Analysis of Algae Concentration in the Lagos Lagoon Using Eye on Water and Algae Estimator Mobile App

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Abstract

Concentrations of chlorophyll and algae in the Lagos lagoon needs to be studied in order to get information on water properties such as water color which indicates life, sediments and dissolved organic matter with the help of eye on water mobile application. Also, information from the study of algae chlorophyll concentrations produces results on amount of chlorophyll a concentration in a body of water and predicts if there will be a likely occurrence of harmful algal bloom (HABs). The HABs issue is a condition when algae in aquatic system rapidly increases in density leading to high production of toxins that give out unappealing odors, shoreline scums and kill fishes. The mobile application is used to estimate algae concentration. The results show the water color of Lagos lagoon is greenish-brown which translates to high nutrients and phytoplankton (food) for aquatic life present and also Makoko possess higher amount of chlorophyll concentration than the other two areas (University of Lagos Waterfront and Ilaje-Bariga from which samples were gotten) reason why Makoko is a major fishing ground and why their locals are engaged in the primary activity. Based on the study conducted on algae chlorophyll concentrations it can be deduced that the Lagos Lagoon which is greenish brown in color, rich in nutrients and phytoplankton possesses moderate amounts of chlorophyll concentrations required to favor aquatic life. In addition, harmful algal blooms (HABs) does not occur, however precautionary measures to be taken if this is so are recommended in this research.

Keywords: Chlorophyll, HABs, Agae Concentration, Mobile App, Lagos, DOM

INTRODUCTION

The concentration of chlorophyll represents the amount of phytoplankton (microscopic algae), which is the source of several aquatic food webs (Chapman, 2013). They provide food for a wide range of sea creatures. Changes in chlorophyll concentration/phytoplankton populations impact fish and aquatic life in the lagoon which can food availability and economic productivity (Chapman, 2013). The amount of phytoplankton present in the lagoon is assessed by measuring chlorophyll concentrations (Gökçe, 2016). In other words, more or less chlorophyll-a concentrations (phytoplankton) means more or less aquatic life respectively, however, if chlorophyll-*a* concentrations are too high they make water quality to be bad and unproductive hence unfavorable to aquatic life (Jamshidi and Bakar, 2011; Li *et al.,* 2017; Ayeni *et al.*, 2018; Ayeni and Adesalu, 2018).

Algae are photoautotrophic cells containing chlorophyll with simple reproductive structures (Spellman and Bieber, 2011; Chapman, 2013; Spellman and Stoudt, 2013; Segečová1 *et al.,* 2017). Algae have a complex growth that they are mistaken for vascular plants (Pires and Dolan, 2012; Delwiche and Cooper, 2015). Algae are found everywhere throughout the world where water is being stored and/or water body and can cause nuisance problems in water treatment plants, drinking water supplies, ponds, swimming pools and cooling towers (Abdel-Raouf *et al.,* 2012; Alrumman *et al.,* 2016). The vast majority of algal species are not harmful and indeed perform an essential role as the primary producers in many aquatic ecosystems (Sanseverino *et al.,* 2016), nevertheless, the harmful algal blooms (HABs) do occur when some or all of the phytoplankton in a bloom exhibit a harmful trait (Anderson *et al.,* 2012; Wells *et al.,* 2015; Bresciani *et al.,* 2018). Thus, many algal blooms are not toxic; and in fact, contrary to common beliefs, discoloration of the water does not indicate whether a species is harmful this could be a problem because the eye on water application also being used for the analysis operates with water colour of the lagoon (Anderson *et al.,* 2001; Zaitsev, 2008). When water is stagnant, it has a high temperature or a high concentration of Nitrates and phosphates and algae bloom might occur which might cause several problems such as oxygen depletion i.e. reduction of oxygen in water (Ingrid and Luuc, 1999; Khan and Ansari 2005).

Analysis using laboratory or mobile apps method is to carrying out a detailed examination of the elements or a structure of a phenomenon for basis of interpretation. Although, human vision is color sensitive, factors such as color metamers, opponent process, color constancy, and color blindness make color measurement by human vision subjective and error-prone. Smart phones are advanced cellular phones that run operating systems capable of high-level computational tasks such as downloading and running mobile application software (apps), internet browsing, and emailing (Byrne and Hilbert, 2003; Nosrat *et al.,* 2012; Schaefer, 2014; Pridmore, 2014; Bootsma *et al.,* 2019).

Water color is an indication for life especially where algae is present, as result a geographically designed mobile application such as Eye on water have been developed by Maris B.V to carry out water color analysis (Ceccaroni *et al*., 2020). Also, chlorophyll-*a* concentrations and likelihood of an algal bloom measurements could be generated from sampling using the Algal estimator mobile application (El-Alem et al., 2012; Ouyang *et al.*, 2017). All these measurements are also derived with complementary aid of the GPS Essentials, weather forecast options, and barometer to achieve a detailed and good analysis as well as reasonable results to take further precautionary measures.

