Earth Sciences
2023; 12(4): 90-98
http://www.sciencepublishinggroup.com/j/earth
doi: 10.11648/j.earth.20231204.12
ISSN: 2328-5974 (Print); ISSN: 2328-5982 (Online)

Spectral Reflectance and Algal Bloom Monitoring of Lake Victoria Using Remote Sensing Techniques, Winum Gulf of Kenya

Vincent Ogembo[1, *], Gavin Akinyi Mohamed[2]

[1]School of Spatial Planning and Natural Resource Management, Jaramogi Oginga Odinga University of Science and Technology, Bondo, Kenya

[2]Department of Survey and Earth Sciences, Ramogi Institute of Advanced Technology, Kisumu, Kenya

Email address:

v.o.ogembo@gmail.com (Vincent Ogembo)

[*]Corresponding author

To cite this article:

Vincent Ogembo, Gavin Akinyi Mohamed. Spectral Reflectance and Algal Bloom Monitoring of Lake Victoria Using Remote Sensing Techniques, Winum Gulf of Kenya. *Earth Sciences*. Vol. 12, No. 4, 2023, pp. 90-98. doi: 10.11648/j.earth.20231204.12

Received: May 22, 2023; **Accepted**: June 9, 2023; **Published**: July 11, 2023

Abstract: The study was aimed at measuring the in situ spectral reflectance of Lake Victoria fresh water which contains algal blooms and different suspended solids. Reflectance spectra of wavelengths 340-1,018 nm were collected from Lake Victoria fresh water using a portable spectroradiometer. The data was collected on a cloud free day between 0912 to 1022 hours. Sunlight was used as a source of illumination while dark surface was applied as control to obtain a near-normal angle of observation at a Pacific Daylight Time (PDT) on 27th October 2022. Google Earth Engine (GEE) was used in analyzing the satellite images of Lake Victoria, Winam Gulf with NDCI index technique which provides an estimation of the chlorophyll-*a* concentration. The averaged spectrum of the Lake Victoria water showed reflectance maxima from 580-710 nm and reflectance minima near 430 nm and above 740 nm wavelengths. This study showed that the higher the NDCI value, the higher the concentration of chlorophyll-*a*, the more sever the algal bloom. On average, the concentration of chlorophyll-*a* was high at 33-50mg/m^3 and highest values recorded between January and February of every year due to high temperatures during the dry season. The Winum Gulf of Lake Victoria is characterized by increasing eutrophication arising from increased anthropogenic activities on the shores of the lake. Major factors contributing to the increased eutrophication include Urban sprawl, industrial loads and agricultural activities. The study, therefore, presents the algal bloom situation and spectral reflectance of the lake under the influence of human activities surrounding Lake Victoria.

Keywords: Spectral Reflectance, NDCI, Chlorophyll-*a*, Lake Victoria Winum Gulf, Google Earth Engine

1. Introduction

Lake Victoria is the second largest freshwater lake by area in the world covering 68,800km^2. Currently, the lake is under severe pressure from human-induced activities such as over-exploitation, eutrophication and introduction of both plant and animal species. Rapid increase in human population in the catchment exerts more pressure on the lake's water resources thus lowering the ecological balance of the lake. Such fresh water lakes are characterized by suspended sediments, dissolved organic carbon and chlorophyll a (Chl *a*) concentration among other solid waste materials [1]. The water composition controls the spectral reflectance of these water bodies [2]. In the assessment of water composition, Chl *a* concentration which exists in all algae groups, is a bio-production indicator in inland water bodies [3]. Turbidity of fresh water lakes is caused by soil particles which lead to increased concentration of suspended particulate materials in water and dissolved organic matter. The turbidity level determines light absorption hence affecting the transparency in a water body [4]. Water quality is often tested by taking water samples from the lake and subjecting the samples to laboratory tests. This process is expensive, time consuming and does not give a universal result for the entire lake [5]. Such research challenges have led to the use of remote sensing technologies in monitoring the quality and composition of water bodies [6].

Remote sensing technique is capable of providing synoptic view and analysis of the lake waters. This is based on the fact that the satellites are able to produce images as they orbit around the earth enabling them to access the synoptic and consistent data about the lakes [7]. Several studies have been done on monitoring the algal bloom concentration in different inland lakes in the world. Song et al. [8] studied the correlation of chlorophyll a concentration in Shitoukoumen reservoir and concluded that Cha *a* is a parameter that can characterize the water composition state of a lake. Currently, mapping floating matters using optical remote sensing requires the detection of a spatial anomaly using the 30 near-infrared (NIR) bands, and then discrimination of the anomaly by comparing its spectral characteristics with 31 known spectra of floating matter, or by using ancillary information (e.g., in certain regions a spatial 32 anomaly can only be caused by a certain type of floating algae).

Despite the fact that description of spectral reflectance of inland water lakes features have been done with several empirical algorithms derived, application of remote sensing techniques remains a challenge because of the highly varied trophic states and different climatic conditions. These algorithms are nearly always site specific, due to changes in the biophysical water characteristics based on the location, and time of the year [9]. The algorithms usually require calibration and reparameterization [10]. Some of the algorithms can be universally applied while others require verification in order to be applied to other types of water. Chl-a in turbid productive waters seems to be accurately estimated by means of NIR-red algorithms [11-13].

Google Earth Engine (GEE) is a new technology used in extracting satellite images and is preferred over the conventional use of Glovis and earth explorer. This is because in cases where the study area is vast, the method gives ease of access and capabilities to leverage the platform for processing as it offers cloud computing functionalities in a free-to-use approach in the explorer web app [14]. It has a parallel high-speed processing capability with Google computational machine algorithms and Application Programming Interfaces (APIs) which support the common coding languages [15]. These modules easily enable the users to extract, analyze and present big spatial data in powerful and easier ways without applying specialized computer coding expertise. Landsat has evolved over time and there are a couple of sensors that have petabytes of data archived overtime [16]. This technique helps in monitoring of water quality and algal bloom concentration in large water bodies.

