International Journal of Innovative Environmental Studies Research 14(4):59-65, Oct-Dec., 2026

© SEAHI PUBLICATIONS, 2026 www.seahipublications.org ISSN: 2354-2918

DOI:10.5281/zenodo.23457807

Assessing the Trophic State of Oguta Lake, Imo State, Nigeria, Using Total Phosphorus and Landsat 8 OLI Imagery

Ighirighir, O.B.[1], Oyiborhoro, R.[1] & Enenajor, E.M.[2]

[1]Federal Polytechnic of Oil and Gas, Bonny Island, Rivers State, Nigeria
[2] Independent researcher, United Kingdom

ABSTRACT

Oguta Lake, the largest freshwater lake in south-eastern Nigeria, was oligotrophic during dry-season sampling, but its reflectance in Landsat 8 OLI imagery did not significantly track its trophic state index. Although the lake supports fishing, domestic water use and tourism, no trophic classification of it had been published. This study estimated Carlson's trophic state index from total phosphorus, TSI (TP), and tested whether it can be related to Landsat 8 OLI band values. Thirty water samples were collected on 31 December 2017 and analysed for turbidity (turbidity meter) and total phosphorus (ascorbic acid method). Turbidity ranged from 0.04 to 0.08 NTU and total phosphorus from 5.1 to 10.2 µg/L. TSI (TP) took two values, 27.6 and 37.6, both in the oligotrophic range. Phosphorus was evenly split between the two values, with no clear spatial pattern. A multiple regression of log-transformed TSI (TP) on Landsat 8 OLI Bands 1–9 was not significant ($R^2 = 0.274$, adjusted $R^2 = -0.053$, $F(9, 20) = 0.837$, $p = 0.591$), and no individual band coefficient was significant at the 0.05 level. The null hypothesis of no relationship was therefore not rejected. The results indicate low phosphorus enrichment at the time of sampling. However, the single sampling date, the use of phosphorus alone, the coarse resolution of the phosphorus data (two distinct values) and the very low turbidity readings limit the strength of these conclusions. Repeat sampling in wet and dry seasons, with chlorophyll-a and Secchi-disc measurements, is recommended before the lake's status is used for management decisions.

Keywords: Oguta Lake; trophic state index; total phosphorus; Landsat 8 OLI; remote sensing; Nigeria

1. INTRODUCTION

Lakes provide fisheries, domestic and municipal water, transport, recreation and tourism, and their condition responds quickly to pressures in the surrounding catchment (Jally et al., 2016). Nutrient enrichment from agricultural runoff, sewage and other human activities accelerates eutrophication, the excessive growth of algae and aquatic plants. In severe cases this depletes dissolved oxygen, harms fish and bottom-dwelling animals, and makes the water unfit for drinking, fish farming and recreation (USEPA, 2000; Membrillo-Abad et al., 2016).

Carlson (1977) proposed a trophic state index (TSI) that converts Secchi-disc transparency, chlorophyll-a or total phosphorus into a single numerical scale of algal biomass. Each of the three variables gives an independent estimate of trophic state, and total phosphorus is widely used because it is the nutrient that most often limits algal growth in fresh water (Carlson, 1977; Brown and Simpson, 2001). Carlson also stressed that trophic state is not the same as water quality: whether a given level of productivity is acceptable depends on how the water is used.

Laboratory analysis of water samples gives accurate point measurements, but it is slow and costly when a lake must be monitored repeatedly. Satellite imagery offers a way to extend such measurements over

space and time. Landsat data have been used to estimate lake clarity and trophic state in Minnesota and Michigan, and archived scenes allow retrospective assessment (Olmanson et al., 2002; Kloiber et al., 2002; Fuller and Minnerick, 2007; Li and Li, 2004). Studies of Indian and Mexican lakes have also related Landsat data to in-situ trophic indicators (Jally et al., 2016; Membrillo-Abad et al., 2016). Such work remains scarce in Nigeria.

