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Spatial Assessment and Mapping of Water Quality in Lake Sentani (Indonesia) Using In-Situ Data and Satellite Imagery

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ABSTRACT

This study aims to examine the water quality of Lake Sentani using both in-situ data and satellite remote sensing data. In-situ data was taken in July 2023 at 18 sampling sites, including temperature, DO, pH, TDS, and water transparency. In-situ data is also used to develop and validate algorithms for estimating water quality from satellite remote sensing data. Multi-temporal Landsat-8 satellite imagery was used to spatially and temporally map the surface water quality of Lake Sentani. In-situ data showed temperature, DO, pH, TDS, and water transparency ranging from 29.3°C to 31.8°C, 1.7 mg/L to 7.9 mg/L, 7.75 to 8.64, 23 mg/L to 46 mg/L, and 2.28 m to 2.94 m, respectively. Only water transparency does not meet the quality standards for water quality (class 1 and class 2), while the other parameters meet class 1 to class 3 quality standards for surface water samples. The accuracy of the algorithm used and the resulting one has a low Mean Absolute Error value, namely 0.81 (temperature), 0.37 (DO), 4.84 (TDS), and 0.12 (water transparency). The temperature and TDS concentrations from the satellite imagery data ranged from 28.110°C to 33.918°C, and 7.829 mg/L to 102.702 mg/L, respectively. Both of these parameters still meet water quality standards. The DO concentrations ranged from 2.228 mg/L to 12.562 mg/L, and water transparency ranged from 0.424 m to 3.151 m. The concentration of DO and water transparency do not meet quality standards in several parts of Lake Sentani, especially in November and August.

Keywords: water quality, spatial and temporal, remote sensing, algorithm, Landsat-8, Lake Sentani.

INTRODUCTION

Lake Sentani is one of the lakes that has become a priority for sustainable lake management based on the results of the Indonesian Lakes National Conference 2009, which declared concern for the condition of lake ecosystems in Indonesia which is increasingly threatened due to damage and pollution. In recent years, the condition and quality of Lake Sentani have been quite worrying and have changed its function as a storage area for waste from domestic activities carried by the river. Lake quality is strongly influenced by the social environment and the number of rivers that flow into it (Akkoyunlu and Akiner, 2012; Musliu et al., 2018), land use around the lake (Wang et al., 2023), internal hydrodynamic processes (Shin et al., 2023), and climate change (Han and Bu, 2023). As many as 14 rivers directly contribute to the quality of Lake Sentani, thus making it a storage area for various anthropogenic waste originating from household and industrial waste (small and medium scale), which can result in the contamination of Lake Sentani (Tanjung et al., 2022). The condition of Lake Sentani has become even more apprehensive after the flash floods that occurred in March 2019, which brought a large volume of anthropogenic waste and accumulated in Lake Sentani so that it has shown symptoms of eutrophication and pollution in several locations (Walukow et al., 2023). Various problems in Lake Sentani can directly threaten the multiple potentials, including as a habitat for aquatic biota, business development potential in the fisheries sector, ecotourism development potential, and potential as a water source for household and industrial needs.

Various studies have been conducted to assess the water quality of Lake Sentani (Walukow et al., 2008; Astuti et al., 2009; Purwanto et al., 2013; Indrayani et al., 2015; Sulawesty and Suryono, 2016; Walukow, 2016; Prasetia and Walukow, 2021) and several rivers leading to Lake Sentani (Walukow et al., 2021; Haerati and Walokuw, 2022; Tanjung et al., 2022). Most of the results of these studies conclude that there has been pollution (mild to moderately polluted) in Lake Sentani and several rivers leading to Lake Sentani, where several environmental parameters have exceeded the established quality standards. In general, the quality of fresh water in Indonesia has been stipulated in the Government Regulation of the Republic of Indonesia No. 22 of 2021 (Pemerintah Republik Indonesia, 2021), where water quality status is the level of water quality conditions at a certain time compared to water quality standards.

Until now, there has been no research that examines the water quality of Lake Sentani spatially and temporally. Previous studies only focused on specific locations, especially around river mouths and settlements, while other locations have yet to be studied. These unstudied locations also have great potential, especially as fish habitat. In addition, previous research only examined water quality at a particular time (data collection time). They should temporarily check Lake Sentani's water quality to determine changing trends. This study aims to assess the water quality of Lake Sentani spatially and temporally using in-situ data and satellite imagery. The advantage of using satellite imagery is that it can be used to estimate water quality parameters spatially and temporally because satellite imagery covers large areas, and previous data is available. In-situ measurements were carried out at several locations, where the data obtained was used as input for developing algorithms from multi-temporal Landsat 8 satellite imagery. Therefore, the novelty of this research is to produce algorithms for several water quality parameters that are appropriate to the conditions of Lake Sentani. The resulting algorithm will be helpful for determining the quality of several water parameters spatially. That is, it can be used to estimate the distribution of water quality in locations that have never been studied before. Meanwhile, temporal data from satellite imagery is helpful for determining trends in changes in several water quality parameters in Lake Sentani.

MATERIALS AND METHODS

Sampling sites

This research was conducted at Lake Sentani in Jayapura Regency, Papua Province, Indonesia. There are 18 sites of in-situ Lake Sentani water quality measurement (Figure 1). The in-situ data collection sites include river mouths, settlements, aquaculture locations, and the middle of the lake.In-situ data collection was carried out on July 4, 2023, from the morning to the afternoon. The water quality parameters measured include water temperature, Dissolved Oxygen (DO), Potential of Hydrogen (pH), Total Dissolved Solids (TDS), and transparency of the waters. The equipment used includes a thermometer (temperature probe TP-07), DO meter (Lutron DO-5519), pH meter (Lutron pH-221E), TDS meter (EZ-9909), and Secchi-disk. In-situ measurements were carried out at surface waters (10 cm depth) at all sites, while at 5 m, 10 m, 15 m, and 20 m depths, they were only carried out at five sites (St. 1, St. 6, St. 9, St. 14, and St. 16). Parameter values of temperature, DO, pH, and TDS on the surface of the waters were measured directly by immersing the probe tip. In contrast, at a depth of 5 m to 20 m, it was estimated by taking water samples using the Van Dorn. Positioning coordinates for in-situ data collection using the Garmin GPSMap 65s Multi-Band.