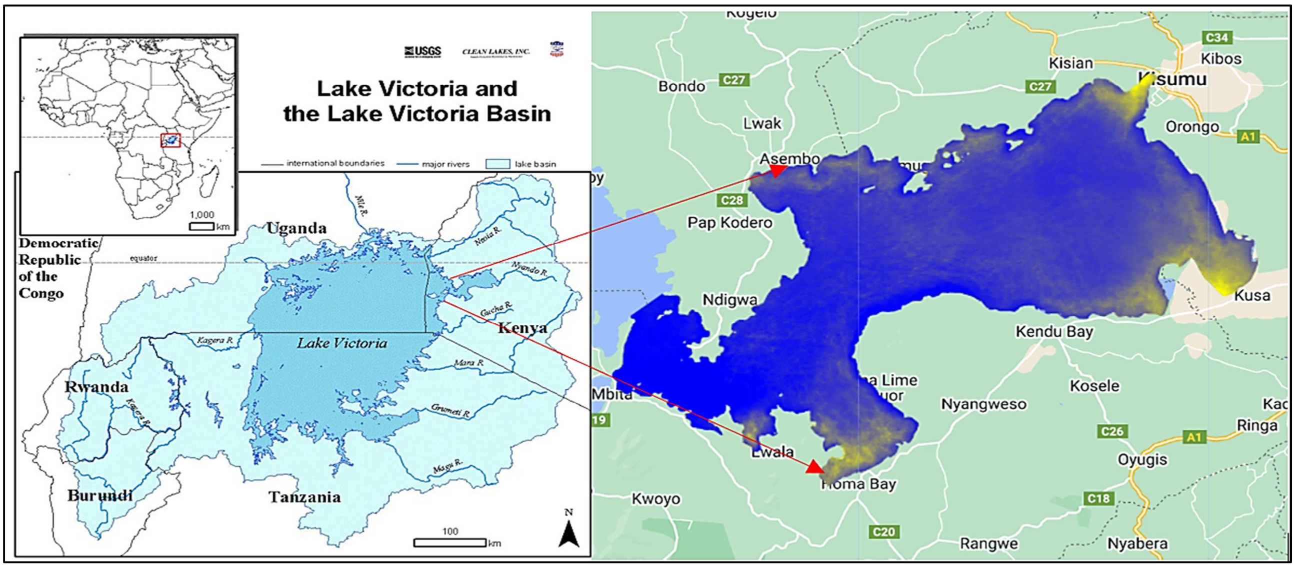

Figure 1. *Map of Lake Victoria and Its Basin.*

The aim of this research was to examine the spectral reflectance of Lake Victoria as characterized by the concentration of chlorophyll *a*, a form of algal bloom. The Winum Gulf of Lake Victoria is characterized by increasing eutrophication arising from increased anthropogenic activities on the shores of the lake. Major factors contributing to the increased eutrophication include Urban sprawl, industrial loads and agricultural activities. The study, therefore, presents the algal bloom situation and spectral reflectance of the lake under the influence of human activities surrounding Lake Victoria.

2. Study Area

The study area was Lake Victoria which is the world's largest fresh water lake of an area of 68,800km^2. It lies within an altitude of 1134m above the sea level and a latitude and longitudes of 0°20´N–3°S and 31°39´E–34°53´W respectively [17]. The lake is shared among East African countries; Tanzania (51%), Uganda (43%) and Kenya (6%). Water balance of the lake is majorly through precipitation and evaporation since the lake basin receives an average annual rainfall of 900-2600mm with evaporation rates of 1100-2400mm [18]. The average depth of the lake is 40m while the maximum depth is 80m hence Lake Victoria is considered to be a shallow lake [19]. The lake supports large scale inland fisheries producing approximately 1 Million tons of fish per annum [20]. About 22% of the Lake Victoria basin area falls within Kenyan boundaries though with only 6% of the lake waters [21].

3. Methodology

3.1. Spectral Reflectance of Lake Victoria

The spectral reflectance of Lake Victoria was measured using spectroradiometer device pointed at the surface of the water. A drive boat was used to access the water surface. Measurement I was taken by pointing the spectroradiometer at the water surface and the data recorded by the device. Measurement II was taken by pointing the devise at the sky while measurement III was taken by pointing the devise at a white reference surface. Measurement IV was recorded by pointing the spectroradiometer at a dark surface with no presence of any light.

Figure 2. *Actual Measurements Using Spectroradiometer Device on Lake Victoria.*

In calculating the reflectance of the lake, the readings from the dark surface were subtracted from the water, sky and reference points readings. The subsequent calculations are as below;

Multiply the (Sky – Dark) radiance by the Fresnel reflectance off the surface of the water

$$Rrs_{sky}=0.025 \text{ x } Radiance_{(Sky-Dark)} \quad (1)$$

Water leaving radiance, Lw, subtract the Fresnel reflectance from the water signal

$$Rrs_{Lw}=Radiance_{(Water-Dark)} - (0.025 \text{ x } Radiance_{(Sky-Dark)}) \quad (2)$$

The downwelling irradiance, Ed, is the radiance off the reference, multiplied by Pi, and divided by the reflectance of the reference

$$Ed=(Ref - Dark)*PI/.95 \quad (3)$$

The remote sensing reflectance, Rrs, is the water leaving radiance, Lw, divided by the downwelling irradiance, Ed

$$Rrs=Lw/Ed \quad (4)$$

Just taking the median to smooth out the curve

$$\text{Hence Reflectance } Rrs=Lw/Ed \quad (5)$$

3.2. Monitoring of Cha-a

The Normalized Difference Chlorophyll Index, NDCI

Google Earth Engine (GEE) was used in analyzing the satellite images of Lake Victoria, Winam Gulf. NDCI index provides an estimation of the chlorophyll-*a* concentration. This was done by exploiting the Red/Near-Infrared reflectance and the Red-edge absorbance specific to the chlorophyll-*a* of plants.

