are Sentinel-2A and Sentinel-2B satellite imagery data. Satellite image data used in remote sensing methods include active sensors and passive sensors. Sentinel-2 satellite image data is a passive sensor because it is included in an optical sensor that measures the electromagnetic radiation from the sun that is reflected from the oceans, land, lakes and the atmosphere. Sentinel 2A satellite image data is multispectral sensor data with high spatial resolution where the data is very important for monitoring and mapping coastal and estuary ecosystems (Katlane et al., 2020).

Sentinel-2 multi-spectral imager (MSI) satellite image data is data developed by the European Space Agency (ESA) with the first data recorded in 2015 (Rahman et al., 2022). Sentinel-2A and Sentinel-2B satellite image data operate with a global return visit for five days at the Equator (Caballero et al., 2022). The first launch of Sentinel-2A was carried out on 23 June 2015 and the first launch of Sentinel-2B was carried out on 7 March 2017 into a 786 km circular orbit sun-synchronous with an inclination of 98.620 and a crossing time at the equator 10:30 am and a phase delay of 180° (Li and Roy, 2017), (Ouma et al., 2020).

Remote sensing data from Sentinel 2 satellite imagery is widely used in environmental quality analysis regarding water quality data, land use change, land vegetation density, flood analysis, shoreline changes and matters relating to other environmental problems (Solovey, 2019). Remote sensing can monitor water quality because water has a strong spectral signature, where the interaction between solar radiation and optically active components changes the spectral properties of water so that it can be used as an indicator of water quality (Novo et al., 2013), (de Oliveira Fagundes et al., 2020).

The process of collecting data to identify sources of pollution in water is a stage of water quality monitoring. The parameters of water quality include chlorophyll-a, Total Suspended Matter (TSM), dissolved oxygen, water temperature, total phosphorus and colored dissolved organic matter (Torres and Blanco, 2021). Chlorophyll-a is a key parameter that indicates the tropical status of the waters, where through the process of photosynthesis, phytoplankton converts CO₂ and H₂O into O₂ resulting in primary production in the water column (Ha et al., 2017), (Ansper and Alikas, 2018). High amounts of phytoplankton biomass cause negative impacts on food webs, biogeochemical cycles, aquaculture and aquatic habitats (Niroumand-Jadidi et al., 2021).

Availability of sunlight, nutrients, phosphorus and nitrogen concentrations affect the growth of phytoplankton and excessive concentrations of phytoplankton endanger the condition of fishing activities, public health, local economy and aquatic ecosystems (Hafeez et al., 2022), (CA-BALLERO et al., 2022). Disruption of aquatic ecosystems can also be caused by high human activities accompanied by the effects of climate change resulting in a decrease in water quality (Mucheye et al., 2022).

Living and dead phytoplankton, detritus, and clay mineral substances are organic and mineral suspended solids contained in TSM. These substances can originate from water bodies, water catchment areas, rivers or coasts or result from suspension from the bottom of lakes (Soomets et al., 2020). Suspended sediments have an influence in controlling water quality where the presence of suspended sediments can cause a large decrease in river capacity (Nguyen et al., 2020).

The existence of high turbidity in the sea and coastal areas is dominated by suspended sediments originating from shoreline erosion, resuspension of the seabed due to waves, sediment loads from river runoff and anthropogenic activities that cause resuspension such as dredging activities (Magrì et al., 2023). The movement of water in the oceans is influenced by water currents and winds, where wind is a meteorological phenomenon that causes movement to produce circulation cells, currents and waves (Soria et al., 2021).

In general, habitat destruction in the benthic zone is caused by high concentrations of TSM (Du et al., 2021). High TSM loads result in reduced light penetration, which can reduce primary production. The decline in primary production resulted in disruption of fishery and aquatic habitats (Niroumand-Jadidi et al., 2022). In addition, the health of the ecosystem in the growth of oysters in the bay is also affected by TSM concentrations (Chau and Wang, 2022).

The quality of the middle and downstream Ayung River which flows into Padang Galak Beach which is included in the waters of Southeast Bali where based on the test results there are two parameters namely physics Total Suspended Matter and biology (Fecal coliform) which turned out to exceed the quality standards. The high value of TSM is thought to be related to the content of dissolved mineral ions found in river water. Fluctuations in the increasing TSM content can be influenced by various factors such as natural factors originating from the process of rock weathering and anthropogenic factors from industrial activities, agriculture and heterogeneous community activity patterns (Widyasari and Putra, 2022).