This study therefore aims to analyze the amount of total and cynanobacteria chlorophyll in algae concentrations in the Lagos Lagoon using mobile apps (algae estimator and eye on water app). This research focuses on algae which have diverse group of plant-like organisms occurring in a wide range of environmental habitats. It is designed to prove that HABs could cause bodies of water to be unusable for drinking and domestic use, harmful to aquatic life, cause an environmental hazard as well as affect human and recreation activities within the area. The study will be useful to carry out precautionary measures and control for healthy, clean and friendly environment.

Study area

Lagos lagoon is a lagoon sharing its name with the city of Lagos, Nigeria (Fig. 1). Lagos is located within the sub-equatorial zone characterized by rainfall, experiences tropical savanna climate (Aw) according to the Köppen climate classification, as there's a significant precipitation difference between the wet season and the dry season. The wet season starts in April and ends in October, while the dry season starts in November and ends in March. The wettest month is June with precipitation total 315.5 millimeters (12.42 in), while the driest month is January with precipitation total 13.2 millimeters (0.52 in). As the city is located near the equator, the temperature remains constant with no significant difference between the hottest month and the coolest month. The hottest month is March with average temperature 28.5 °C (83.3 °F), while the coolest month is August with average temperature 25.0 °C (77.0 °F).

The Lagos lagoon lie behind the barrier beach and extend for 210km along the coast. They are flanked by tidal wetlands and swamps, located west, with these features are the boundaries of University of Lagos and its environs which comprises of the waterfront, known as University of Lagos Waterfront, shorelines of Ilaje-Bariga and shorelines of Makoko community which formed the three sampling locations for this study.

The Lagos Lagoon has an average of 2-4 meters deep but it is 10m deep in the entrance at the commodore channel (Lagos Harbor) which empties the lagoon into the Atlantic Ocean. It is separated from the Atlantic Ocean by a long sand spit to 5km wide, which has swampy margins on the Lagoon side. With the exception of the commodore channel, the lagoon is fairly shallow and is not plied by Ocean-going Ships but by smaller barges and boats. The Lagos lagoon is tidal, water from the Atlantic Ocean moves into the lagoon during high tides and recedes during low tides. It is affected by a powerful longshore drift and also fed by several rivers of which the most important are Ogun, Ona/Ibu, Oshun, Shasha and Oni.

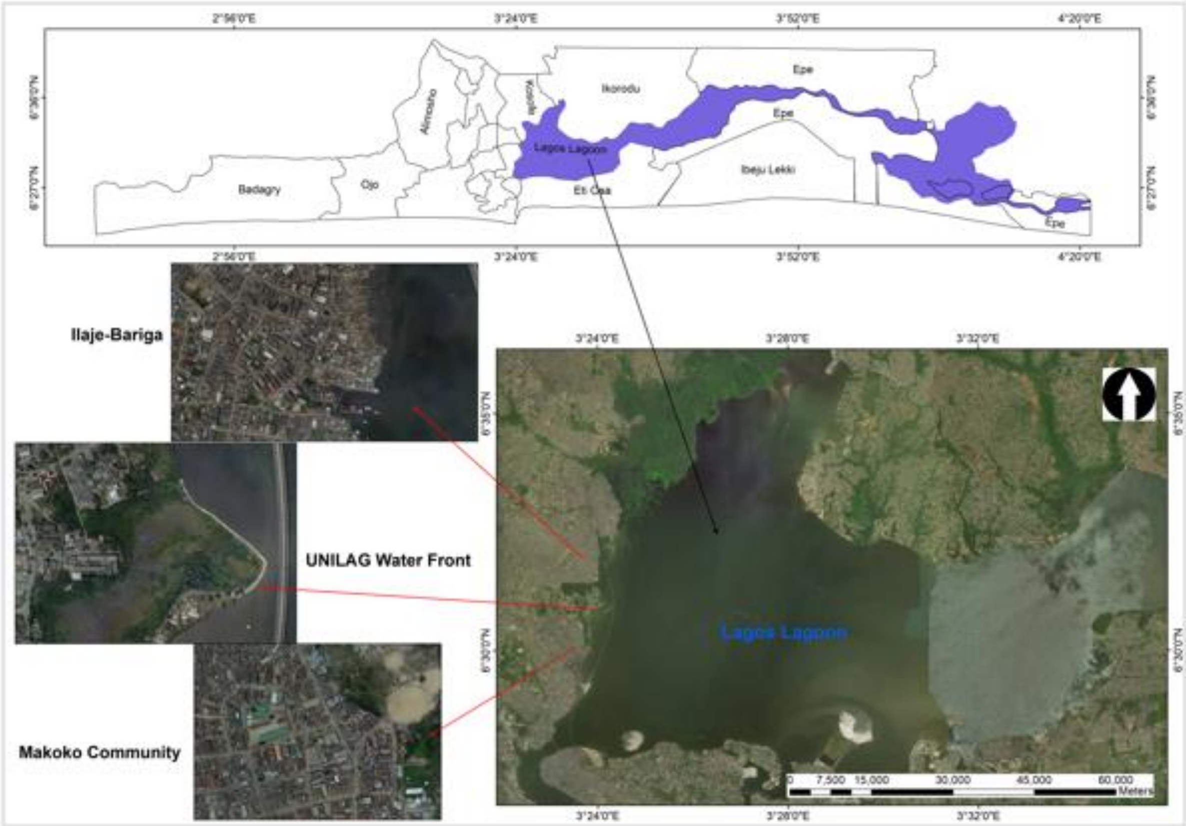


Figure 1: Locations of Ilaje-Bariga, University of Lagos Waterfront and Makoko Community along Lagos Lagoon