Oguta Lake in Imo State is the largest freshwater lake in south-eastern Nigeria. It supports fishing, sand mining, transport and domestic water supply, and it has tourism potential (Ahiarakwem et al., 2012a). Earlier work on the lake examined its physical and environmental condition and water chemistry using Landsat TM imagery and field analysis (Ahiarakwem et al., 2012a, 2012b). To our knowledge, however, no trophic state classification of the lake has been published.

This study therefore had three objectives: (i) to describe the distribution of turbidity and total phosphorus across Oguta Lake; (ii) to determine the lake's trophic state from total phosphorus using Carlson's index; and (iii) to test the relationship between the calculated TSI and Landsat 8 OLI band values. The null hypothesis (H_0) was that there is no statistically significant relationship between TSI(TP) and Landsat 8 OLI reflectance.

2. Study area

Oguta Lake lies in Oguta Local Government Area of Imo State, in a natural depression on the east-bank floodplain of the River Niger downstream of Onitsha, at about latitude 5°41′–5°44′ N and longitude 6°45′–6°50′ E (Figure 1; Ahiarakwem et al., 2012a). The lake is linear in shape, with a reported surface area of about 1.8 km² in the dry season and 2.48 km² in the wet season, a shoreline of about 10 km, a maximum depth of about 8 m and a mean depth of about 5.5 m.