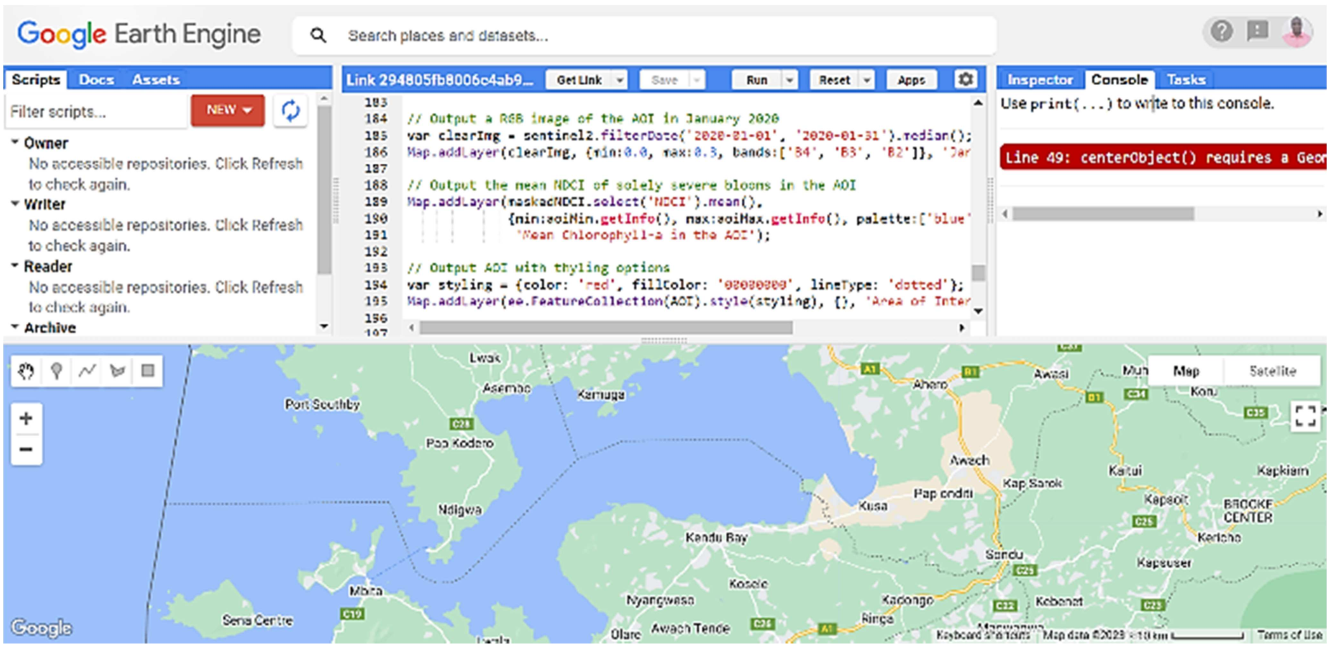

Figure 3. *Google Earth Engine (GEE) Interface Pre-Coding Steps for Winam Gulf.*

For Sentinel-2 satellite image was used and the NDCI applied using Band 5 and Band 4 within a normalizing equation as follows:

$$NDCI = \frac{B5-B4}{B5+B4} \tag{6}$$

When NDCI was created, the authors (Mishra and Mishra, 2012) provided a range of values to estimate the concentration of chlorophyll-*a* from space. They created the table below:

Table 1. *Comparison Between NDCI and Chl-a Concentration in Lake Victoria.*

NDCI range	Chl-*a* concentration range (mg m^{-3})
<-0.1	<7.5
-0.1 to 0	7.5 – 16
0 to 0.1	16-25
0.1 to 0.2	25-33
0.2 to 0.4	33-50
0.4 to 0.5	>50
0.5 to 1	Severe Bloom

Source: Mishra and Mishra, 2012

The algal bloom situation in the Winam Gulf of Lake Victoria was monitored over two years, 2020 and 2021 using NDCI in the Google Earth Engine. Four sites were chosen, i.e Kisumu bay, Nyando bay, Sondu bay and Asembo bay. The trend in algal bloom concentration in the lake was monitored per site and mean NDCI value generated and recorded. The values generated are on a 2 time-series daily NDCI values and showing monthly NDCI values (Figure 6).