METHODOLOGY

This study adopted systematic applied field method using the direct primary method of data collection with the aid of 'eye on water app' instruments and Global Positioning System (GPS). The data were collected using a canoe to navigate the shorelines across the sampling locations - Ilaje, Bariga, University of Lagos Lagoon front and Makoko shore.

Eye on Water

The Eye-On Water app is a web-based application that allows the user to make a contribution to science and supply information about the water color for both fresh water and salt waters (lake, rivers, coastal waters, seas and oceans). The measurement is sent to the central server where it is validated and stored after which it becomes visible via their website www.eyeonwater.org.

Based on the assertion that water color is an indication of life e.g. algae, therefore from the color of the sample, algae chlorophyll concentrations are derived using the algae estimator mobile application and based on Forel-Ule scale (Table 1). These colors indicate the proportion of microscopic algae, sediment and dissolved material in water. However, some natural phenomena can change water color but it does not mean that the water is of bad quality.

Table 1: Different water color parameters and attributes

S/N	Water Color	Forel-Ule Scale(Fu)	Attributes
1	Indigo blue to greenish blue with high light penetration	1-5	These waters have often low nutrients levels and low production of biomass. The color is dominated by microscopic algae (phytoplankton)
2	Greenish blue to blueish green	6-9	The color is still dominated by algae but also increased dissolved matter and some sediments may be present. Typical for areas toward the open sea.
3	Greenish	10-13	Often coastal waters which usually display increased nutrients and phytoplankton levels, but also contain minerals and dissolved organic material.
4	Greenish brown to brownish green	14-17	Usually with high nutrient and phytoplankton concentrations, but also with increased sediment and dissolved organic matter. Typical for near-shore areas and tidal flats.
5	Brownish green to cola brown	18-21	Waters with an extremely high concentration of humid acids, which are typical for rivers and estuaries.

Procedures

a) Take a picture of the water with the sun on your back over your left or right shoulder. Angle of the camera to your back should be less than 30 otherwise the lens will not open. Here pictures of the Lagos lagoon were taken for this Study.
b) Compare the colored bars with either the color of the water being observed or much easier, the color of the water you just cut (Fig. 2a).
c) Select one of the bars (3 colored tomes each) that matches the color of the water you are observing by swiping the bar to see all options then tap the color bar icon (+).
d) Answer 3 simple questions: Is it raining? Did you see the bottom? Are you an Expert?
e) Click send
f) Go to the Eye on Water website to view all your measurement

Methods of Data Collection for Algae Estimator

In predicting the occurrence of Algal bloom in shallow waters with the Algae Estimator application, the following set of parameters have to be derived;

a) PO4/phosphate Concentration (mg/L) value between 0.0001 and 7
b) Temperature at Surface of the lagoon (℃)
c) Temperature at bottom of the lagoon (℃)

d) Lagoon depth (m)
e) Brightness (lux)
f) Chl a value which can be derived by getting the (Total chlorophyll value and (all types of algae, Cyano chlorophyll values i.e. blue-green algae). Alternatively, estimated depth using Secci disc, Conc. (ug/L) value between 0 and 1 and dissolved oxygen (ug/L) value between 1-100

After deriving these 6 parameters primarily with the instruments and laboratory tests, the values are input and submitted in the application, it then brings out the data set and produces a graph of chl-a conc (ug/L) plotted against time (h) as shown in Fig. 2b. The time represents how many hours it will take if an algal bloom is likely to occur in the shallow water.

- Green- Total Chlorophyll
- Blue- cyano Chlorophyll
- Red- is a constant (40) set by world Health organization (WHO) which is the Risk limit for toxic HAB from cyanobacteria to occur.