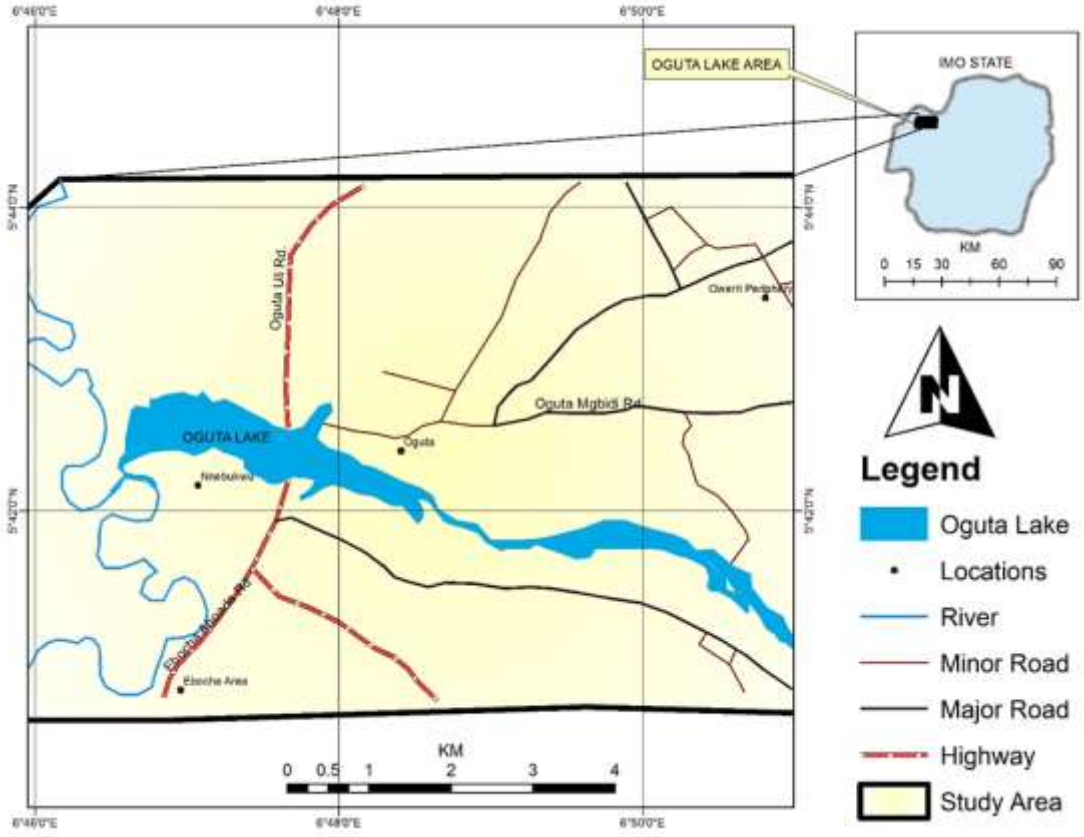

Figure 1. *Location of Oguta Lake and the study area, Imo State, Nigeria.*

The climate is equatorial, with mean monthly temperatures of about 25–28 °C and mean annual rainfall of about 2,500 mm, most of it between May and October. November to April is the drier, warmer period. The lake is fed by the Njaba and Awbana rivers throughout the year and by the Utu stream in the rainy season, and it receives overflow from the Niger at the peak of the rains. It drains into the Orashi River. The Orashi and the lake water are visibly different in colour at their confluence and do not mix immediately, which is a local tourist attraction.

Residents use the lake for fishing, transport, sand mining, bathing, washing and domestic water supply, and the state government regards it as a tourism and recreation asset. Sewage disposal, fishing practices that involve chemicals, and runoff from neighbouring farmland have been reported as pressures on the lake (Ahiarakwem et al., 2012a, 2012b).

3. MATERIALS AND METHODS

3.1 Research design and sampling

The study used a correlational design to test the relationship between a field-derived trophic index and satellite reflectance. The lake was overlaid with a 50 m × 50 m grid in QGIS, and 30 sampling stations were selected at random from complete grid cells (cells at least three-quarters within the lake were also eligible) so that the whole lake was covered. Station coordinates were recorded with a hand-held Garmin 72 GPS receiver. Water samples were collected on 31 December 2017 in labelled plastic bottles, rinsed beforehand with distilled water and then with water from the station, and were kept in a cooler away from light until analysis (Figure 2).