Changes in Chlorophyll-a and TSM in coastal waters in South East Bali can be an indicator of changes in marine environmental conditions. Communities in South East Bali are highly dependent on marine resources for their daily lives. Therefore, it is important to monitor and manage marine resources sustainably. This research can increase public awareness of the importance of maintaining the quality of the marine environment and managing marine resources sustainably.

In this study, the concentrations of chlorophyll-a and TSM in the southeastern coastal waters of Bali were analyzed to assess the trophic status and sediment load in the region. These two water quality parameters were derived using remote sensing techniques based on Sentinel-2 satellite imagery. The research offers a seasonal analysis of chlorophyll-a and TSM levels using multi-date Sentinel-2 data for the southeastern waters of Bali. Although remote sensing has been applied in previous studies to evaluate water quality in other parts of Indonesia, much of this work has been fragmented or has not utilized Sentinel-2 imagery (Indrivaningtyas et al., 2022) (hanintyo et al., 2021). In contrast, locally focused investigations of this ecologically sensitive and economically significant area remain scarce. By integrating high-resolution satellite data with seasonal comparisons, this study aims to provide new insights into the spatiotemporal dynamics of water quality in a region where marine biodiversity and tourism are closely interconnected.

MATERIALS AND METHODS

The Sentinel-2 satellite imagery data used in this study is data at level 1C. Sentinel-2B level 1C satellite image data, namely data recorded on October 10th, 2018, November 8th, 2020 and November 03rd, 2022. Sentinel-2A satellite imagery data used in this analysis using different season variations, where the 2018 recording is the transition season from dry to rainy, the 2020 and 2022 recording is the rainy season. The selection of the date analyzed in satellite imagery data is based on the smallest cloud cover percentage. As is typical in Indonesia during the rainy season, high levels of cloud cover create a significant limitation, often resulting in data loss in visible-infrared satellite imagery (Nuarsa et al., 2018) such as Sentinel-2. High cloud cover will result in inaccurate results in the analysis. According to (Putra et al., 2021), satellite image data that is good for use in analysis is image data that has cloud cover of no more than 20%. Information about the image data

used in this study will be displayed in Table 1. Rainfall is one of the climate elements that causes the rate of erosion which causes sedimentation accumulation. High rainfall has an effect on increasing sedimentation in the form of high total suspended matter (TSM) values which have an impact on decreasing river water quality. Sedimentation in the form of suspended solids causes many water problems such as river shallowing, coastal erosion, changes in the coastline. Another impact that can arise is the occurrence of turbidity in river water which interferes with the penetration of sunlight into the water (Taufik Ibrahim and Kusratmoko, 2018).

Research conducted by (Yan et al., 2018) provides information on things that can cause errors in the Sentinel 2A image data recording process. This is useful for minimizing errors in the analysis of Sentinel 2A image data. Based on the results of the study, it was found that 97% of the Sentinel 2A image data that had been recorded in the study area did not have any technical errors. This proves that the Sentinel 2A image data is suitable for use and can be accounted for.

Recording data with level 1C is data that has been corrected radiometrically, but has not been corrected atmospherically. (Uwe et al., 2013). In using Case 2 Regional Coast Color (C2RCC), atmospheric correction of Sentinel-2A and Sentinel-2B Level 1C image data is included in the processing so that the calculation of water quality parameters can be analyzed (Karki et al., 2020). The initial process carried out in processing satellite image data is the resampling process and the subset process. The results of the resampling process and the subset process are shown in Figure 1 and Figure 2.

The resampling process in Sentinel-2 image data processing is required to correct geometrically distorted pixels in the original data recording (Roy et al., 2016). Image distortion is a change in the shape or size of an image due to the image acquisition process or the process due to exposure to light or sunlight (Salat and Achmady, 2018). The subset process is needed to focus on

Table 1. Sentinel-2 image data information

No	Recording date	Data type	Time (UTC)	Cloud cover (%)	
1	October 10 th , 2018	Sentinels 2B Level 1C	02:16:49.024	1.13	
2	November 8 th , 2020	Sentinels 2B Level 1C	02:18:59.024	2.94	
3	November 03 rd , 2022	Sentinels 2A Level 1C	02:18:41.024	14.21	



Figure 1. Results of resampling data



Figure 2. Results of subsets data

the research area so that data processing can be streamlined (Astiti et al., 2019).