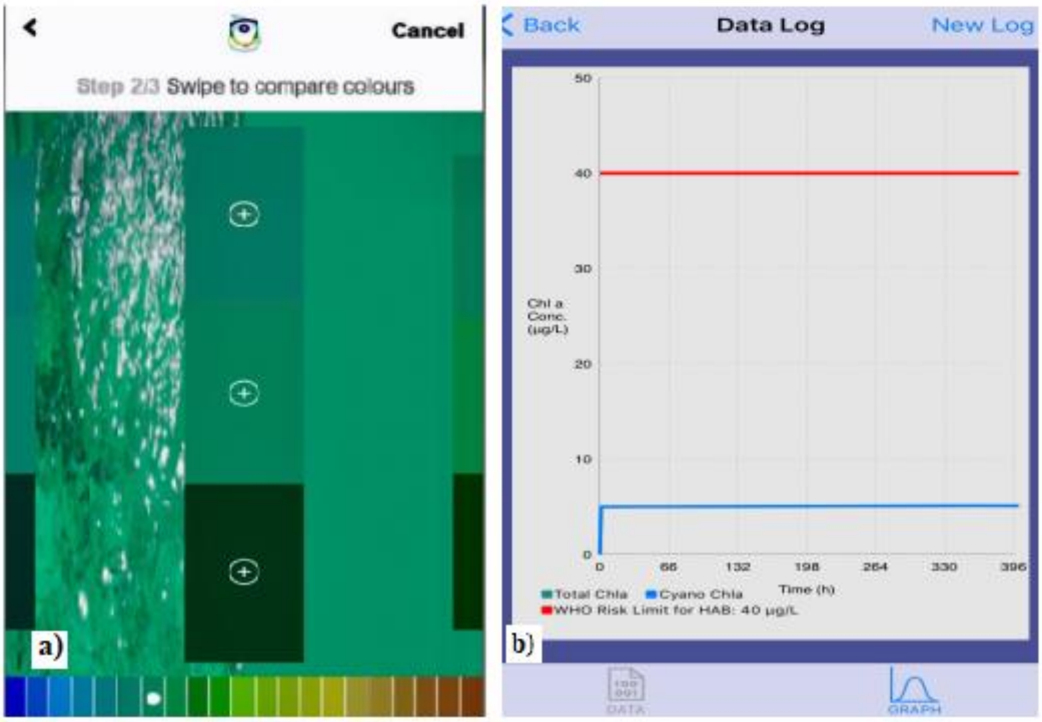


Figure 2: a) Example of water color analysis **b)** Example of Algal Bloom Graph

If the green and blue lines are both in horizontal projection like in the example above, it shows the water is in a normal condition. If the green and the blue lines project upwards towards the red line it simply means there are high levels of total and cyano chlorophyll on the water. And if precautionary measures are not taken, it's a matter of hours (days) to reach a Harmful condition. If the green and blue lines projects upwards and surpass the red line (constant) it means HABs will occur and if not occurring yet, will do so in a matter of hours given by the graph.

In addition to the above methods, GPS Essentials for collecting coordinates of the sample areas, Google earth, Barometer, weather radar softwares are also used alongside the instrument stated earlier for collection of data for the study. The laboratory test / analysis was carried out at the Environmental Laboratory, Department of Chemistry, University of Lagos, Nigeria.

RESULTS AND DISCUSSION

Water Color derived from Eye on Water Mobile App for the three locations

As shown in figure 3a, Makoko water indicates Greenish brown to brownish green usually with high nutrients and phytoplankton concentrations but also increased sediments and dissolved organic matter which is typical for water near shore areas and tidal flats. The University of Lagos Waterfront water color with Forel-ule (Fu value) 16 indicates Greenish brown to brownish green usually with high nutrients and phytoplankton concentrations but also increased sediments and dissolved organic matter (Fig. 3b). This is also attribute to typically to water near shore areas and tidal flats. Ilaje-Bariga water color with Forel-ule (Fu value) 16 indicates Greenish brown to brownish green usually with high nutrients and phytoplankton concentrations but also increased sediments and dissolved organic matter which is typically attributed to water body near shore areas and tidal flats (Fig. 3c).