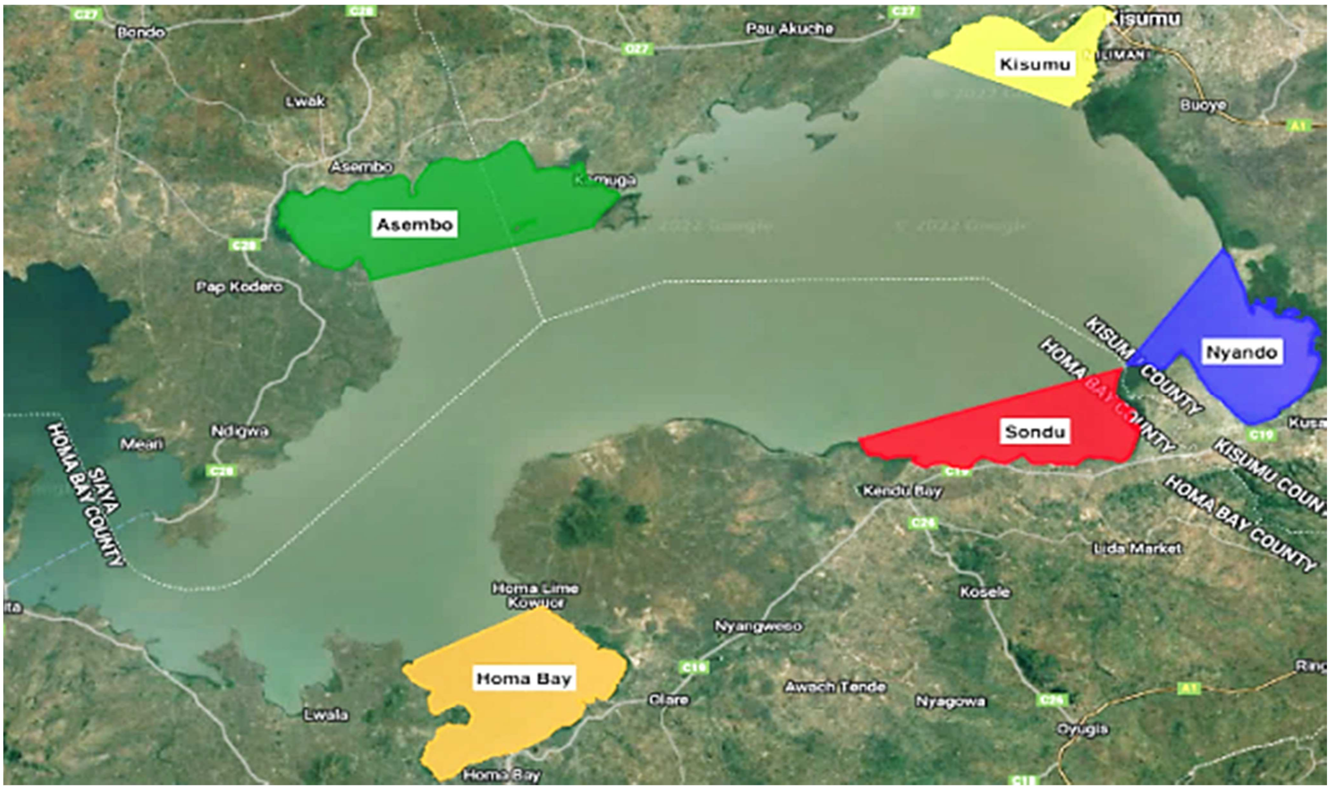

Figure 4. *Selected Sites (Lake Victoria Winum Guld Bays) for the NDCI Study.*

4. Results

4.1. Spectral Reflectance

The reflectance wavelengths recorded by the devise ranged from 339nm-1018nm. The measurements of radiance obtained when the spectroradiometer was pointed at the water surface produced a range of -107.41 to 9.09 with the respective wavelengths. The radiance obtained while spectroradiometer was pointed at the sky ranges from -106.87 to 10.23. Dark surface produced -138.51 to 11.49 radiance while a reference surface of white color produced a radiance range of -106.82 to 10.38 as shown in Table 2.

Table 2. *Wavelength Reflectance Parameters and Reflectance Computation.*

Wavelength (nm)	Measurement #1 Spectroradiometer pointed at the water	Measurement #2 Spectroradiometer pointed at the sky	Measurement #3 Spectroradiometer covered, no light	Measurement #4 Spectroradiometer pointed at the white reference
	USB2G146711_16-30-59-331.txt	**USB2G146711_16-32-00-759.txt**	**USB2G146711_12-55-05-747.txt**	**USB2G146711_16-32-56-049.txt**
	Water	**Sky**	**Dark**	**Reference**
	Thu Oct 27 16:30:59 EAT 2022	Thu Oct 27 16:32:00 EAT 2022	Fri Oct 28 12:55:05 EAT 2022	Thu Oct 27 16:32:56 EAT 2022
	Scans to average: 10			
	Integration Time (sec): 3.000000E-1			
339.887	-107.41	-106.87	-138.51	-106.82
340.26	-2.31	-2.77	0.69	-1.32
340.634	-1.41	-1.37	1.89	-0.72
341.008	-0.71	-0.27	3.19	-0.32
341.382	0.29	1.23	4.29	1.28
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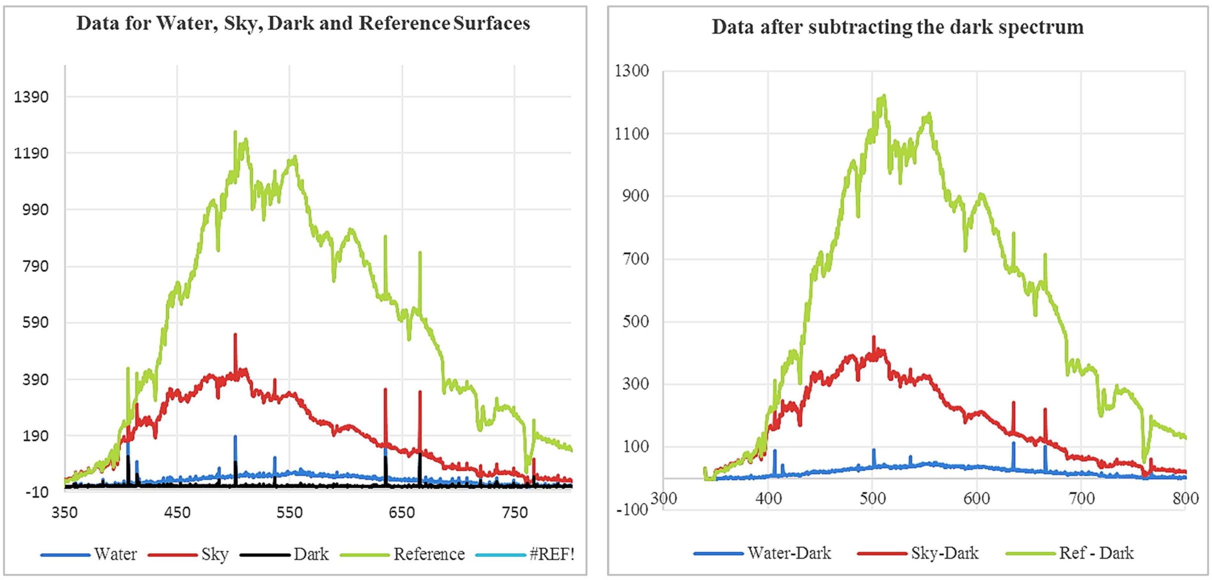
1017.762	8.69	8.73	10.19	10.48
1018.041	9.09	10.23	11.49	10.38