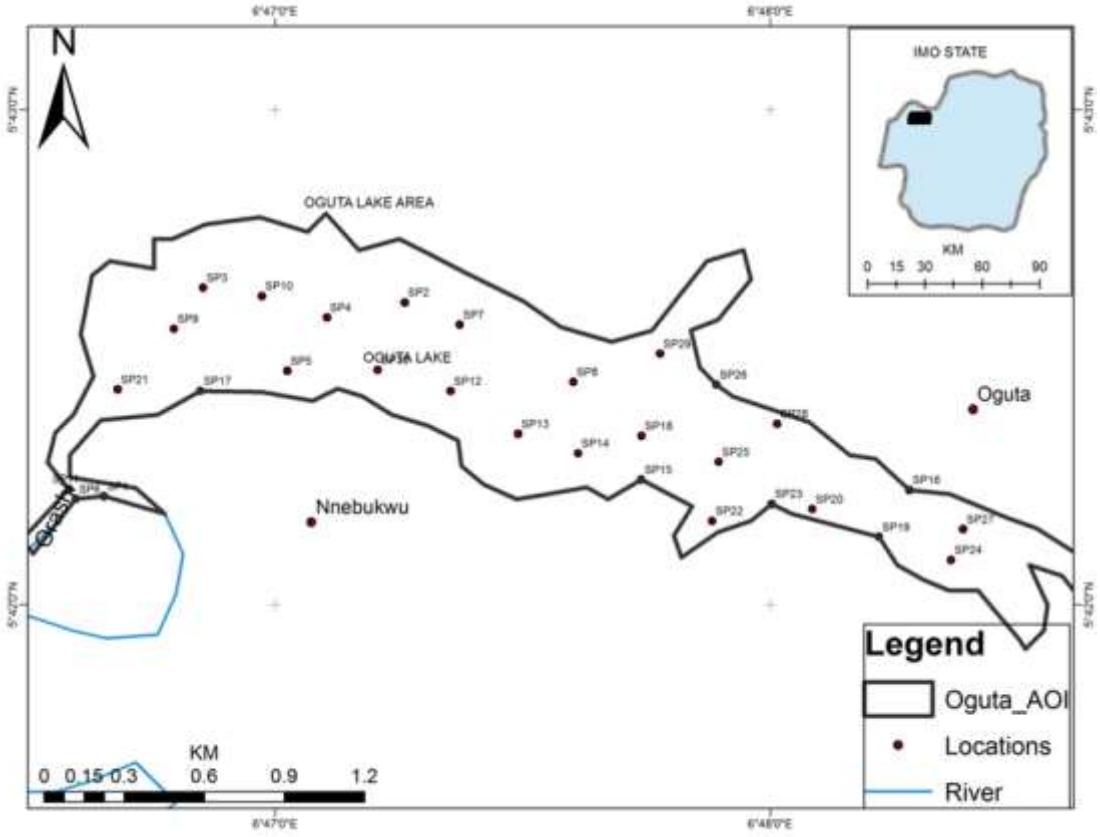

Figure 2. *Distribution of the 30 water sampling points across Oguta Lake.*

3.2 Laboratory analysis

Turbidity was measured with a turbidity meter and is reported in nephelometric turbidity units (NTU). Total phosphorus (TP) was determined by the ascorbic acid method and is reported in µg/L. All analyses were carried out in the Plant Science and Biotechnology Laboratory, University of Port Harcourt.

3.3 Trophic state index

The trophic state index based on total phosphorus was calculated for each station using Carlson's (1977) equation:

$$TSI(TP) = 14.42 \ln(TP) + 4.15$$

where TP is total phosphorus in µg/L. Trophic classes followed the scale in Table 1 (Carlson, 1977; Carlson and Simpson, 1996). Because the index was computed from phosphorus alone, it describes the lake's nutrient-based trophic state and not its overall water quality.

Table 1. Trophic classes by TSI value

TSI	Trophic class
< 40	Oligotrophic (values below 30 indicate very clear, nutrient-poor water)
40–50	Mesotrophic
50–70	Eutrophic
> 70	Hypereutrophic

3.4 Satellite data

A Landsat 8 Operational Land Imager (OLI) scene for 31 December 2017, the date of field sampling, was downloaded from the United States Geological Survey (USGS) Earth Explorer after previewing it to select a scene with minimal cloud cover. Band values for Bands 1–9 (30 m resolution, with Band 8 panchromatic at 15 m) were extracted at each sampling station in ArcGIS 10.2. [Authors to confirm: product level and whether atmospheric correction was applied.]

3.5 Statistical analysis

The natural logarithm of TSI (TP) was used as the dependent variable in a multiple linear regression on the nine Landsat 8 OLI band values in SPSS. The log transformation was applied to stabilise variance and reduce skew. Pearson correlations between TSI(TP) and each band, and among the bands, were also computed. The null hypothesis of no relationship was tested at the 0.05 significance level using the F-test of the overall model and the t-tests of individual coefficients. Correlation strength was described using the categories of Dancey and Reidy (2004).

4. Results

4.1 Turbidity and total phosphorus

Turbidity was very low across the lake, 0.04–0.08 NTU, and total phosphorus ranged from 5.1 to 10.2 µg/L (Table 2). Turbidity was 0.04 NTU at 27 stations and 0.08 NTU at three (SP6, SP17 and SP26); all three of these stations were also in the higher phosphorus group. Total phosphorus took only two values, 5.1 µg/L at 15 stations and 10.2 µg/L at the other 15. The two phosphorus groups were not spatially separated: their mean latitudes (5.7060° and 5.7061° N) and longitudes (6.7928° and 6.7887° E) were similar, and neither differed significantly (Mann–Whitney U, $p = 0.74$ and $p = 0.28$ respectively). Every station was far below the 30 µg/L level above which algal blooms become likely in lakes (Bill, 2012).

Table 2. Summary of measurements at the 30 stations, 31 December 2017

Variable	Range	Distribution across stations
Turbidity (NTU)	0.04–0.08	0.04 at 27 stations; 0.08 at 3 stations
Total phosphorus (µg/L)	5.1–10.2	5.1 at 15 stations; 10.2 at 15 stations
TSI(TP)	27.6–37.6	27.6 at 15 stations; 37.6 at 15 stations

4.2 Trophic state

TSI (TP) was 27.6 where TP was 5.1 µg/L and 37.6 where TP was 10.2 µg/L. Both values are below 40, so by the scale in Table 1 every station, and therefore the lake as a whole, was oligotrophic on the phosphorus criterion. The 15 stations at 27.6 fall below 30, the range associated with very clear, nutrient-poor water.