Sentinel-2 MSI data has 13 bands with resolutions of 10 m, 20 m and 60 m, including a band at a wavelength of 705 nm (Band 5) which captures the red edge to perform chlorophyll-a analysis in deep water bodies (Warren et al., 2019; Bramich et al., 2021). Waters with phytoplankton have two maximum absorption bands in the electromagnetic spectrum, namely in the blue region with a wavelength of around 440 nm (Band 2) and in the red region with a wavelength of around 670 nm (Band 4). The high reflectance of chlorophyll is found in the green band with a wavelength of around 560 nm (Band 3) and the peak reflection from the presence of phytoplankton is in the near infrared region with a wavelength of around 700 nm (Band 8) (Aranha et al., 2022).

In the current study, chlorophyll-a estimations and TSM analyses were carried out using the C2RCC processor was applied uniformly to all three Sentinel-2 images. According to (Soriano-González et al., 2022), C2RCC is a development of the original Case 2 Regional processor which has been adapted to satellites with different multispectral data and its updates have been developed to make atmospheric corrections in complex waters. The Case 2 Regional Processor is a development carried out by Doerffer and Schiller by using a large database to simulate the transfer of radiation from water jets leaving water signals and atmospheric emission from satellite signals. The use of C2RCC has been validated in multiple sensors and additional neural networks have been trained for extreme IOP ranges giving good results for optically complex waters (Filipponi, 2018). In the TSM analysis, the algorithm of the C2RCC processor takes the first optical property inherent in the 443 nm wavelength and uses these parameters to estimate the concentration of the optically active substance (Delgado et al., 2018). According to (Molkov et al., 2019), at the peak height the wavelength of 705 nm is the right parameter for predicting chlorophyll-a and TSM. The absorption of phytoplankton pigments at 443 nm was converted to apig, and the chlorophylla concentration was calculated using Equation 1 (Handoko et al., 2024).

The C2RCC processor algorithm for analyzing chlorophyll-a can be seen in Equation 1:

$$chla = 22_apig (443)^{1.04}$$
 (1)

Case 2 Regional Coast Colour (C2RCC) is the original processor developed for the analysis of coastal waters. It was later complemented with Case-2 Extreme Waters (C2X), a processor used for extreme cases, trained with higher absorption and scattering coefficients. C2X-Complex-Net (C2XC) is an intermediate processor, trained with values above C2RCC and below C2X absorption coefficients (Cuartero et al., 2023).The C2RCC processor used in the analysis is included in the Sentinel Application Platform (SNAP) application.

The algorithm for determining the concentration of Total Suspended Solids in the form of the Case 2 Regional Coast Color Processor (C2RCC) algorithm is an algorithm that has been tested to produce good detection of total suspended solids for Sentinel-2 imagery. The C2RCC processor relies on a large database of simulated water-emission reflectance and associated Top of Atmosphere (ToA) radiances. Neural Networks were tested with the aim of performing spectral inversion for atmospheric correction, such as determination of water-emission radiance from ToA radiance, as well as optical captures that record the properties of water bodies (Octaviana et al., 2020).

The C2RCC processor algorithm for analyzing TSM can be seen in Equation 2:

$$TSM = btot_a_nn1 \times 1.73$$
(2)

where: *btot_a_nnl* – scattering by particles.

In this study, the use of the C2RCC algorithm on Sentinel-2 imagery to monitor water quality in the Bali region. Unlike previous studies that only focused on certain water quality parameters, our study monitors several water quality parameters simultaneously, including monitoring chlorophyll-a and TSM parameters. Observation of the distribution of TSM and chlorophyll-a simultaneously is very important to be carried out in order to determine the water quality in a body of water. High TSM values cause water turbidity, thus preventing the penetration of sunlight needed by phytoplankton for the photosynthesis process. According to (Widiaratih et al., 2022), the availability of chlorophyll-a in waters can be used as a reference in selecting areas that have potential for fishing, marine cultivation and other uses.

Sentinel application platform (SNAP) is a special software provided by the European Space Agency (ESA) to process Sentinel-1, Sentinel-2, and Sentinel-3 satellite imagery data with each toolbox based on the type of image data to be processed. Toolbox is a device in the SNAP application that is developed in providing tools to visualize, process data sets and analyze each type of Sentinel satellite imagery data. Sentinel-1 Toolbox is a special tool device for processing Sentinel-1 imagery data with the Satellite Aperture Radar (SAR) data type. Sentinel-2 toolbox is a special tool device for processing Sentinel-2A imagery data and Sentinel-2B imagery data. Sentinel-3 Toolbox is a special tool device for processing Sentinel 3 imagery data (Gorroño et al., 2017; Zuhlke et al., 2015).