Wavelength (nm)	Measurement #1 minus Measurement #3	Measurement #2 minus Measurement #3	Measurement #4 minus Measurement #3	Sky - dark radiance times the Fresnel reflectance	Water leaving radiance, Lw	The downwelling irradiance, Ed		The remote sensing reflectance, Rrs	Median to smooth out the curve
	Water-Dark	**Sky-Dark**	**Ref - Dark**	**0.025 (Sky-Dark)**	**(Water-Dark)-(0.025 (Sky-Dark))**	**Ed=(Ref - Dark)*PI()/.95**	**Wavelength**	**Rrs=Lw/Ed**	**Rrs=Lw/Ed**
339.887	31.1	31.64	31.69	0.791	30.309	104.7969	339.887	0.289216523	0.37289515
340.26	-3	-3.46	-2.01	-0.0865	-2.9135	-6.646948	340.26	0.438321423	0.35071838
340.634	-3.3	-3.26	-2.61	-0.0815	-3.2185	-8.631112	340.634	0.372895153	0.37289515
341.008	-3.9	-3.46	-3.51	-0.0865	-3.8135	-11.60735	341.008	0.328541599	0.39416757
341.382	-4	-3.06	-3.01	-0.0765	-3.9235	-9.953888	341.382	0.394167574	0.37289515
1017.762	-1.5	-1.46	0.29	-0.0365	-1.4635	0.959012	1017.76	-1.5260	0.19388
1018.041	-2.4	-1.26	-1.11	-0.0315	-2.3685	-3.67070	1018.04	0.64524	-0.2574

The spectral data for the water, sky, dark and reference surfaces were plotted with the resulting graphs as shown in Figure 5a. Resultant Reference data was acquired by subtracting the dark surface data from the reference surface data as shown in Figure 5b.



A B

Figure 5. *Spectral Data for the Different Reference Surfaces.*

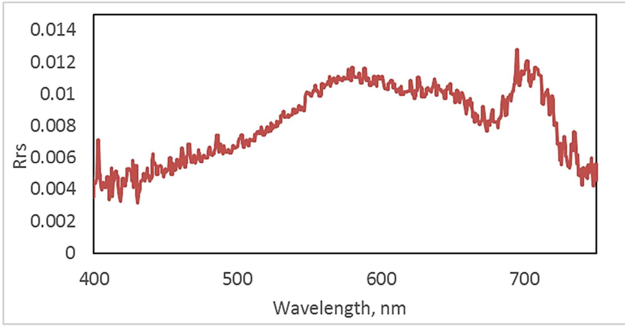


Figure 6. *Spectral Signature of Lake Victoria Reflectance.*

The spectrum produced has a magnitude and a shape which is shifting toward the right end of the spectrum as shown in Figure 6. Comparing with that of Green Bay spectrum as studied by [23] paper, the reflectance of Lake Victoria Winam Gulf shifts to the right because of sediments suspended in the water due to the turbulence of the waves by shore.

4.2. The Normalized Difference Chlorophyll Index, NDCI

NDCI for Lake Victoria

Mean NDCI for 2020 and 2021 are as shown in Figure 7 and Figure 8 respectively. Kisumu City shoreline registered a continuous mean value in 2020 compared to 2021 followed by Homabay Town shoreline. Nyando, Sondu and Asembo sites showed varying mean NDCI across the two years. The mean NDCI for Winam Gulf of Lake Victoria is presented in Figure 9.