4.3 Relationship between TSI (TP) and Landsat 8 OLI bands

The multiple regression of ln TSI (TP) (mean 3.475, SD 0.158) on Bands 1–9 was not significant: $R = 0.523$, $R^2 = 0.274$, adjusted $R^2 = -0.053$, $F(9, 20) = 0.837$, $p = 0.591$. No individual coefficient was significant (all $p > 0.13$; Table 3). The negative adjusted R^2 shows that the nine bands together explained no more variance than would be expected by chance with 30 observations.

Single-band correlations with TSI (TP) were also weak and non-significant at the two-tailed 0.05 level. The strongest positive correlation was with Band 3 (green; $r = 0.287$, $p = 0.124$; $r^2 = 0.082$). Band 9 (cirrus) had the largest correlation in absolute terms ($r = -0.341$, $p = 0.065$), but this band is designed for cloud detection and not for water. The bands were also highly intercorrelated (for example Bands 1 and 2, $r = 0.979$; Bands 6 and 7, $r = 0.979$; Bands 3 and 4, $r = 0.954$), which makes individual coefficients in the full model unstable.

Table 3. Correlation of each Landsat 8 OLI band with TSI(TP), and coefficients of the nine-band regression (n = 30)

Band	r with TSI(TP)	p (r, two-tailed)[a]	B	SE	p (coefficient)
B1 (coastal/aerosol)	0.169	0.37	−58.18	87.44	0.513
B2 (blue)	0.192	0.31	19.28	61.77	0.758
B3 (green)	0.287	0.12	54.45	41.68	0.206
B4 (red)	0.235	0.21	−14.54	22.24	0.521
B5 (NIR)	0.005	0.98	−1.73	9.93	0.864
B6 (SWIR 1)	0.077	0.69	1.29	23.60	0.957
B7 (SWIR 2)	0.114	0.55	−0.35	24.71	0.989
B8 (panchromatic)	0.173	0.36	−3.96	9.66	0.686
B9 (cirrus)	−0.341	0.07	−251.71	160.71	0.133

[a] Calculated from r and n = 30. Dependent variable: ln TSI (TP); intercept 6.092 (SE 1.999, $p = 0.006$).

Because no overall or individual test reached the 0.05 level, the null hypothesis of no statistically significant relationship between TSI (TP) and Landsat 8 OLI reflectance was not rejected.

5. DISCUSSION

5.1 Trophic state of Oguta Lake

On the phosphorus criterion, Oguta Lake was oligotrophic at the time of sampling. Phosphorus concentrations of 5.1–10.2 µg/L are well below the roughly 30 µg/L threshold associated with algal blooms (Bill, 2012), and they agree in direction with Ahiarakwem et al. (2012a), who reported low concentrations of nutrients, including phosphate, and a small area affected by eutrophication. Ahiarakwem et al. (2012a) attributed this to the flushing of nutrients through the lake. The lake receives perennial inflow from the Njaba and Awbana rivers and drains to the Orashi, so a short residence time is a plausible explanation, although residence time was not measured here. Because phosphorus often limits algal growth in fresh water (Perlman, 2018), low phosphorus is consistent with limited algal biomass.

An oligotrophic classification describes low nutrient-driven productivity. It does not by itself mean the water is safe to drink or free from other pollutants, because Carlson (1977) distinguishes trophic state from water quality. Microbiological quality, dissolved oxygen, nitrogen and contaminants from sewage and chemical fishing were not measured. Low productivity also implies a limited food base for fish, which is relevant to fisheries management.