In-situ data spatial mapping

The Geographic Information System approach with the data interpolation method can be used to estimate the water quality value of Lake Sentani in the unsampled part of the lake (Hamuna and Tanjung, 2021). Interpolation is a method for predicting values on a grid not represented by sample points (Childs, 2004). In this study, the

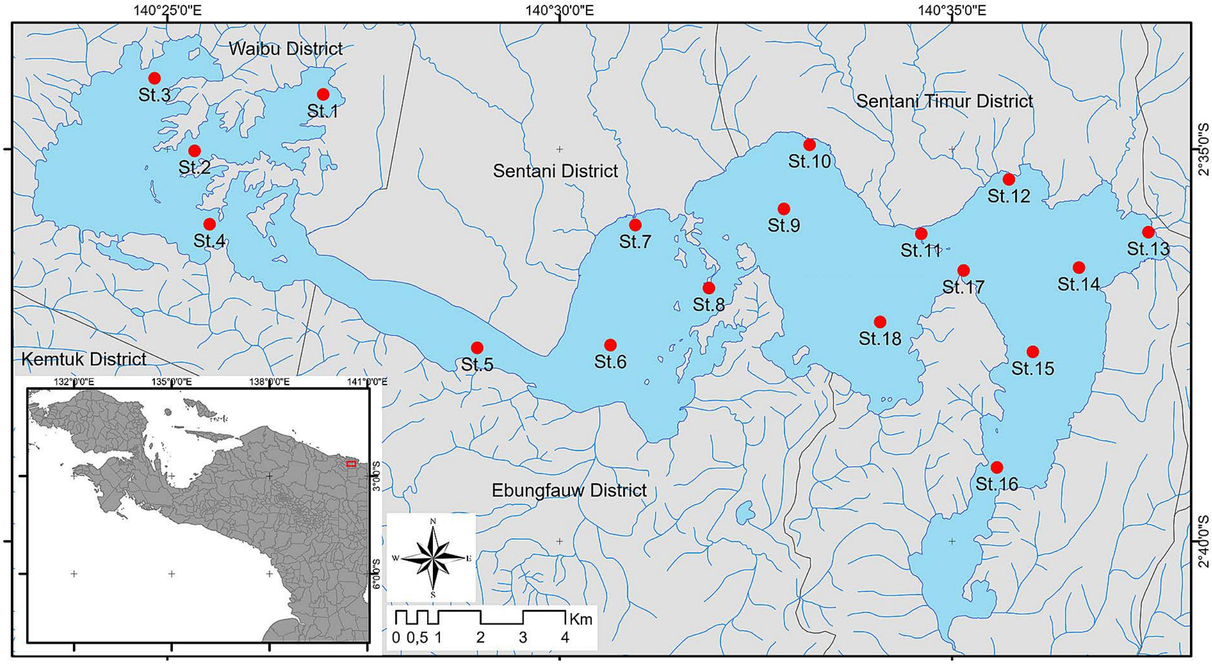

Figure 1. Study location map showing sampling sites in Lake Sentani, Jayapura Regency, Indonesia

interpolation method used is Spline with barriers. The Spline algorithm is an accurate interpolation that passes through every surface data point (Hofierka et al., 2002), and in several studies obtained low root mean square error values in interpolating water quality data (North and Livingstone, 2013; Kamaruddin et al., 2021; 2022; Jaffar et al., 2022). These barriers aim to process data interpolation only in the study area (Lake Sentani). In this study, the polyline features data of Lake Sentani produced by the Geospatial Information Agency of Indonesia (Badan Informasi Geospasial; BIG) are used as barriers in the interpolation process, which can be obtained from the website https://tanahair.indonesia.go.id.

Satellite image processing and algorithm development

Satellite imagery has been widely used for assessing and monitoring lake water quality in various countries (Politi et al., 2015; Mushtaq and Lala, 2016; Blix et al., 2018; Song and Wang, 2019; Jaelani and Ratnaningsih, 2019; Pereira et al., 2020; Wang et al., 2021; Seleem et al., 2022; Cruz-Montez et al., 2023). The satellite imagery used in this study is Landsat-8 level 1 at path/row 101/62, which can be downloaded from the website http://earthexplorer.usgs.go. The characteristics of Landsat 8 images are presented in Table 1. In this study, several Landsat-8 satellite imagery

Table 1. Characteristics of each band in the Landsat 8 satellite imagery

Bands		Wavelength (µm)	Resolution (m)
1	Coastal/Aerosol	0.433–0.453	30
2	Blue	0.450–0.515	30
3	Green	0.525–0.600	30
4	Red	0.630–0.680	30
5	Near-Infrared	0.845–0.885	30
6	Shortwave Infrared (SWIR) 1	1.560–1.660	30
7	Shortwave Infrared (SWIR) 2	2.100–2.300	30
8	Panchromatic	0.500–0.680	15
9	Cirrus	1.360–1.390	30
10	Thermal Infrared (TIRS) 1	10.60–11.20	100
11	Thermal Infrared (TIRS) 2	11.50–12.50	100

datasets were used to monitor changes in the water quality of Lake Sentani, including those acquired on July 1, 2023, May 14, 2023, November 19, 2022, and August 15, 2022. Satellite image processing starts from image correction to the application of algorithms to determine the water quality of Lake Sentani. The geometric correction of satellite imagery aims to match the coordinates of the image to the location of the measurement results in the field. Radiometric calibration aims to obtain ToA emission values by changing the Digital Number of satellite images applied to the thermal bands (B10 and B11) using the following Equation 1 (United States Geological Survey, 2019):

$$L_\lambda' = M_L \times Digital\ Number \times A_L \quad (1)$$

where: L_λ' – the ToA spectral radiance value, M_L – the band-specific multiplicative rescaling factor, A_L – the band-specific additive rescaling factor. The M_L and A_L values can be known from the image metadata.