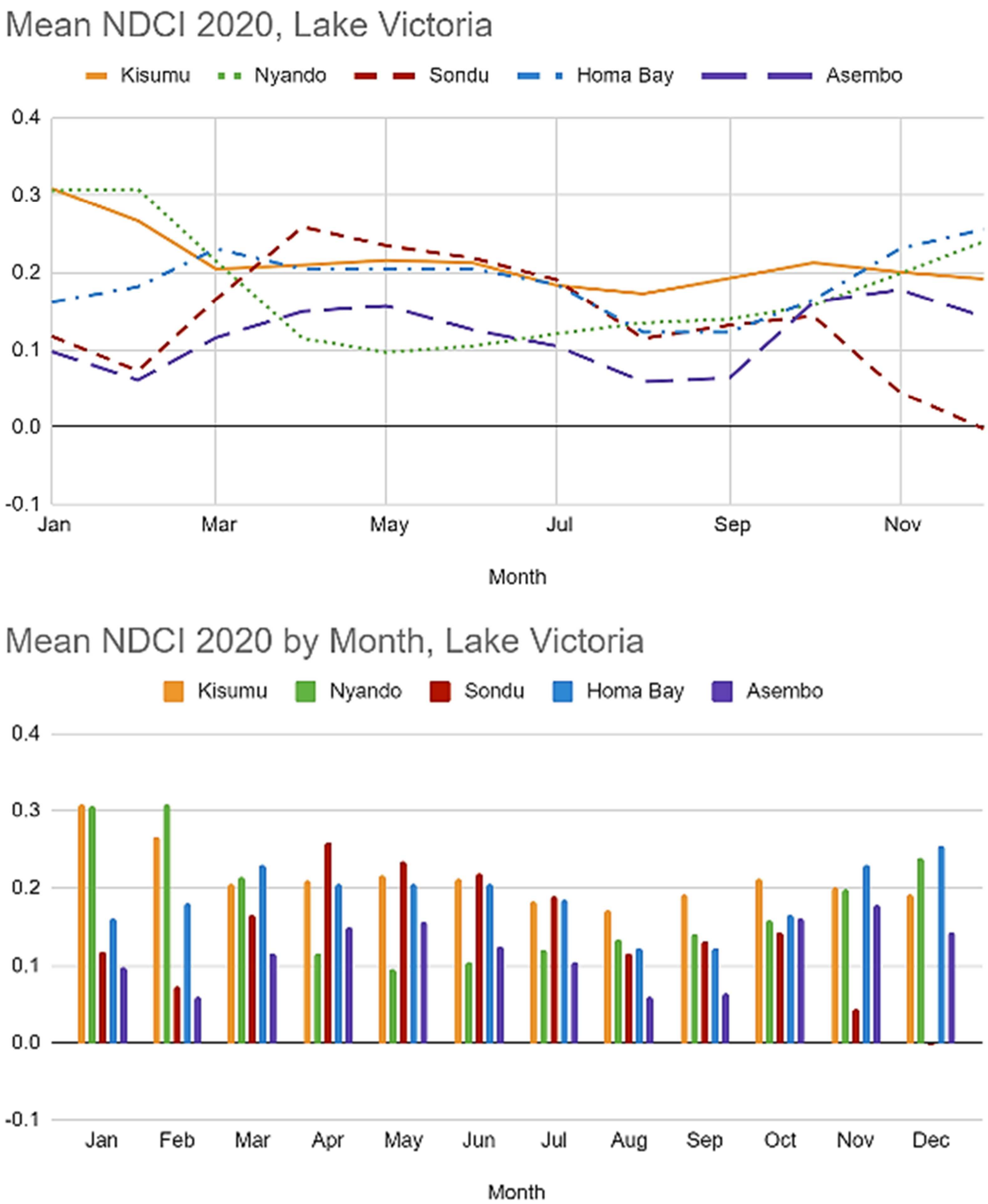


Figure 7. *Mean NDCI for Winam Gulf in 2020.*

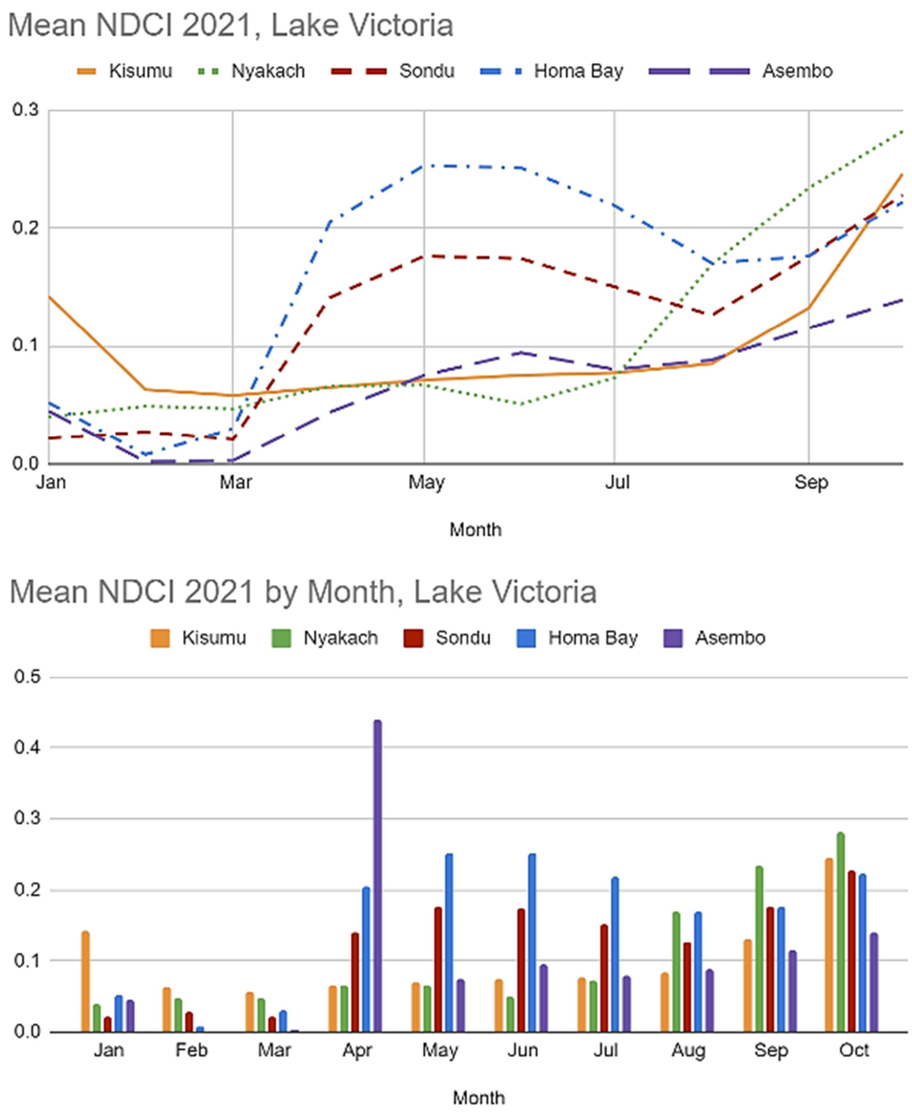


Figure 8. *Mean NDCI for Winam Gulf in 2021.*

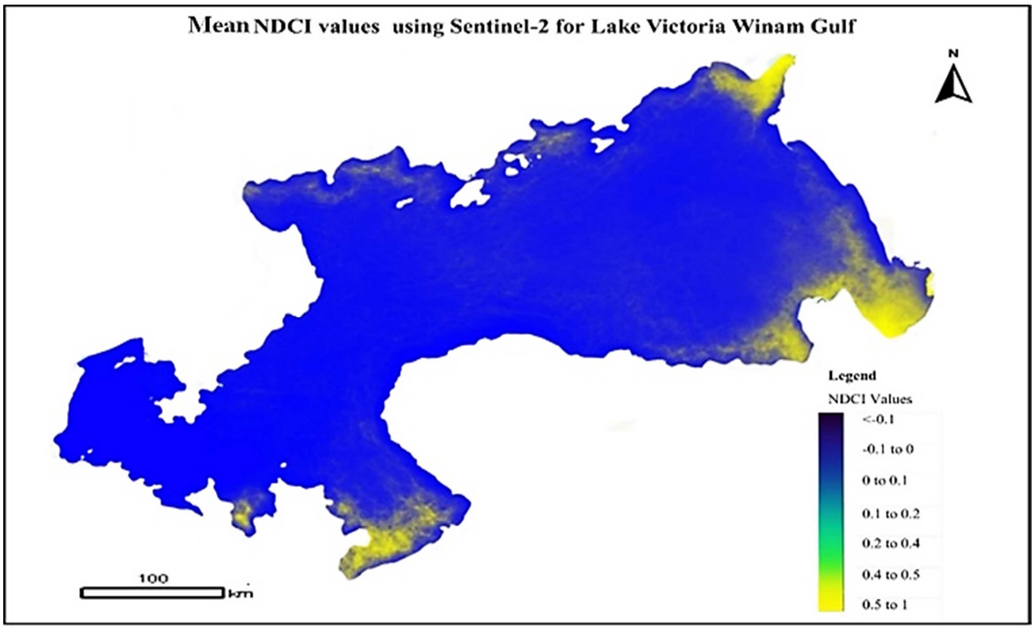


Figure 9. *Mean NDCI values in Winam Gulf using Sentinel-2 in a Google Earth Engine.*

5. Discussion

The averaged spectrum of the Lake Victoria water shows reflectance maxima from 580-710 nm and reflectance minima near 430 nm and above 740 nm wavelengths. The reflectance gradually decreases from 720–1,018nm and has very low reflectance in the 400–520 nm wavelength region. Our results show that the spectral reflectance of suspended solid particles at this stage remains low for wavelengths longer than 1,000 nm in the near-infrared region of the spectrum. These spectral results have implications in selecting the spectral ratios and refining the algorithms that will be used to estimate algal bloom content using satellite models. The validity of the Rrs (λ) measurements was demonstrated through taking measurements by pointing the reflectometer device in different media such as water surface, sky, white surface and dark reference surface.