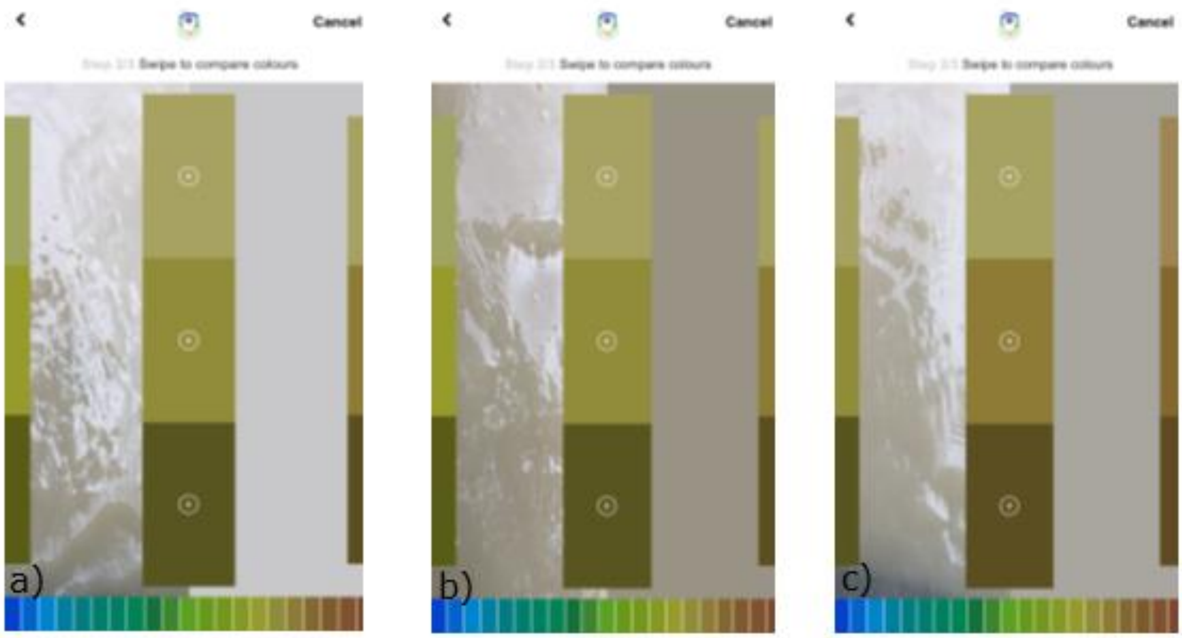


Figure 3: a) Makoko Water Color, b) University of Lagos Waterfront Water Color, c) Ilaje-Bariga Water Color

This color indicates the proportion of microscopic Algae, Sediments and dissolved organic material in water.

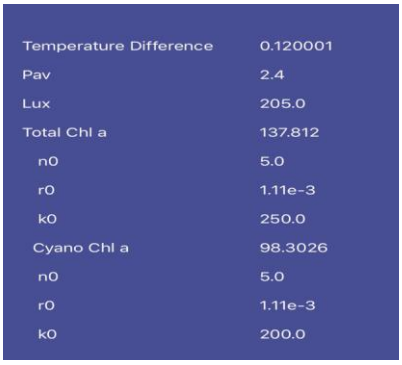
Chlorophyll-*a* Concentration

In Makoko, the total cyanobacteria chlorophyll concentrations in water are at normal but slightly increased level (Table 2 and figs. 4a & 5a). The values are 137.81 and 98.3 respectively. Fluctuates from 5 ug/l – 9 ug/l (micrograms per liter) chlorophyll concentration over a 363-hour period (15 days). This simply means that concentrations are normal and the occurrence of HAB Is not occurring because the green and the blue line does not project upwards to surpass the red line (constant 40 ug/L) set by the world Health Organization (WHO) which is the risk limit for toxic HAB from cyanobacteria to occur.

Table 2: Chlorophyll Concentration derived from Algae Estimator Mobile App.

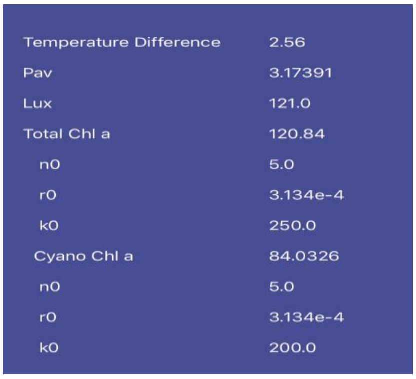
	Makoko	University of Lagos Waterfront	Ilaje-Bariga
GPS coordinates	6°29'46''N 3°23'47''E	6°31'8''N 3°24'7''E	6°32'6''N 3°24'7''E
PO_4 (0.0001-7)	O.72 m/L	0.73	0.77 m/L
Surface temperature	26.84°	27.36°	26.53°
Bottom temperature	26.72°	24.80°	26.19°
Lake depth (meters)	0.3m	0.23m	0.45m
Brightness (lux)	205	252	126
Secci Depth (meters)	0.15m	0.17m	0.2m
Dissolved oxygen 1-100	6.5 ug/L	6.6 ug/L	6.2 ug/L
Humidity	75%	75%	76%
Altitude	2m	1.9m	2.1m

Analysis of algae concentrations



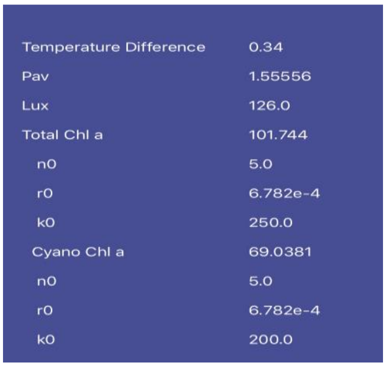
Temperature Difference	0.120001
Pav	2.4
Lux	205.0
Total Chl a	137.812
n0	5.0
r0	1.11e-3
k0	250.0
Cyano Chl a	98.3026
n0	5.0
r0	1.11e-3
k0	200.0

Fig. 4a: Makoko data log



Temperature Difference	2.56
Pav	3.17391
Lux	121.0
Total Chl a	120.84
n0	5.0
r0	3.134e-4
k0	250.0
Cyano Chl a	84.0326
n0	5.0
r0	3.134e-4
k0	200.0

Fig. 4b: University of Lagos Waterfront data log



Temperature Difference	0.34
Pav	1.55556
Lux	126.0
Total Chl a	101.744
n0	5.0
r0	6.782e-4
k0	250.0
Cyano Chl a	69.0381
n0	5.0
r0	6.782e-4
k0	200.0