Next, the ToA spectral radiance value is converted to obtain the brightness temperature value from B10 and B11. The equation to obtain the brightness temperature value is as follows (United States Geological Survey, 2019):

$$TB = \frac{K2}{Ln\left(\frac{K1}{L_\lambda}\right) + 1} - 273.15 \quad (2)$$

where: TB – the brightness temperature, $K1$ and $K2$ – calibration constants, both of which can be known from the image metadata.

In addition to radiometric corrections atmospheric correction was also carried out which aims to obtain ToA reflectance values applied for B1 to B7. The equations for making atmospheric corrections are as follows (United States Geological Survey, 2019):

$$\rho_\lambda' = M_\rho \times Digital\ Number \times A_\rho \quad (3)$$

$$\rho_\lambda = \frac{\rho_\lambda'}{sin\,(\theta_{SE})} \quad (4)$$

where: $\rho_{\lambda'}$ – ToA planetary reflectance, M_ρ – a band-specific multiplicative rescaling factor, A_ρ – a band-specific addictive rescaling factor, ρ_λ – ToA reflectance corrected for sun angle, and θ_{SE} – local sun elevation angle. The image metadata can tell M_ρ, A_ρ, and θ_{SE} values.

Estimation of surface water temperature (ST) in Lake Sentani from satellite imagery is carried out by transforming the brightness temperature value of TB10, which has been obtained previously, into a surface temperature value using an algorithm developed by Arief et al. (2015) as follows:

$$ST = 0.0234(TB10)^3 - 1.3107(TB10)^2 + 24.335(TB10) - 119.68 \quad (5)$$

The estimation of DO, TDS, and water transparency parameters was done by developing an algorithm from the correlation relationship between in-situ data and Landsat-8 satellite imagery acquired on July 1, 2023. The correlation of in-situ data with the ToA reflectance value corrected for the sun angle from B1 to B7 is used to estimate water transparency and TDS values. While the correlation between in-situ data and the brightness temperature of TB10 or TB11 is used to estimate DO values because there is a relationship between water temperature and DO (Karakaya et al., 2011; Lin et al., 2014; Chatziantoniou et al., 2022).

Data analysis

Analysis of Lake Sentani water quality data was carried out descriptively by comparing the values of water quality parameters (water temperature, water transparency, DO, pH, and TDS) from in-situ data and estimated satellite imagery with water quality standards class 1 (for drinking water), class 2 (for water recreation and freshwater fish farming), and class 3 (freshwater fish farming) based on Government Regulation of the Republic of Indonesia No. 22 of 2021 which is presented in Table 2 (Pemerintah Republik Indonesia, 2021).

Statistical analysis

Statistical analysis is needed to validate the accuracy of estimated water temperature, water transparency, DO, and TDS from satellite imagery. The validation was carried out by comparing the estimation results from satellite imagery with in-situ measurement data at each sampling site. The method used in the validation stage is

Table 2. Lake water quality standards

Parameters	Class 1	Class 2	Class 3
Temperature (°C)	Dev 3	Dev 3	Dev 3
DO (mg/L)	6	4	3
pH	6–9	6–9	6–9
TDS (mg/L)	1000	1000	1000

determining the Mean Absolute Error (MAE) value (Chatziantoniou et al., 2022). MAE calculates the precision, which represents the average distance between the estimate and the true value based on the following equation:

$$\mathrm{MAE} = \sum_{i=1}^{n} \frac{|y_i - x_i|}{n} \quad (6)$$

where: y_i – the estimated value from satellite imagery, and x_i – the in-situ measured value.

RESULTS

In-situ data

The results of in-situ measurements of the five environmental parameters in Lake Sentani are presented in Table 3. The water temperature ranges from 29.3°C to 31.8°C, where the maximum temperature is at the water's surface, and the minimum is at a depth of 20 m. Likewise, the DO parameter, where the maximum value is at the water's surface, and the minimum is at a depth of 20 m with a DO value range between 1.7 mg/L to 7.9 mg/L. The high concentration of DO on the surface can be due to the high photosynthetic process in the surface waters compared to the deeper parts of the waters. The pH values ranged from 7.75 to 8.64, with the highest pH at the surface and the lowest at a depth of 20 m. The pH values from in-situ data at the time of this study indicate that the waters of Lake Sentani tend to be alkaline. Conversely, the concentration of TDS from in-situ data will be higher at a depth of 20 m compared to the surface waters, where the measured TDS concentration ranges from 23 mg/L to 46 mg/L. The water transparency level ranges from 2.28 m to 2.94 m.

The results of in-situ data show that the deeper the water, the lower the temperature, DO, and pH. The analysis results show that the coefficient of determination (R^2) for water depth's effect on the average temperature, DO, and pH values are 0.957, 0.954, and 0.998, respectively. The depth of the waters also affects the concentration of TDS, where the deeper the waters will increase the concentration of TDS with a coefficient of determination (R^2) of 0.910. The values of the coefficient of determination show a very strong and significant effect of water depth on changes in temperature, DO, pH, and TDS.

The spatial distribution and range of surface water quality values of Lake Sentani from the interpolation of in-situ data for parameters of

Table 3. Results of in-situ measurements for five water quality parameters in Lake Sentani

Depth	Temperature (°C)	DO (mg/L)	pH	TDS (mg/L)	Transparency (m)
Surface (0 m)	30.1–31.8	6.2–7.9	8.35–8.64	23–47	2.28–2.94
5 m	29.7–31.3	4.1–6.1	8.15–8.52	25–40	-
10 m	29.5–31.8	2.9–5.7	9.71–8.39	31–43	-
15 m	29.4–29.9	2.1–4.2	7.82–8.24	34–45	-
20 m	29.3–29.9	1.7–3.6	7.75–8.08	36–46	-