After the results of the analysis of chlorophyll-a and TSM are obtained, the next step is to export the results to the Google Earth application and perform mapping which can be done through the Quantum GIS (QGIS) or ArcGIS applications. The type of classification value of chlorophyll-a which indicates the status of the waters will be displayed in Table 2 and the type of classification value from TSM which indicates the status of contamination will be shown in Table 3.

RESULTS AND DISCUSSION

Figure 3 is results of the analysis of the recorded data on 10 October 2018, which is a transitional season from the dry season to the rainy season, show data that the status of the waters at several points in the shallow waters of Matahari Terbit Beach, Sindhu Beach, Segara Ayu Beach, Karang Beach, Sanur Beach and Mertasari Beach belonging to the mesotrophic and eutrophic class shown in light blue and green with chlorophyll-a values ranging from 7.72-12.61 mg/m³. At several points in the waters around the Bali Mandara Toll Road, eutrophic class deep waters were also found. At several points in the Tukad Badung estuary reservoir, the chlorophyll-a value ranged from 12.61-18.86 mg/m³ which was shown in green and yellow colors indicating the status of the waters belonging to the eutrophic class. The same chlorophyll-a value was also obtained at the water points around Sakenan Temple which is on Serangan Island and Nusa Dua Beach. The status of eutrophic and super-eutrophic waters is found at water points at Pasiran Pier, Serangan Beach,

 Table 2. Classification of water status based on

 Chlorophyll-a value

Class	Chlorophyll-a (µg·L ⁻¹ or mg/m ³)		
Ultraoligotrophic	CL ≤ 1.17		
Oligotrophic	1.17 < CL ≤ 3.24		
Mesotrophic	3.24 < CL ≤ 11.03		
Eutrophic	11.03 < CL ≤ 30.55		
Super-eutrophic	30.55 < CL ≤ 69.05		
Hypereutrophic	69.05 < CL		

Note: Novo et al., 2013.

 Table 3. Suitability of waters for fisheries based on

 TSM values

TSM value (mg/L)	Influence on fisheries interests		
< 25	No effect		
25–80	Little impact		
81–400	Deficient		
> 400	Not good		

Note: (Dwi et al., 2008).



Figure 3. Mapping of chlorophyll-a in the southeastern sea of Bali Island (2018)

and Lebangan Bay. The highest chlorophyll-a value was 39.19 mg/m³. Eutrophic and supereutrophic waters are also found at water points on Sawangan Beach, Solace Beach and Natan Beach. At several points on Gunung Payung Beach and Timbis Beach, the status of the waters is classified as eutrophic. In the waters within the study area, the status of the waters belongs to the ultraoligotrophic and oligotropic classes shown in dark blue. Research conducted by (Dewanti Luh Putu Puspita et al., 2018) in the waters of Serangan Island, found 22 genus of phytoplankton horizontally and 29 genus of phytoplankton vertically consisting of three classes. While the results of observations of the composition of zooplankton horizontally found 3 genus of zooplankton consisting of the Maxillopoda class and the Malacostraca class and 8 genus of zooplankton vertically originating from the Maxillopoda class, the Malacostraca class, and the Branchiopoda class. Chlorophyll-a and phytoplankton abundance have a close relationship, where chlorophyll-a is the main indicator of phytoplankton abundance. Chlorophyll-a, as the main photosynthetic pigment in phytoplankton, reflects the biomass and photosynthetic activity of phytoplankton. This relationship is often linear with a high correlation, indicating that increasing chlorophyll-a concentration tends to be in line with increasing phytoplankton abundance (Adani et al., 2013).