Fig. 4c: Ilaje-Bariga data log

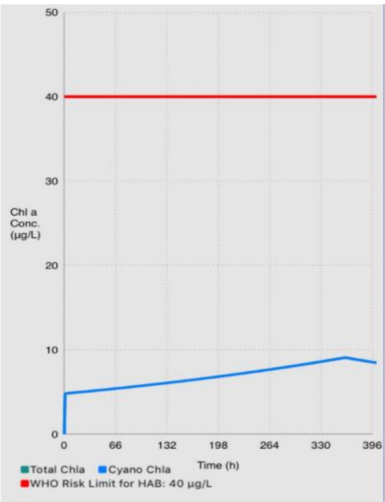


Fig. 5a: The graph of the analysis of algae concentrations determined by the parameters in the data log for Makoko

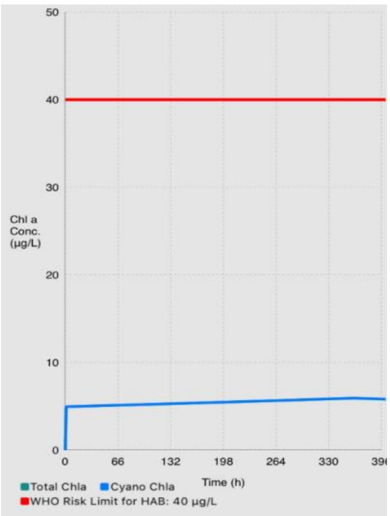


Fig. 5b: The graph of the analysis of algae concentrations determined by the parameters in the data log University of Lagos Waterfront

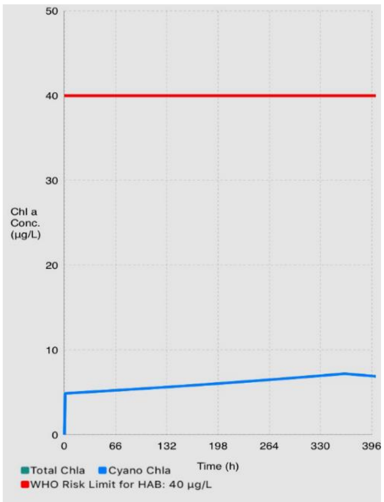


Fig. 5c: The graph of the analysis of algae concentrations determined by the parameters in the data log Ilaje-Bariga

In University of Lagos Waterfront the total cyanobacteria chlorophyll concentrations in water are at normal but slightly increased level (Table 2 and figs. 4b & 5b). The values are 120.84 and 84 respectively. Fluctuates from 5 ug/l – 6 ug/l (micrograms per liter) chlorophyll concentration over a 363-hour period (15 days). This simply means that concentrations are normal and the occurrence of HAB Is not occurring because the green and the blue line does not project upwards to surpass the red line (constant 40 ug/L) set by the world Health Organization (WHO) which is the risk limit for toxic HAB from cyanobacteria to occur.

In Ilaje-Bariga, the total cyanobacteria chlorophyll concentrations in water are at normal but slightly increased level (Table 2 and figs. 4c & 5c). The values are 101.74 and 69 respectively. Fluctuates from 5 ug/l –7 ug/l (micrograms per liter) chlorophyll concentration over a 363-hour period (15 days). This simply means that concentrations are normal and the occurrence of HAB Is not occurring because the green and the blue line does not project upwards to surpass the red line (constant 40 ug/L) set by the world Health Organization (WHO) which is the risk limit for toxic HAB from cyanobacteria to occur.

Comparison of Total and Cyano chlorophyll Concentration from the three locations

As shown in fig. 6, Makoko has the highest chlorophyll *a* concentration of the three which means more phytoplankton (microscopic algae) source of food for fishes in the lagoon this shows the reality of the community why the population are engaged primarily in fishing. University of Lagos Waterfront has a moderate amount of chlorophyll *a* concentration which implies a moderate number of fishes which attract fishermen along its boundaries. Ilaje-Bariga has lower amount of chlorophyll *a* concentration compared to Makoko and University of Lagos Front phytoplankton is still present hence fishes could be found along the area in relatively lower amounts.