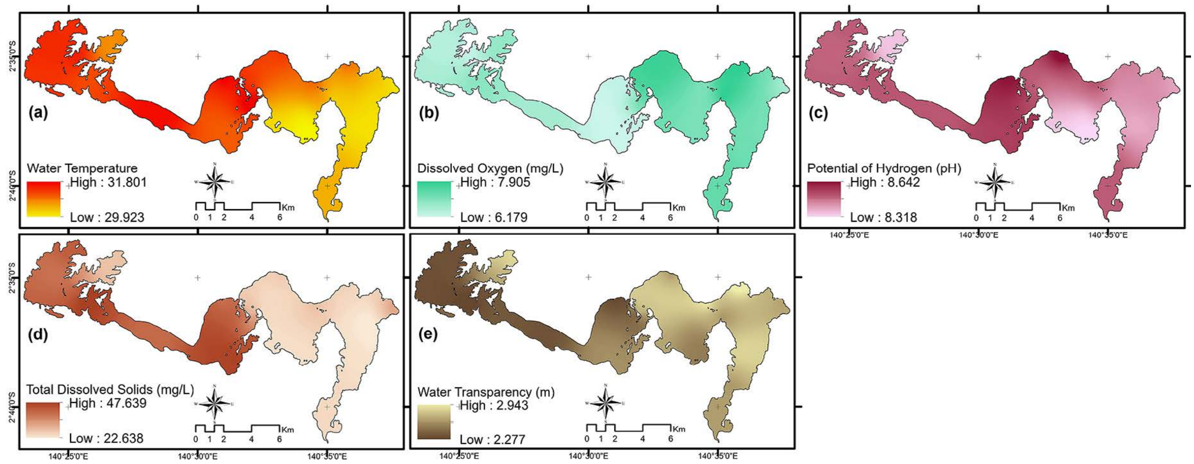

Figure 2. Spatial distribution of surface water quality in Lake Sentani interpolated from in-situ data

temperature, DO, pH, TDS, and water transparency are presented in Figure 2. Water temperature, pH, and TDS tend to be higher in the east and middle of Lake Sentani than in the west. In contrast, DO concentrations and the level of water transparency were higher in the eastern part of Lake Sentani than in the western and central parts of Lake Sentani. The mean values of temperature, DO, pH, TDS, and water transparency of the interpolated waters were 30.883±0.529°C, 6.942±0.481 mg/L, 8.466±0.065, 33.178±8.852 mg/L, and 2.579±0.175 m, respectively. These average values are relatively the same as the average values of in-situ data on the surface of the waters for the parameters of temperature, DO, pH, TDS, and transparency of the waters, namely 30.911±0.591°C, 7.017±0.535 mg/L, 8.471±0.079, 32.111±8.145 mg/L, and 2.601±0.200 m, respectively.

Algorithm accuracy

In this study, the algorithm developed to predict water quality values included using the TB11 value for DO, a combination of B1, B3, and B4 remote sensing reflectance values for TDS, as well as a combination of B1, B2, and B3 remote sensing reflectance values for water transparency (Table 4). The R^2 value of the three algorithms ranges from 0.41 to 0.49. At the same time, the algorithm for predicting water temperature from Landsat-8 satellite imagery uses the existing algorithm. The pH parameter cannot be predicted because there is no exact algorithm, either the developed or the current algorithm.

The accuracy of the algorithm used to predict water temperature and the resulting algorithm for predicting DO, TDS, and water transparency values from Landsat-8 satellite imagery are presented in Table 4. The MAE values for temperature, DO, and water transparency are very low, namely 0.81, 0.37, and 0.12, respectively. The MAE values are close to the decimal precision of in-situ measurements. The range of MAE values is acceptable for most real-life applications as environmental parameter values fluctuate, especially temperature and DO. Meanwhile, the MAE value for water transparency is very small and can be assumed to be the same as the in-situ measurement value. The MAE value for the TDS parameter is greater than 1 (MAE = 4.84), but this accuracy is considered reasonable and acceptable for data sets with a high range of values.

Lake Sentani water quality from Landsat-8 satellite imagery

The results of multitemporal Landsat-8 satellite imagery processing show no significant difference in the temperature of the waters of Sentani Lake each time the image is used (Figure 3). The water temperature in July 2023, May 2023, November 2022 and August 2022 ranged from 29.940°C to 33.918°C (average 30.096±0.105°C), 28.260°C to 30.195°C (average 29.972±0.038°C), 29.940°C to 33.637°C (average 30.024±0.075°C), and 28.110°C to 30.195°C (average 29.947±0.335°C), respectively. The maximum high water temperature values in July 2023 and November 2023 are likely biased or noise values due to satellite imagery disturbances, such as cloud cover. Spatially, the spatial distribution of water temperature in July 2023 and May 2023 is relatively even. The water temperature in November 2022 in the western and eastern parts of Lake Sentani is lower than in the central region; on the contrary, in August 2022, it is higher.

The spatial and temporal distribution of DO concentrations in Lake Sentani from Landsat-8 satellite imagery is presented in Figure 4. Spatially, the distribution of DO in July 2023 and May 2023 was relatively even, except for a few relatively lower locations. In November 2022, DO concentrations were higher in the central to western parts of Lake Sentani, while in August 2022, they were higher in the central part of Lake

Table 4. The algorithm used to estimate the value of water quality parameters from Landsat-8 satellite imagery

Parameters	Algorithm	Data input	R^2	MAE	References
Temperature	$0.0234(TB10)^3 - 1.3107(TB10)^2 + 24.335(TB10) - 119.68$	Brightness temperature	-	0.81	Arief et al. (2015)
DO	$1.3752TB11 - 17.964$	Brightness temperature	0.49	0.37	This study
TDS	$-60.886((B1+B4)/B3) + 192.26$	Remote sensing reflectance	0.41	4.84	This study
Transparency	$6.9767(B1/(B2+B3)) - 2.9648$	Remote sensing reflectance	0.42	0.12	This study