These measured reflectance values correspond with other studies of inland waters with similar composition. Nevertheless, differences can be found mostly in the location of reflectance maxima in certain parts of the electromagnetic spectrum. The differences found in the obtained reflectance spectra can be attributed to the various contributing absorptions of phytoplankton and suspended sediments [24]. The higher reflectance of our localities compared with the clear lakes discussed in the literature may be caused by the presence of a high amount of light-refracting mineral particles, giving rise to the low transparency. The methods of measurement and the conditions during measurement can also affect the magnitude of reflectance [25].

The development of remote sensing instruments and techniques has ushered in a new era of monitoring, with various satellites now providing information on chlorophyll-concentrations. This study showed that the higher the NDCI value, the higher the concentration of chlorophyll-*a*, the more sever the algal bloom. On average, the concentration of chlorophyll-*a* was high at 33-50mg/m^3 and highest values recorded between January and February of every year due to high temperatures during the dry season. There was a concentration drop from March to September and this was alluded to the long rainy and cooler periods which hinders the growth of algae in Lake Victoria. The October to December period showed an increased concentration of chlorophyll-*a* due to the short rains.

From Figure 6, it is evident that Chl-*a* concentration is higher at the shores than the middle of the lake. This is because the shores are more susceptible to nutrient enrichment as compared to the rest of the lake due to surface run off and waste disposal from the various human activities taking place. However, nutrient enrichment due to surface runoff is dependent on the topography of the catchment area as asserted by Wetzel, R., G. [26].

The mean NDCI map shows that Nyando study site had high concentrations of Chl-*a* which is attributed to the continuous flow of River Nyando from the northern part of Lake Victoria which drains a lot of nutrients into the Lake. Kisumu City and Homabay town shores are characterized by sheltered bays which has limited waves and water circulation as well as possibilities of effluent run-off from the population in the urban areas. These factors contributed to higher concentrations of Chl-*a* in the urban study sites.

The major contributors of nutrient enrichment along the shore regions are: surface run off; constant mixing of the lake especially in shallower regions and waste disposal from the various human activities that take place in the lake's catchment area. These provide favourable conditions for increased development of algae resulting in high Chl-*a* concentrations. Left unmitigated, it is suspected that this has led to the development of harmful algal blooms (cynobacteria). The algal bloom has resulted to the development of water hyacinth in Lake Victoria as well as producing toxins that are poisonous to both humans and the fish [27] as well as the birds and animals that drink from the lake.

Thus the high level of suspended matter in this study is linked with the result of high influx of sediments into the lake. That is, during seasons of heavy rainfalls and flooding, agro-chemicals (such as phosphorus and nitrogen) are transported through surface run-offs into Winam Gulf of Lake Victoria resulting in the bloom of algae. Moreover, the sequential increase in the rainfall and flooding amounts as a result of global climatic changes has made this phenomenon a frequent one and are thus recurrently experienced in various regions in Africa and around the world [28-30].

6. Conclusion and Recommendations

From this study, it is evident that remote sensing provides a novel and efficient way of monitoring Chl_a and suspended solids in Lake Victoria. The in-situ spectral reflectance measured produced a magnitude and a shape which is shifting towards the right end of the spectrum. Comparing that of Green Bay spectrum as studied by O'Donnell, D. M. et al. [23] paper, the reflectance of Lake Victoria Winam Gulf shifted to the right because of sediments suspended in the water due to the turbulence of the waves by shore. This study showed that the higher the NDCI value, the higher the concentration of chlorophyll-*a*, the more sever the algal bloom. On average, the concentration of chlorophyll-*a* was high at 33-50mg/m^3 and highest values recorded between January and February of every year due to high temperatures during the dry season. The high level of suspended matter in this study is linked with the result of high influx of sediments into the lake. Some of the potential beneficiaries will be the Fisheries Sector, the National Environmental Management Authority, Water Resource Authority, Research Institutions etc.

References

[1] Schwab D. J, Leshkevich G. A. and Muhr G. 1992. Satellite Measurements of Surface Water Temperature in the Great Lakes. *Journal of Great Lakes Research* 18 (2): 247-258.

[2] Hudson, S. J., Moore, G. F., Bale, A. J., Dyer, K. R. And Aitken, J., 1994, An operational approach to determining suspended sediment distributions in the Humber estuary by airborne multi-spectral imagery. Proceedings of the First Airborne Remote Sensing Conference and Exhibition, Strasbourg, France, 11–15 September 1994.

[3] Odermatt, D., Giardino, C. and Heege, T., 2010. Chlorophyll retrieval with MERIS Case-2-Regional in perialpine lakes. *Remote Sensing of Environment* 114: 607–617.

[4] Stefouli, M. and Charou, E., 2012. Ohrid Lake Monitoring using Meris and Landsat Images. In *Proceedings of the 5th International Conference on Water, Climate and Environment*. 28th May – 2nd June, 2012, Ohrid, Republic of Macedonia.

[5] Cavalli, R., M. Laneve, G., Fusilli, L., Pignatti, S. and Santini, F., 2009. Remote sensing water observation for supporting Lake Victoria weed management. *Journal of Environmental Management* 90: 2199–2211.