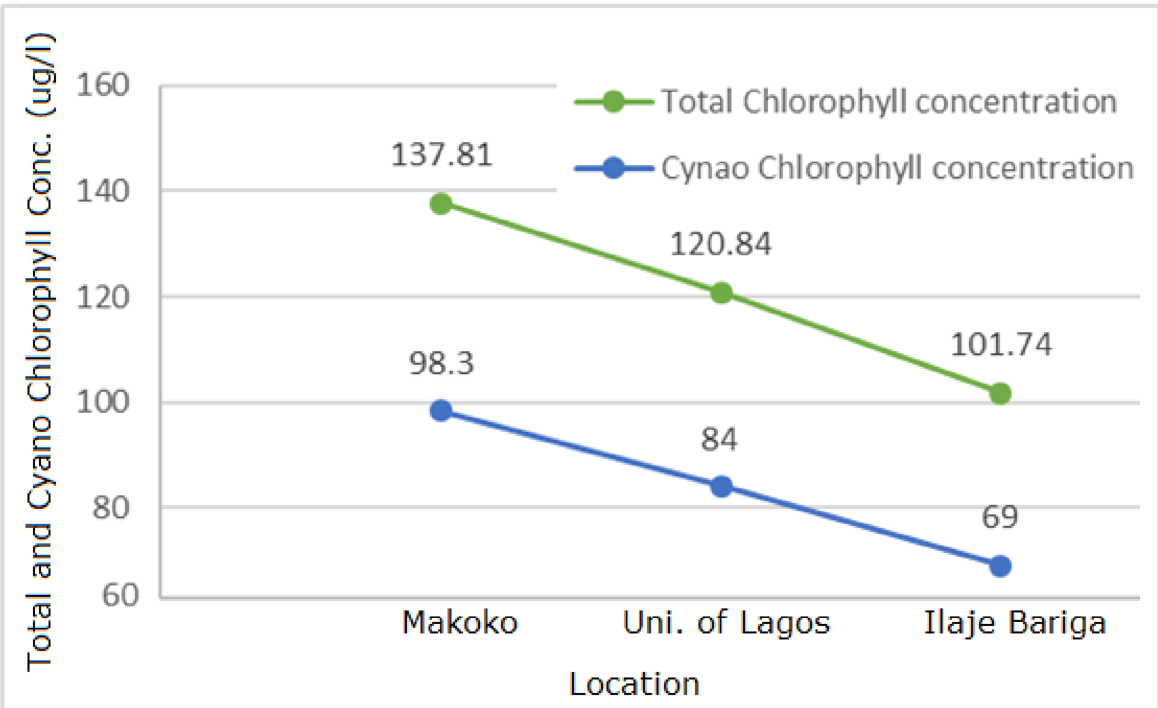


Fig. 6: Comparison of Total and Cyano chlorophyll Concentration

CONCLUSION

The Eye on water application gives an insight on the nature of the water at Lagos Lagoon based on its majorly brownish color. It suggests 2 things; that the water contains high nutrients and phytoplankton concentrations which is a key part of freshwater ecosystem. Phytoplankton is the base of several aquatic food for a wide range of sea creatures including whales, shrimps, snails, crabs and jellyfish. This suggestion is to a large extent true because there is presence and evidence of aquatic life (fishes and crabs) at the Lagos lagoon especially along the shorelines which is why fishing is a major primary activity for fishermen around the vicinity of Makoko.

Increased sediments and dissolved organic matter typically for near shore areas, relatively close to a shore and tidal flats. The lagoon is flanked by tidal wetlands and swamps and empties into the Atlantic Ocean via the commodore channel, this greatly supports this second suggestion as sediments and dissolved organic matter majorly comes from the flanked tidal wetlands and swamps. These colors indicate the proportion of microscopic algae (phytoplankton), chlorophyll concentrations in water as discussed earlier as well as sediments and dissolved organic material in water, however some natural phenomena can change water color but it does not necessarily mean that the water is of bad quality.

In conclusion, this study of algae and chlorophyll concentrations and the likely occurrence of toxic HABs from cyanobacteria in the Lagos lagoon determined by the values of the 7 parameters derived from the field (primary data) of the case study and analyzed with the algae Estimator application shows the different chlorophyll concentrations in the three points of the study area and shows there is no likely occurrence of HABs in the lagoon. However, because the effects of HABs can cause bodies of water to be unusable for recreation, drinking, harmful to aquatic life and the environment in general, precautionary measures that could be taken supposedly the results of the analysis were otherwise are;

References

Abdel-Raouf, N., A.A. Al-Homaidan and I.B.M. Ibraheem (2012): Microalgae and wastewater treatment, *Saudi J Biol Sci. 19(3): 257–275*

Alrumman, S. A., A. F. El-kott and S. M. A. S. Keshk (2016): Water pollution: source & treatment, *American Journal of Environmental Engineering, 6(3): 88-98*

Anderson, D. M., A. D. Cembella, and G. M. Hallegraeff (2012): Progress in understanding harmful algal blooms (HABs): Paradigm shifts and new technologies for research, monitoring and management, *Ann Rev Mar Sci, 4: 143–176*. doi:10.1146/annurev-marine-120308-081121

Ayeni, A. O. and T. A. Adesalu (2018): Validating Chlorophyll-a concentrations in the Lagos lagoon using RS & Lab methods – Methods X 5, 1204-1212

Ayeni, A. O., T. A. Adesalu and J. K. Aro (2018): Assessment of Chlorophyll-a Concentrations in the Lagoon, Lagos State, Nigeria, *Ife Research Publications in Geography*, 16 (1): 13-24

Bootsma, R. J., R. Casanova and F. T. J. M. Zaal (2019): Fractional-Order Information in the Visual Control of Locomotor Interception. Perception, *SAGE Publications,* 48 (1)187-187

Bresciani, M., Cazzaniga, I., Austoni, M. et al. (2018): Mapping phytoplankton blooms in deep subalpine lakes from Sentinel-2A and Landsat-8. *Hydrobiologia* 824, 197–214 (2018).