5.2 Turbidity and phosphorus data quality

The turbidity readings (0.04–0.08 NTU) are two to three orders of magnitude lower than the 10–40 NTU reported earlier for the lake (Ahiarakwem et al., 2012a), and are far below what would be expected for a floodplain lake fed by sediment-laden rivers. Seasonal differences alone are unlikely to explain a gap of this size. Instrument calibration, the lower detection limit of the meter, or settling of particles in stored samples are more likely causes and should be checked before the values are interpreted physically. The three stations with 0.08 NTU were all in the higher phosphorus group, but the association was not significant ($r = 0.33$, $p = 0.07$).

Similarly, the phosphorus results had only two distinct values, and the higher one is exactly twice the lower. This pattern suggests that the analytical resolution or reporting limit of the method, not real variation across the lake, determined the values. The oligotrophic classification of the 5.1 µg/L group is fairly robust, since it would take more than a doubling of true concentration to reach the oligotrophic–mesotrophic boundary (TSI 40, about 12 µg/L). The 10.2 µg/L group lies within 2 µg/L of that boundary, so its classification is more sensitive to analytical error. The spatial distribution of phosphorus, however, cannot be resolved with these data.

5.3 Why no relationship with Landsat 8 OLI was found

Several factors probably contributed to the absence of a significant relationship.

- **Little variation to explain.** The dependent variable took only two values 10 TSI units apart, with no spread within either group, and the lake was uniformly clear and nutrient-poor.
- **Weak optical signal.** Phosphorus affects reflectance only indirectly, through algae and suspended matter. In clear, low-chlorophyll water the signal is small compared with sensor and atmospheric noise. Successful Landsat studies have mostly related reflectance to Secchi-disc depth, turbidity or chlorophyll-a, often using band ratios (Olmanson et al., 2002; Kloiber et al., 2002; Fuller and Minnerick, 2007; Zhao et al., 2011).
- **Model overfitting.** Nine strongly intercorrelated predictors were fitted to 30 observations (20 residual degrees of freedom), which inflates uncertainty in individual coefficients.
- **Atmosphere and season.** The scene was acquired in the dry season, when haze is common over the region, and the lake is narrow relative to the 30 m pixel size, so land or shoreline contamination of pixels is possible.

The earlier work cited here found Band 1 or the 3:1 band ratio most useful for turbidity in Minnesota lakes (Olmanson et al., 2002). Our finding that Band 3 had the largest positive, though non-significant, correlation therefore should not be read as confirming those results. The data neither support nor contradict a band-specific relationship.

5.4 Limitations

- A single sampling date in the dry season; seasonal variation was not captured.
- Total phosphorus was the only nutrient index; chlorophyll-a and Secchi-disc depth were not measured, so the classification could not be cross-checked.
- Low resolution of the phosphorus data and doubtful absolute turbidity values (Section 5.2).
- Possible lag or mismatch between field sampling time and the satellite overpass, and uncertain atmospheric correction.

6. CONCLUSIONS AND RECOMMENDATIONS

Oguta Lake was oligotrophic on the phosphorus criterion at the end of December 2017, with TSI (TP) of 27.6–37.6 and total phosphorus of 5.1–10.2 µg/L. This is the first trophic state classification of the lake that we are aware of. It indicates low nutrient-driven productivity at the time of sampling, but it does not on its own establish that the water is suitable for drinking or other uses.

Landsat 8 OLI band values showed no statistically significant relationship with TSI (TP) ($F(9, 20) = 0.837$, $p = 0.591$), and the null hypothesis was not rejected. With the present data, Landsat 8 OLI cannot be recommended as a stand-in for field measurements of phosphorus in this lake.

We recommend that:

1. Sampling be repeated in the wet and dry seasons, when runoff, river inflow and flushing differ, to establish how stable the classification is.
2. Chlorophyll-a and Secchi-disc depth be measured together with total phosphorus, so that the three Carlson indices can be compared, and that phosphorus be analysed with a method and detection limit that resolve concentrations in the 1–15 µg/L range.
3. Turbidity be re-measured with a calibrated meter, and nitrogen, dissolved oxygen and faecal indicator organisms be added if the lake's suitability for drinking or aquaculture is to be assessed.