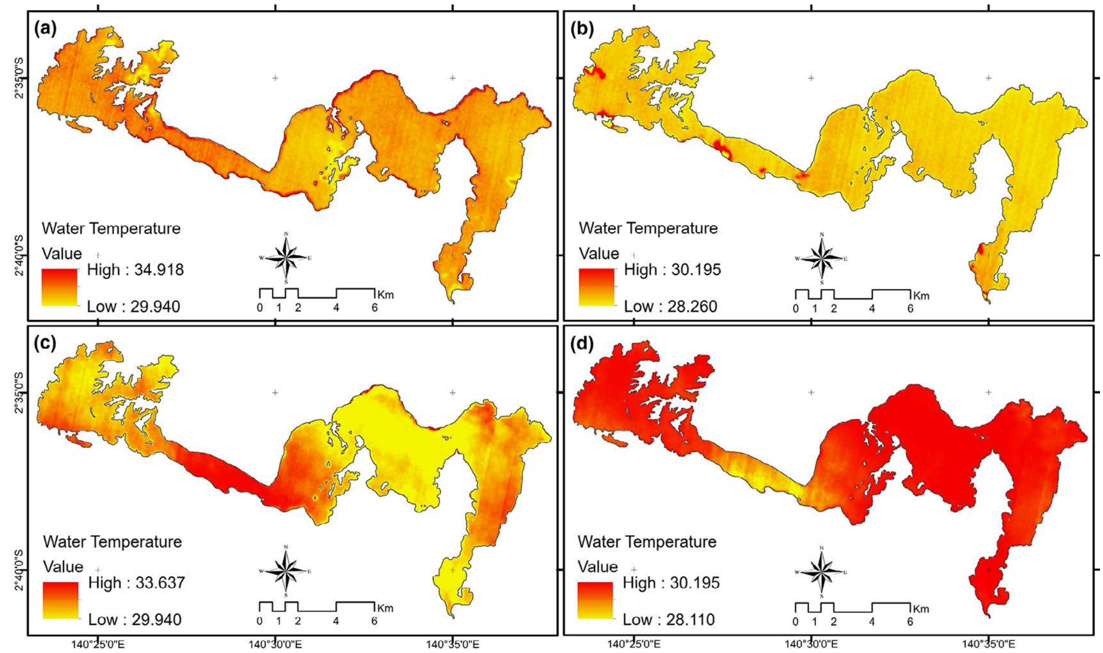

Figure 3. Spatial distribution of water temperature in Lake Sentani extracted from Landsat-8 satellite imagery; (a) July 2023, (b) May 2023, (c) November 2022, and (d) August 2022

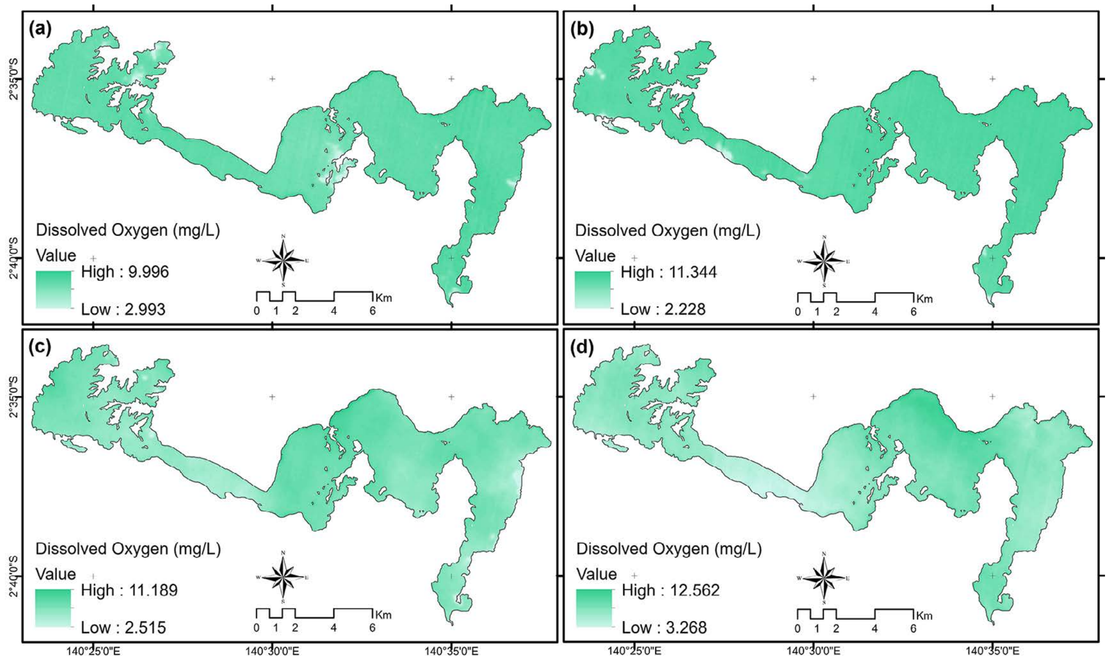

Figure 4. Spatial distribution of dissolved oxygen (DO) concentrations in Lake Sentani extracted from Landsat-8 satellite imagery; (a) July 2023, (b) May 2023, (c) November 2022, and (d) August 2022

Sentani. The DO values in May 2023 were higher than in August 2022, July 2023, and November 2022, namely 7.830±0.523 mg/L, 7.263±1.046 mg/L, 6.929±0.451 mg/L, and 5.882±1.177 mg/L, respectively. The distribution of TDS concentrations in July 2023, November 2022, and August 2022 was higher in the central part of Lake Sentani than in the east and west (Figure 5). In contrast, in May 2023, it was relatively higher in the eastern part of Lake Sentani. Even though the maximum TDS value in November 2022 was lower than in other periods, the average TDS in November 2022 was higher than in August 2022, May 2023, and July 2023, namely 47.679±4.399