[6] Chavula G., Sungani H. and Gondwe, K. 2012. Mapping Potential Fishing Grounds in Lake Malawi Using AVHRR and MODIS Satellite Imagery, *International Journal of Geosciences*, 2012, 3, 650-658 doi: 10.4236/ijg.2012.33065.

[7] Garmo, P. and Radius A., 2012. Improvement of vessel detection by Satellite Rader Imagery. The Growing Use of GMES across Europe's Regions. NEREUS publication, October 2012.

[8] Song, K., Li, L., Wang, Z., Liu, D., Zhang, B., Xu, J., Du, J., Li, L., Li, S., Wang, Y., 2012. Retrieval of total suspended matter (TSM) and chlorophyll-a (Chl-a) concentration from remote-sensing data for drinking water resources. *Environmental monitoring and assessment* 184, 1449–1470.

[9] Liu Y, Islam MA, Gao J (2003) Quantification of shallow water quality parameters by means of remote sensing. Prog Phys Geogr 27: 24–43. doi: 10.1191/0309133303pp357ra.

[10] Yacobi YZ, Moses WJ, Kaganovsky S et al (2011) NIR-red reflectance-based algorithms for chlorophyll-a estimation in mesotrophic inland and coastal waters: lake Kinneret case study. Water Res 45: 2428–2436. doi: 10.1016/j.watres.2011.02.002.

[11] Gitelson, A., Garbuzov, G., Szila´ Gyi, F., Mittenzwey, K.-H., Karnieli, A. And Kaiser, A., 1993, Qualitative remote sensing methods for real-time monitoring of inland waters quality. International Journal of Remote Sensing, 14, pp. 1269–1295.

[12] Dekker, A. G. And Peters, S. W. M., 1993, The use of the Thematic Mapper for the analysis of eutrophic lakes: a case study in the Netherlands. International Journal of Remote Sensing, 14, pp. 799–821.

[13] Moses WJ, Gitelson AA, Berdnikov S et al (2012) Operational MERIS-based NIR-red algorithms for estimating chlorophyll-a concentrations in coastal waters—the Azov Seacase study. Remote Sens Environ 121: 118–124. doi: 10.1016/j.rse.2012.01.024.

[14] Kennedy, R. E., Yang, Z., Gorelick, N., Braaten, J., Cavalcante, L., Cohen, W. B., Healey, S., 2018. Implementation of the LandTrendr algorithm on google earth engine. Remote Sens. 10, 691.

[15] Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R., 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sens. Environ. 202, 18–27.

[16] Tamiminia, Haifa & Salehi, Bahram & Mahdianpari, Masoud & Quackenbush, Lindi & Adeli, Sarina & Brisco, B.. (2020). Google Earth Engine for geo-big data applications: A meta-analysis and systematic review. ISPRS Journal of Photogrammetry and Remote Sensing. 10.1016/j.isprsjprs.2020.04.001.

[17] Juma, Dauglas & Wang, Hongtao & Fengting, Li. (2014). Impacts of population growth and economic development on water quality of a lake: Case study of Lake Victoria Kenya water. Environmental science and pollution research international. 21. 10.1007/s11356-014-2524-5.

[18] Zhou, F., Tang, Q., Guimberteau, M., Ciais, P., & Dai, C. (2014). Quantifying the unauthorized lake water withdrawals and their impacts on the water budget of eutrophic lake Dianchi, China. *Journal of hydrology*, *565*, 39-48.

[19] Muyodi, Fredrick & Bugenyi, Fredrick & Hecky, Robert. (2010). Experiences and lessons learned from interventions in the Lake Victoria Basin: The Lake Victoria Environmental Management Project. Lakes & Reservoirs: Research & Management. 15. 77 - 88. 10.1111/j.1440-1770.2010.00425.x.

[20] LVFO, 2009a: Technical report of the stock assessment working group. − Implementation of a Fisheries Management Plan, Lake Victoria Fisheries organisation, Jinja, Uganda, 20 pp.

[21] Ochieng, O. E., Kevin, O. B. I. E. R. O., & Mbonge, M. J. (2013). Lake Victoria and the common property debate: Is the tragedy of the commons a threat to its future?

[22] Mishra, S. and Mishra, D. R. (2012) Normalized Difference Chlorophyll Index: A Novel Model for Remote Estimation of Chlorophyll—A Concentration in Turbid Productive Waters. Remote Sensing of Environment, 117, 394-406. http://dx.doi.org/10.1016/j.rse.2011.10.016

[23] O'Donnell, D. M., Effler, S. W., Perkins, M. G., Strait, C. M., Lee, Z., Greb, S., 2013. Resolution of optical gradients and pursuit of optical closure for Green Bay, Lake Michigan. J. Great Lakes Res. 39 (S1), 161–172 (this issue).

[24] Lee, Z., Ahn, Y. H., Mobley, C., Arnone, R., 2010. Removal of surface-reflected light for the measurement of remote-sensing reflectance from an above-surface platform. Opt. Express 18, 26313–26324.

[25] Bhatti AM, Rundquist D, Schalles J et al (2009) A comparison between above-water surface and subsurface spectral reflectances collected over inland waters. Geocarto Int 24: 133–141. doi: 10.1080/10106040802460707.

[26] Wetzel, R., G. 2001. *Lake and River Ecosystems. Limnology*. 3rd edition. Academic Press.

[27] Tusseau-Vuillemin, M. H. 2001. Do food processing industries contribute to the Eutrophication of aquatic systems? *Ecotoxicology and Environmental Safety,* 50 (2): 143-52.

[28] O'Reilly, C. M., Alin, S. R., Plisnier, P. -D., Cohen, A., & McKee, B. A. (2003). Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature*, 424, 766−768.

[29] Muhoza S., Sinyenza, S., Makasa D., Lukwessa L., Zulu C. I., Phiri, H. (2006). Climate variability as recorded in Lake Tanganyika (Climlake): *Final report. Belgian Science Policy.* 119 pp.

[30] Verburg, P., Hecky, R. E., & Kling, H. J. (2006). Climate warming decreased primary productivity in Lake Tanganyika, inferred from accumulation of dissolved silica and increased transparency. *Verh. Internat*.