Figure 4 is the results of the analysis of the data recorded on November 8th 2020, which is the rainy season, show that the status of the waters at several shallow water points on Sanur Beach, Sindhu Beach, Segara Ayu Beach, Karang Beach and Mertasari Beach belong to the mesotrophic, eutrophic and supereutrophic classes shown in blue. light to orange with chlorophyll-a values ranging from 5.46–31.65 mg/m³. The class status of eutrophic and supereutrophic waters is found in several points of the shallow waters of Tanjung Parangan, Serangan Beach, Lebangan Bay, Tanjung Benoa Beach, Nusa Pudut, Nusa Dua Beach, and Timbis Beach with chlorophyll a values ranging from 11.73-43.65 mg/m³. In the waters within the study area, the status of the waters belongs to the ultraoligotrophic and oligotropic classes shown in dark blue. Based on research conducted by (Pratama et al., 2020), the overall composition of the fish obtained was 537 individual fish consisting of 22 species and originating from 11 families. The results of the measurement of the community structure values obtained showed that the seagrass ecosystem of Sindhu Beach waters has a fish community structure in a stable condition. The types of seagrass found at the research location were diverse, consisting of 8 species of seagrass. The results of the measurement of water quality parameters showed that the condition of the waters of the Sindhu Beach seagrass ecosystem was still



Figure 4. Mapping of chlorophyll-a in the southeastern sea of Bali Island (2020)

optimal for the life of marine biota in the ecosystem, one of which was fish. According to (Dhama et al., 2023), as one of the coastal ecosystems, seagrass beds function as a place of residence for aquatic biota and have an important role in maintaining the sustainability and diversity of aquatic biota. Seagrass contains chlorophyll-a which functions in the process of photosynthesis where this process can help absorb carbon and store carbon so that it can be a way to overcome climate change (Sembiring et al., 2020).

Figure 5 is the results of the analysis of the data recorded on November, 3rd 2022, which is the rainy season, show that the status of the waters at several shallow water points on Sanur Beach, Segara Ayu Beach, Karang Beach and Mertasari



Figure 5. Mapping of chlorophyll-a in the southeastern sea of Bali Island (2022)

Beach belong to the mesotrophic, eutrophic and supereutrophic classes shown in blue light to orange with chlorophyll-a values ranging from 7.5 to 31.06 mg/m³. Class status of eutrophic and supereutrophic waters is found in several shallow water points of Tanjung Parangan, Serangan Beach, Lebangan Bay, Tanjung Benoa Beach, Nusa Pudut, Nusa Dua Beach, Gunung Payung Beach, Timbis Beach and Pandawa Beach with chlorophyll a values ranging from 13.29-42.11 mg/m^3 . In the waters within the study area, the status of the waters belongs to the ultraoligotrophic and oligotropic classes shown in dark blue. Based on field research from (Arafat, Yolla Serina and Dr. Ir. Umi Zakiyah, 2023), the results of chlorophyll-a measurements in Benoa Bay waters for laboratory analysis ranged between 0.1-0.4 mg/m³. Based on the analysis of water quality conducted, Benoa Bay waters have a low fertility rate or oligotrophic where the primary productivity is 0.3560-0.3756. his statement is in accordance with the results of the analysis of water status based on satellite image data analysis.

The concentration of chlorophyll-a in waters is highly dependent on the availability of nutrients and the intensity of sunlight. If nutrients and sunlight are sufficiently available, the concentration of chlorophyll-a will be high and vice versa. At coastal areas and coastal waters, the concentration of chlorophyll-a is higher. While in the open sea area the concentration becomes low. This is evidenced by the mapping of the distribution pattern of chlorophyll-a where high chlorophyll-a values are found in coastal locations and coastal waters. This happens because coastal areas or beaches receive direct nutrient intake through land runoff.

The characteristics of locations that have high chlorophyll-a values are found in locations adjacent to mangrove forests. According (Hidayah et al., 2016), the existence of a mangrove forest ecosystem will affect the exchange of nutrients between nearby ecosystems so that they can supply each other for the sustainability of life between ecosystems. In addition, mangrove plant litter is also a source of carbon and nitrogen for the forest itself and the surrounding waters. According (Abdur Rauf, 2023), mangrove litter in the form of leaves, twigs and other biomass that falls becomes a source of food for aquatic biota and nutrients that greatly determine the productivity of marine fisheries.

The higher the nutrient content in a body of water, the higher the abundance of phytoplankton and the concentration of chlorophyll-a. According (Indrawan et al., 2023),in the waters of Benoa Bay, high chlorophyll-a values were found because in these waters there are marine biota such as snapper, madah fish, muduk fish, parrot fish, balonang fish, mullet fish, red clams, manila clams, blood clams, and green clams (Table 4).