4. Future satellite work use several image dates, atmospherically corrected reflectance, band ratios and a simpler model (one or two predictors), and consider sensors with finer resolution or more frequent coverage.
5. Relevant authorities consider routine monitoring of the lake, given its importance to local livelihoods and its tourism potential.

REFERENCES

Ahiarakwem, C.A., Nwankwor, G.I., Onyekuru, S.O. and Idoko, M.A. (2012a). An assessment of the physical and environmental aspects of a tropical lake: a case study of the Oguta Lake watershed, Niger Delta Basin, Nigeria. *America International Journal of Contemporary Research*, 2(7), 53–60.

Ahiarakwem, C.A., Nwankwor, G.I., Iwuagwu, C.J., Ejike, E.N. and Onyekuru, S.O. (2012b). Water quality monitoring of a tropical lake and associated rivers: a case study of Oguta Lake and its tributaries, Niger Delta Basin, southeastern Nigeria. *Journal of Environmental Science and Engineering A*, 1(6A), 818.

Bill, J. (2012). *Interpreting lake data*. Indiana Clean Lakes Program, School of Public and Environmental Affairs, Indiana University. Brown, T. and Simpson, J. (2001). Managing phosphorus inputs to urban lakes: I. Determining the trophic state of your lake. *Watershed Protection Techniques*, 3(4), 771.

Carlson, R.E. (1977). A trophic state index for lakes. *Limnology and Oceanography*, 22(2), 361–369.

Carlson, R.E. and Simpson, J. (1996). *A coordinator's guide to volunteer lake monitoring methods*. North American Lake Management Society, Madison, WI.

Dancey, C. and Reidy, J. (2004). *Statistics without maths for psychology: using SPSS for Windows*. Prentice Hall, Harlow.

Fuller, L.M. and Minnerick, R.J. (2007). *Predicting water quality by relating Secchi-disk transparency and chlorophyll a measurements to Landsat satellite imagery for Michigan inland lakes, 2001–2006*. US Geological Survey Fact Sheet 2007-3022.

Jally, S.K., Balabantaray, S.K. and Mishra, A.K. (2016). Analysis of trophic state index of Chilika Lake during pre and post monsoon season using in-situ and Landsat-8 data observations. *Octa Journal of Environmental Research*, 4(4).

Kloiber, S.M., Brezonik, P.L. and Bauer, M.E. (2002). A procedure for regional lake water clarity assessment using Landsat multispectral data. *Remote Sensing of Environment*, 82, 38–47.

Li, R. and Li, J. (2004). Satellite remote sensing technology for lake water clarity monitoring: an overview. *Environmental Informatics Archives*, 2, 893–901.

Membrillo-Abad, A.S., Torres-Vera, M.A., Alcocer, J., Prol-Ledesma, R.M., Oseguera, L.A. and Ruiz-Armenta, J.R. (2016). Trophic state index estimation from remote sensing of Lake Chapala, Mexico. *Revista Mexicana de Ciencias Geológicas*, 33(2), 183–191.

Olmanson, L.G., Bauer, M.E. and Brezonik, P.L. (2002). Use of Landsat imagery to develop a water quality atlas of Minnesota's 10,000 lakes. *Proceedings of the Pecora 15/Land Satellite Information IV/ISPRS Commission I/FIEOS 2002 Conference*.

Perlman, H. (2018). Phosphorus and water. USGS Water Science School. https://www.usgs.gov/special-topics/water-science-school

USEPA (2000). *Nutrient criteria technical guidance manual: lakes and reservoirs*. EPA-822-B00-001. US Environmental Protection Agency, Office of Water, Washington, DC.

Zhao, D., Cai, Y., Jiang, H., Xu, D. and Zhang, W. (2011). Estimation of water clarity in Taihu Lake and surrounding rivers using Landsat imagery. *Advances in Water Resources*, 34(2), 165–173.