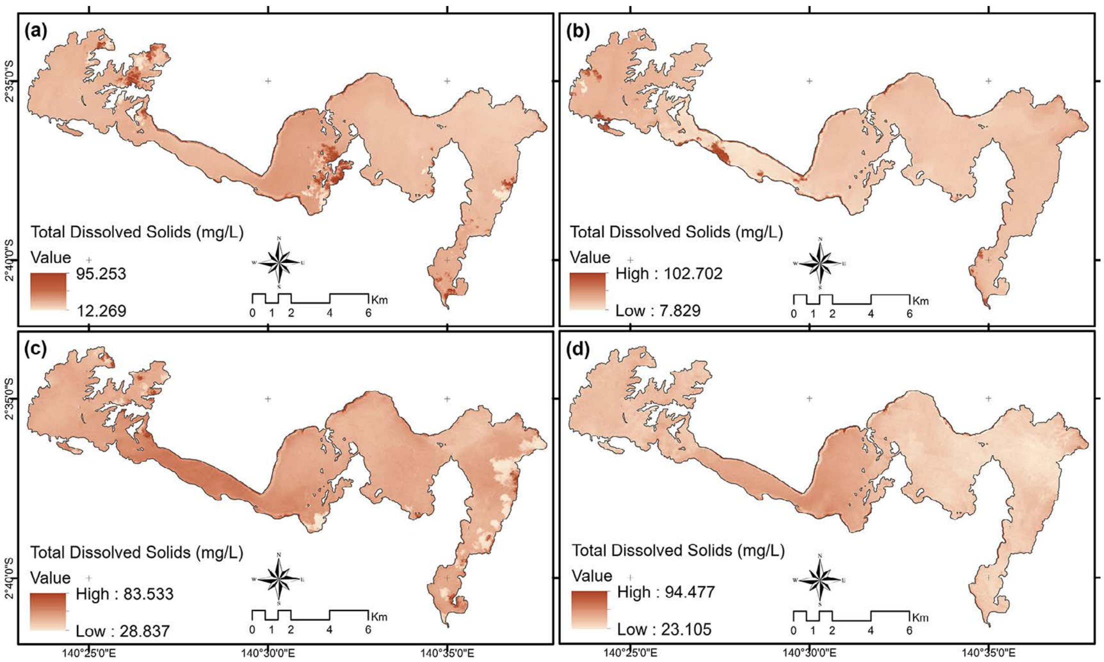

Figure 5. Spatial distribution of total dissolved solids (TDS) in Lake Sentani extracted from Landsat-8 satellite imagery; (a) July 2023, (b) May 2023, (c) November 2022, and (d) August 2022

mg/L, 45.239±4.202 mg/L, 36.737±6.802 mg/L, and 33.136±7.917 mg/L, respectively.

The transparency of the waters in July 2023 and May 2023 is relatively the same and evenly distributed throughout Lake Sentani, except for a few locations with a lower level of transparency (Figure 6). Transparent waters in November 2022 are found higher up in the western part of Lake Sentani. Likewise, in August 2022, the level of water transparency was also higher in the western part, although not overall. The average level of water transparency in May 2023 was higher than in July 2023, November 2022, and August 2022, namely 2.577±0.271 m, 2.552±0.306 m,

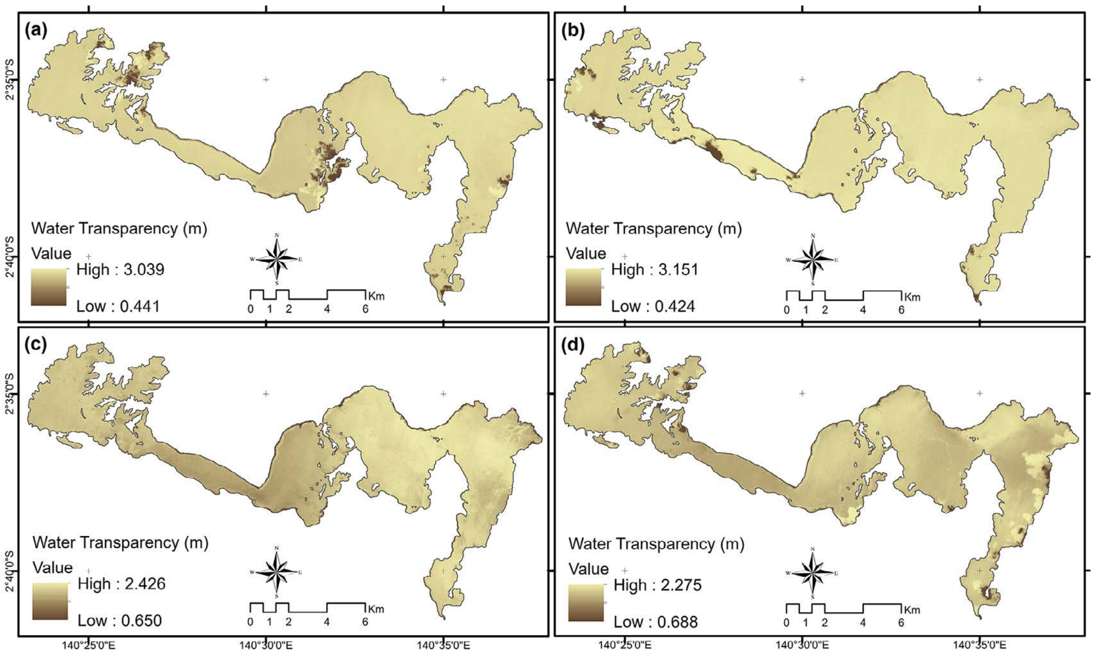

Figure 6. Spatial distribution of water transparency in Lake Sentani extracted from Landsat-8 satellite imagery; (a) July 2023, (b) May 2023, (c) November 2022, and (d) August 2022

2.135±0.140 m, and 1.929±0.154 m, respectively. Water temperature, DO, TDS, and water transparency in Lake Sentani in July 2023 at 18 sampling sites, from both in-situ data and satellite imagery, are relatively the same, with relatively similar average values (Table 5). So, the algorithm used to predict these four parameters is very accurate. Likewise, the average temperature values in May 2023, November 2022, and August 2022 are relatively the same as in-situ data, where the difference is less than 1°C. The average DO concentration from satellite imagery in May 2023 and August 2022 at 18 sampling sites was higher than in-situ data, but the difference was less than 2 mg/L. Still, the average DO concentration in November 2022 was very low, with a difference of more than 3 mg/L compared to DO concentrations in other months (in-situ data and satellite imagery). TDS concentrations in Lake Sentani at 18 sampling sites were higher in November 2022 and August 2022. On the other hand, the average level of water transparency in the two data periods is lower.