Figure 6 is the results of the analysis of the recorded data on 10 October 2018, which is a transitional season from the dry season to the rainy season, show data that the concentration of TSM is at several points in the shallow waters of Matahari Terbit Beach, Sindhu Beach, Segara Ayu

Data date	Class of chlorophyll-a data	Color	Chlorophyll-a value (mg/m ³)	
October 10th, 2018	Ultraoligotrophic	Dark blue	0.00	
	Oligotrophic	Light blue	3.18	
	Mesotrophic	Light blue	7.72	
	Eutrophic	Green, yellow and orange	12.61–25.23	
	Super-eutrophic	Red	31.59–39.19	
November 8 th , 2020	Ultraoligotrophic	Dark blue	0.55	
	Oligotrophic	Light blue	3.24	
	Mesotrophic	Light blue	5.46	
	Eutrophic	Green and yellow	11.73–24.96	
	Super-eutrophic	Orange and red	31.65–43.65	
November 03 rd , 2022	Ultraoligotrophic	Dark blue 1.17		
	Oligotrophic	Light blue	2.37	
	Mesotrophic	Light blue	7.5	
	Eutrophic	Green and yellow	13.29–25.13	
	Super-eutrophic	Orange and red	31.06–42.11	

Table 4. Chlorophyll-a data in research area 2018–2022



Figure 6. Mapping of TSM in the southeastern sea of Bali Island (2018)

Beach, Karang Beach, Sanur Beach and Mertasari Beach. ranged from 5.08-12.17 mg/L where the range of TSM values did not affect fisheries interests. At water points in Lebangan Bay and Tanjung Parangan, TSM values range from 8.42-42.77 mg/L, where a range of values greater than 25 mg/L indicates that these conditions have little effect on fisheries interests. TSM values ranging from 8.42-42.77 mg/L were also found at several points in the shallow waters of Nusa Dua Beach, Natan Beach and Timbis Beach. According to (Ernawati and Restu, 2021), the results of TSS measurements in Benoa Bay waters carried out in July-August 2018 were at point 1 of 22.50 mg/L, point 3 of 23.50 mg/L, point 4 of 20.00 mg/L, and point 5 of 21.00 mg/L. The results of the field analysis carried out in that month were not much different from the results of the analysis of satellite imagery carried out in October 2018, where the months had similar seasons, namely the transition season from dry to rainy.

Figure 7 is the results of the analysis of the data recorded on November 8th 2020, which is the rainy season, show that the TSM values at several shallow water points on Sanur Beach, Segara Ayu Beach, Karang Beach and Mertasari Beach range from 10.23–31.98 mg/L, where the range of values greater than 25 mg/L indicates that these conditions have little effect on the interests of fisheries. At several shallow water points in Tanjung

Parangan, Serangan Beach, Lebangan Bay, Tanjung Benoa Beach, Nusa Pudut, Nusa Dua Beach and Timbis Beach, TSM values ranged from 10.23–42.11 mg/L. Based on research conducted by (Putra et al., 2021) on TSS sampling on June 26, 2020 in the mangrove area located adjacent to Benoa Bay, the TSS value in the area ranged from 0.12–1.19 mg/L. Sampling during the study was carried out during the dry season, so the TSS value in the area was not high.

Figure 8 is the results of the analysis of the data recorded on November 03rd 2022, which is the dry season, show that the TSM values at several shallow water points on Sanur Beach, Segara Ayu Beach, Karang Beach and Mertasari Beach range from 10.16-26.87 mg/L. At several shallow water points in Tanjung Parangan, Serangan Beach, Lebangan Bay, Tanjung Benoa Beach, Tukad Badung estuary reservoir, Nusa Pudut, Nusa Dua Beach and Timbis Beach, TSM values ranged from 15.11-42.70 mg/L. Based on research conducted by (Risuana et al., 2017), it was found that the TSS concentration was 22.44 mg/L in the Badung River. A TSM value that is greater than 25 mg/L indicates that this condition has little effect on the interests of fisheries. Based on research conducted by (Rizka et al., 2020), giving TSS concentrations of 10 mg/L; 30 mg/L and 50 mg/L has a significant effect on reducing zooxanthellae density in coral polyps, the higher



Figure 7. Mapping of TSM in the southeastern sea of Bali Island (2020)