Byrne, A. and D. R. Hilbert (2003): Color realism and color science. *Behavioral and Brain Sciences,* 26, 3–64

Ceccaroni, L, J. Piera, M. R. Wernand, O. Zielinski, J. A. Busch, H. J. Van Der Woerd, Raul Bardaji, A. Friedrichs, S. Novoa, P. Thijsse, F. Velickovski, M. Blaas and K. Dubsky (2020): Citclops: A next-generation sensor system for the monitoring of natural waters and a citizens' observatory for the assessment of ecosystems' status. PLoS ONE 15(3): e0230084.

Chapman, R. L. (2013): Algae: The world's most important plants-An Introduction, *Mitig Adapt Strateg Glob Change, 18 (1): 5–12*

Delwiche, C. F. and E. D. Cooper (2015): The Evolutionary origin of a terrestrial flora. *Curr Biol. 25(19): R899-910.* doi: 10.1016/j.cub.2015.08.029

El-Alem, A., K. Chokmani, I. Laurion and S. E. El-Adlouni (2012): Comparative Analysis of Four Models to Estimate Chlorophyll-a Concentration in Case-2 Waters Using MODerate Resolution Imaging Spectroradiometer (MODIS) Imagery, *Remote Sens.* 2012, 4(8), 2373-2400.

Gökçe, D. (2016): Algae as an Indicator of Water Quality, Algae - Organisms for Imminent Biotechnology, Nooruddin Thajuddin and Dharumadurai Dhanasekaran, IntechOpen,

Ingrid, C. and Luuc, M. (1999): Preventative Measures. In: Ingrid C. and Jamie B. (Eds): Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management 1999 WHO online.

Jamshidi, S. and Bakar, N. B. A. (2011): A study on Distribution of Chlorophyll-a in the Coastal Waters of Anzali Port, south Caspian Sea, *Ocean Sci. Discuss., 8, 435–451*

Khan, F. A. and Ansari, A. A. (2005): Eutrophication: An Ecological Vision, *The Botanical Review*. 71(4): 449–482

Li, X., S. Jian and W. Zhong-Liang (2017): Chlorophyll-A Prediction of Lakes with Different Water Quality Patterns in China Based on Hybrid Neural Networks, *Water, 9, 524;* doi:10.3390/w9070524 www.mdpi.com/journal/water

Nosrat, M., R. Karimi and H. Hasanvand (2012): Mobile Computing: Principles, Devices and Operating Systems, *World Applied Programming, 2 (7): 399 - 408*

Ouyang, Z, C. Shao, H. Chu, R Becker, T. Bridgeman, C. A. Stepien, R. John and J. Chen (2017): The Effect of Algal Blooms on Carbon Emissions in Western Lake Erie: An Integration of Remote Sensing and Eddy Covariance Measurements, *Remote Sens.,* 9(1), 44; https://doi.org/10.3390/rs9010044

Pires, N. D. and L. Dolan (2012): Morphological Evolution in Land Plants: New Designs with Old Genes, *Phil. Trans. R. Soc. B, 367: 508–518*

Pridmore, R. W. (2014): Orthogonal Relations and Color Constancy in Dichromatic Colorblindness. PLoS ONE 9(9): e107035. https://doi.org/10.1371/journal.pone.0107035

Sanseverino, I., D. Conduto, L. Pozzoli, S. Dobricic and T. Lettieri (2016): Algal bloom and its Economic Impact; pp. 52, EUR 27905 EN; doi:10.2788/660478

Schaefer, S. (2014): Colorimetric water quality sensing with mobile smart phones, pp. 100 https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0074338.

Segečová1, A., J. Červený1 and T Roitsch (2017): Stress Response Monitoring of Photoautotrophic Higher Plant Suspension Cultures by Fluorescence Imaging for High-Throughput Toxic Compound Screening, *JEP, 8 (6): 678-692*

Spellman, F. R. and M. L. Stoudt (2013): Environmental Science: Principles and Practices, Scarecrow Press Inc., Maryland, pp. 657

Spellman, F. R. R. M. Bieber (2011): The Science of Renewable Energy, CRC Press, USA, pp. 307

Wells, M. L., V L. Trainer, T. J. Smayda, B. S.O. Karlson, C. G. Trick, R. M. Kudela, A Ishikawa, S. Bernard, A. Wulff, D. M. Anderson, and W. P. Cochlan (2015): Harmful

Algal Blooms And Climate Change: Learning from the past and present to Forecast the Future, *Harmful Algae, 49: 68–93.* doi:10.1016/j.hal.2015.07.009.
Zaitsev. Y. (2008): An Introduction to the Black Sea Ecology. Odessa: Smil Edition and Publishing Agency ltd, 228 p. ISBN 978-966-8127-83-0.