DISCUSSION

This study has provided a spatial description of several parameters of the water quality of Lake Sentani. Lake water quality plays an important role in meeting various human needs (as a source of drinking water to support aquaculture and recreation activities) and as a natural prerequisite for sustaining biodiversity. The water quality of Lake Sentani from in-situ measurements in this study is similar to the results of previous studies. The results of research by Astuti et al. (2009) showed the range of water temperature, DO, pH, and water transparency ranged from 29.4°C to 32.0°C, 0.14 mg/L to 7.05 mg/L, 7.5 to 9.0, and 1.4 m to 2.2 m, respectively. Likewise, the results of research by Sulawesty and Suryono (2016) which obtained values for parameters of water temperature, DO, pH, and transparency of waters in the range between 22.68°C to 30.07°C, 0.20 mg/L to 12.59 mg/L, 6.63 to 8.74, and 2.1 m to 3.2 m, respectively. The two results of these studies also show that depth affects water parameters, the same results as this study. The deeper the waters will cause a decrease in water temperature, DO concentration, and pH. The results of research by Prasetia and Walukow (2021) found water temperature, DO, pH, and TDS on the surface waters of Lake Sentani (Gelanggang Expo; St.13 in this study) were 29.6°C, 6.1 mg/L, 8.14, and 69 mg/L, respectively. These results are relatively the same as the results of this study for the parameters of water temperature, DO, and pH, namely 30.1°C, 6.6 mg/L, and 8.39, respectively. The TDS concentration differed significantly, but both were still in the very low category (69 mg/L and 32 mg/L). The concentration of TDS in Lake Sentani is still lower than the concentration of TDS in several rivers as inlets for Lake Sentani, which range from 24 mg/L to 166 mg/L (Tanjung et al.,

Table 5. Summary of comparison of in-situ data and estimated Landsat-8 satellite imagery at 18 sampling sites in Lake Sentani

Data type	Period	Parameter	Temperature (°C)	DO (mg/L)	TDS (mg/L)	Transparency (m)
In-situ	July 2023	Min	30.1	6.2	23	2.28
		Max	31.8	7.9	47	2.94
		Mean±SD	30.911±0.591	7.017±0.535	32.111±8.145	2.601±0.200
Satellite image	July 2023	Min	30.027	6.610	25.083	2.365
		Max	30.211	7.598	42.726	2.749
		Mean±SD	30.101±0.062	7.013±0.929	32.108±5.183	2.601±0.129
Satellite image	May 2023	Min	29.949	8.661	29.466	2.104
		Max	29.980	9.200	55.953	2.759
		Mean±SD	29.961±0.009	8.954±0.157	37.104±5.481	2.594±0.137
Satellite image	Nov 2022	Min	29.940	2.937	43.205	1.761
		Max	30.193	6.286	55.918	2.276
		Mean±SD	30.017±0.068	3.873±1.013	47.098±3.101	2.124±0.157
Satellite image	Aug 2022	Min	28.799	5.994	41.010	1.745
		Max	30.193	10.296	55.235	2.085
		Mean±SD	29.986±0.317	8.428±1.049	45.633±4.311	1.949±0.094

2022) and 31.752 mg/L to 287.712 mg/L (Walukow et al., 2008).

Referring to lake water quality standards, the parameters of water temperature, DO, pH, and TDS from in-situ data (water surface) in this study still meet water quality standards for class 1 to class 3. Water transparency does not meet the quality standards for water quality for class 1 (minimum is 10 m) and class 2 (minimum is 4 m). Likewise, water temperature and TDS concentration from satellite imagery still meet spatially and temporally quality standards. Even though some locations have high water temperatures, they are still considered suitable because they have not exceeded the set temperature deviation (the difference with the air temperature above the water surface is 3°C). The DO concentration did not meet the quality standard for class 1 in several locations (in the central and eastern parts of Lake Sentani) in July 2023, May 2023, and August 2022, while in November 2022, it was dominant that it did not meet the class 1 quality standard (Figure 7). Likewise, water transparency in several parts of the lake (especially in the middle and on the outskirts of the lake) does not meet class 3 quality standards (Figure 8). Specifically in November 2022 and August 2022, water transparency does not meet class 1 to class 3 quality standards in all parts of Lake Sentani because the level of water transparency is very low (ranging from 0.650 m to 2.426 m for November 2022 and 0.688 m to 2.275 m for August 2022). The low level of water transparency on the shores of the lake can be caused by the large amount of garbage from community activities around Lake Sentani. Also, the water is dirty (blackish). Low water transparency can be caused by high levels of water turbidity, generally caused by suspended particles such as clay, mud, dissolved organic materials, bacteria, plankton, and other organisms (Irianto and Triweko, 2019), also because of the large amount of rubbish that has accumulated in the lake. High turbidity will cause a significant decrease in sunlight penetration, so the photosynthesis process cannot occur (Kangabam et al., 2017). Therefore, to increase water transparency in Lake Sentani, it is necessary to appeal to the public not to dredge rivers or throw rubbish into rivers. Indirectly, it can increase the DO concentration in the waters of Lake Sentani. If the waters are clear, sunlight can reach deeper waters so that the photosynthesis process occurs by phytoplankton, algae, and aquatic plants in Lake Sentani. More oxygen is produced by the photosynthetic process of algae, which is mainly found in the epilimnion zone, while the presence of oxygen in shallow, stagnant waters and many aquatic plants in the littoral zone is mainly produced from photosynthetic activity by aquatic vegetation (Irianto and Triweko, 2019). Generally, using satellite imagery and the right algorithm can strengthen