Figure 8. Mapping of TSM in the southeastern sea of Bali Island (2022)

the concentration of TSS given, the higher the decrease in zooxanthellae density. At the tissue level, TSS affects the thickness of coral polyp tissue. The stress conditions in corals caused by TSS can be seen from the decrease in zooxanthellae density and chlorophyll concentration in coral polyp tissue (Table 5). The characteristics of suspended loads produced by the watershed are related to the water discharge and the season that occurs. The correlation between water discharge and total volume concentration of suspended particles based on satellite shows a high correlation. The peak water discharge in a watershed is always associated with a high value of total volume concentration of suspended particles. The peak water discharge in a river flow generally occurs during the rainy season. Based on the results of research conducted by (Tanto et al., 2017), the ebb and

Data Date	Influence on fisheries interests	Color	TSM value (mg/L)	
October 10th, 2018	No effect	Dark blue, light blue and orange	0.01–17.91	
	Little impact	Red	25.53-42.77	
November 8 th , 2020	No effect	Dark blue, light blue and orange	0.66–21.13	
	Little impact	Red	26.45-42.11	
November 03 rd , 2022	No effect	Dark blue, light blue and orange	1.34–20.86	
	Little impact	Red	26.87-42.70	

Table 5.	TSM	data	in	research are	a 20	018-	-2022
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flow of ocean currents significantly affect ocean currents in Benoa Bay waters. The current speed during the full moon is higher than the speed of the quarter current in the area. A fairly high current reaching 1.715 m/s occurs at the mouth of the bay during the full moon with an irregular pattern.

Ocean currents are one of the physical oceanographic factors that influence the process of sedimentation (addition) and abrasion (reduction) of land. The presence of physical oceanographic factors affects the distribution of TSM in the waters. According to (Wijayanti, 2020), high current speeds cause high TSM values, while low current speeds tend to precipitate suspended sediment and cause sedimentation.

However, it is important to note that the chlorophyll-a and TSM values presented here have not been validated with field measurements, which is a key limitation of this study. The lack of in situ chlorophyll-a concentrations or TSM sampling limits the accuracy assessment of satellitederived estimates. In this study, to prove the accuracy of the analysis results using C2RCC, the researcher validated it with other field research in places that still cover the research area adjusted to the same year or season in the analysis. Although C2RCC is a robust processor trained on a global database of water optical properties (Filipponi, 2018), regional tuning is often necessary to reduce bias and improve precision (Warren et al., 2019). Future studies should incorporate groundbased sampling of water quality parameters coinciding with Sentinel-2 overpasses to enable quantitative validation of remote sensing outputs and to assess algorithm performance under local optical conditions.

To improve and sustain the results of this study, it is recommended that future research need to analyze chlorophyll-a and TSM values over a longer time period, including across different seasons. This would allow for a more detailed understanding of the range and variation of these values. Chlorophyll-a plays an important role in determining the trophic status of the waters, while TSM is a useful indicator of water conditions relevant to fisheries. Both parameters are key indicators of overall water quality in the study area. Another recommendation arising from this analysis is the need for continuous monitoring, improved water quality management, and the development of informed policies to support sustainable use of the region's aquatic resources.

CONCLUSIONS

This study analyzed chlorophyll-a and TSM concentrations in the south-eastern coastal waters of Bali using Sentinel-2 satellite imagery to evaluate the region's trophic status and sediment load. The findings demonstrate that the seasonal variation plays a significant role in influencing the results of Sentinel-2 satellite data analysis. The highest chlorophyll-a concentrations were recorded during the rainy season, with peak values observed on 8 November 2020 (43.65 mg/ m³), 3 November 2022 (42.11 mg/m³), and during the transitional period on 10 October 2018 (39.19 mg/m³). These elevated values were primarily detected in shallow coastal areas such as Tanjung Parangan, Serangan Beach, Lebangan Bay, Tanjung Benoa Beach, Nusa Pudut, Nusa Dua Beach, and Timbis Beach. Based on the findings, shallow waters in the study area are classified as mesotrophic to supereutrophic, indicating moderate to high nutrient levels, whereas deeper waters fall into the ultraoligotrophic to oligotrophic categories, reflecting low nutrient concentrations.

Similarly, the highest TSM concentrations were also recorded during the transition from the dry to the rainy season, particularly on 10 October 2018 (42.77 mg/L), followed by values recorded during the rainy season on 3 November 2022 (42.70 mg/L) and 8 November 2020

(42.11 mg/L). The highest TSM levels were also concentrated in shallow-water locations. Despite these elevated values, TSM concentrations above 25 mg/L are generally considered to have limited impact on fisheries, suggesting that current sediment conditions are not likely to pose a significant threat to fishery activities in the region.

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