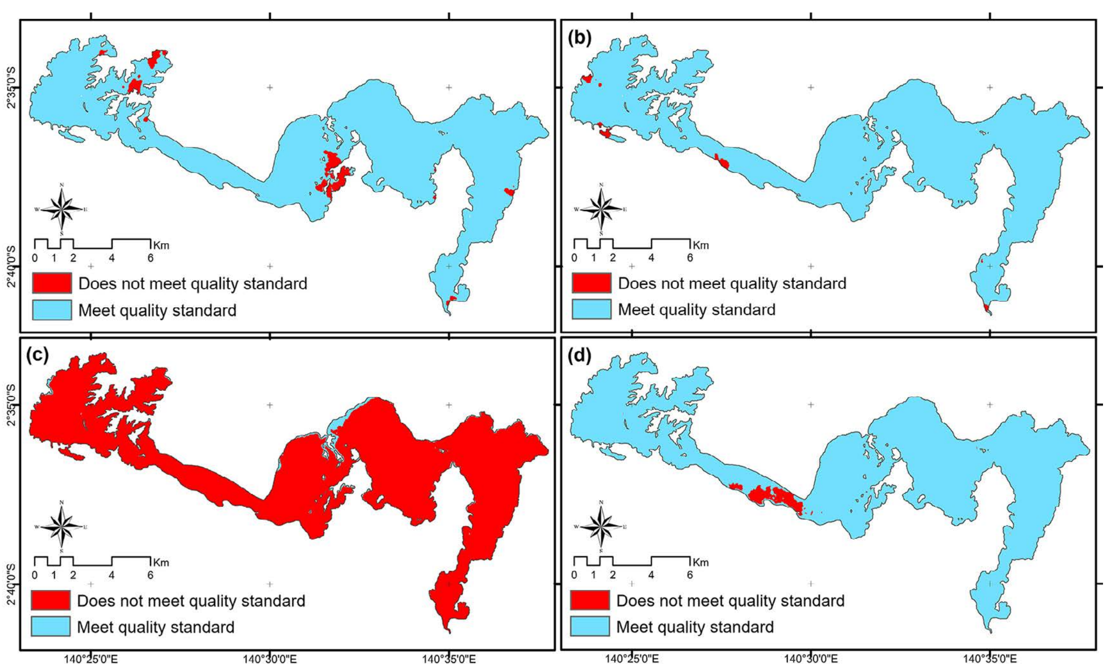

Figure 7. Spatial distribution of DO concentrations that do not meet class 1 quality standards; (a) July 2023, (b) May 2023, (c) November 2022, and (d) August 2022

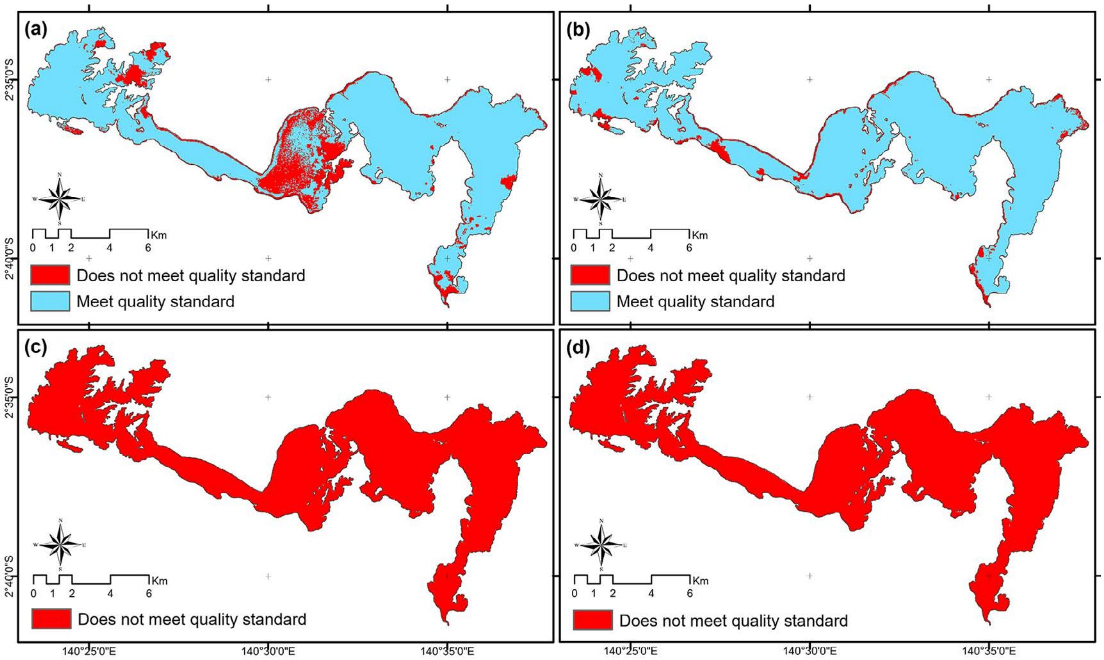

Figure 8. Spatial distribution of water transparency that does not meet class 3 quality standards; (a) July 2023, (b) May 2023, (c) November 2022, and (d) August 2022

the ability of water resources researchers and provide convenience for decision-makers to monitor changes in water quality more effectively and in time series (Gholizadeh et al., 2016; Cao et al., 2023). In this study, the regression method used to explore the relationship between water quality parameters from in-situ data and the spectral reflection of satellite images is different when compared to the algorithm used in other studies. However, the resulting algorithm has a low MAE (Mean Absolute Error) value, so the accuracy of the estimated value from satellite imagery can be used to predict the water quality of Lake Sentani.

CONCLUSIONS

The results of this study have provided an overview and information on the water quality of Lake Sentani, which includes parameters of water temperature, DO, pH, TDS, and water brightness from in-situ data and remote sensing imagery. In addition, an algorithm is also produced, which is very useful for monitoring changes in the water quality of Lake Sentani from Landsat-8 satellite imagery data. Based on in-situ data, the water temperature, DO, pH, and TDS in Lake Sentani still meet the water quality standards at all sampling sites. In contrast, water transparency does not meet the quality standards for class 1 and class 2 water at all sampling sites. Water temperature and TDS concentration from satellite imagery still meet spatially and temporally quality standards. The DO concentrations did not meet the quality standards for class 1 in July, May, and August in the central and eastern parts of Lake Sentani, while in November, they did not meet the quality standards in all parts of the lake. Likewise, water transparency does not meet class 3 quality standards in the middle and outskirts of the lake; however, in November and August, it does not meet class 1 to class 3 quality standards in all parts of Lake Sentani.

Policymakers can consider multi-temporal satellite remote sensing data as an alternative method for gathering information on changes in surface water quality in Lake Sentani. Further studies are urgently needed, including the addition of other environmental parameters to determine the water quality status of Lake Sentani. Collecting in-situ data in a seasonal context for algorithm development is also necessary.

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