Original Research Article

Spatio–Temporal Variation Of Chlorophyll, Nutrients and Productivity in Lagos Lagoon Using Remote Sensing Approach.

Comment [IT1]: Please add the city/country where the lagoon is located

ABSTRACT

Comment [IT2]: Please make the abstract in one paragraph only.

Spatio–temporal variation in Chlorophyll, Nutrients and Primary Productivity of some selected sampling stations in Lagos lagoon were investigated using conventional method from November 2019 to July 2020, in order to compare the result with data from satellite image using MODIS Aqua. Global Positioning Receiver was used to capture the geographic coordinates of the sampling stations. Water sampling was carried out monthly using standard methods during wet and dry seasons. The observed data were subjected to statistical analysis using Microsoft Excel and SPSS version 20.

In wet season, the highest mean value for Chlorophyll a (1.15±0.02µg/L) was recorded in Ofin while the lowest values (0.06±0.01 µg/L) was observed in Okobaba. During the dry season, the highest mean value (0.75±0.10 µg/L) was in Ofin while the lowest mean value (0.27±0.0.08µg/L) was recorded in Ibeshe.

The MODIS satellite variation in chlorophyll-a showed that the highest value of highest recorded value (1.37±0.00µg/L) was in wet season (Ijede) while the lowest value (0.12±0.01 µg/L) was observed in dry season (Okobaba). The highest transparency value (0.97±0.01mg/L) was recorded in dry season (Ofin) while the lowest value (0.35±0.25mg/L) was recorded in wet season (Oworonsoki). The highest mean value of Surface Sea temperature was recorded in the dry season of Apapa (30.28±1.15^{o}C) while the lowest mean value (26.41±1.15^{o}C) was observed in Okobaba in the wet season.

The chlorophyll-a concentration analyzed using standard method and MODIS satellite, in both dry and wet seasons in the sampled stations differ greatly from one another in terms of the mean concentration. The primary productivity of Lagos Lagoon was relatively low, with no significant spatial variations between sampling stations.

The results of sea surface temperature, transparency and chlorophyll 'a' estimation from the MODIS revealed that the values were positively correlated with laboratory result with r^2-value of 0.67, 0.80 and 0.77. This indicates that MODIS data and laboratory results generated for Lagos Lagoon were positively related.

1.1 Introduction

Chlorophyll-*a* (chl-*a*) is a universally acknowledged indicator of phytoplankton abundance and trophic state due to its visible manifestation and for being part of the eutrophication process [1]. It is an essential plant pigment and concentration of it could be used to reflect algal biomass and level of primary production. Hence, chlorophyll concentration can be used to estimate the total quantity of plant material or biomass [2]. The variation in chlorophyll-a (chl-a) is of greater concern in the evaluation of phytoplankton abundance and trophic state especially in the Lagoons.

Nutrients are important in the aquatic system for primary production and they can be divided majorly into the primary nutrients; nitrogen and phosphorus (limiting nutrients) [3] and secondary nutrients which includes silicate and sulphate. The presence of these nutrients in high amount leads to higher productivity in the aquatic system, distorting its balance and leading to Eutrophication.

Primary productivity is the rate at which atmospheric or aqueous carbon dioxide is converted by autotrophs (primary producers) to organic material. Primary production via photosynthesis is a key process within the ecosystem, as the producers form the base of the entire food web, both on land and in the aquatic environment [4]. Primary productivity is strongly dependent upon light availability and the presence of nutrients [5][6].

There is a rapidly growing interest in the application of satellite remote sensing technology in environmental management due to limitations of conventional method of monitoring water quality [7]. The reasons for such interest are based on several advantages, such as: synoptic view of the satellite images, which allows the user to retrieve information from large geographic areas; acquisition of data from places that are otherwise difficult to access; temporal resolution, which can provide a historical dataset allowing the users to retrieve information from the past [8]. Remote sensing technology has been increasingly used to facilitate the decision-making process for environmental managers and policy makers.

Satellite data on chlorophyll concentrations and Sea Surface Temperature (SST) have been used to delineate regions, or ecological provinces, in the ocean with similar physical and biological forcing [5]. These ecological provinces are not fixed in time or space but vary seasonally and inter-annually. These changes can affect the recruitment, survival, condition, distribution patterns and migration of fish stocks [9] [5]

1.2 Statement of Research Problem

Comment [IT3]: It is uncommon to have sub-heading like this in an article published in a journal. It would be better to delete the sub-heading. Please check the journal template.

Remote sensing technique is an economical way to monitor water quality because it can be used to assess large area in a short time on a repetitive basis. The traditional method of water quality assessment using laboratory analysis has been found to be very tedious and costly [10]. While it is easy to update water quality parameters using remote sensing data, which allows continuous monitoring of water quality [8].

Numerous studies [11][12] have focused on deriving chlorophyll-*a* concentration information from remote sensing satellites in inland water bodies. Chlorophyll a concentration depends on phytoplankton growth following nutrient inputs. The magnitude and variability of oceanic primary production are poorly known on a large scale, largely because of the high spatial and temporal variability of marine phytoplankton concentrations. Hence, applications of satellites are very vital tools in fisheries research and management.

1.3 Aim and Objectives of the Study

Comment [IT4]: Same as the above comment.

The aim of this study is to use remote sensing technology to compliment conventional method in the analysis of Spatio–Temporal Variation of Chlorophyll, Nutrients and Productivity.

Comment [IT5]: Please add the location.

1.3.1 Objectives of the Study are to:

Comment [IT6]: It would be better to just delete the heading and to combine all the objectives as a sentence.

i. analyze spatio-temporal variation of chlorophyll in Lagos Lagoon

ii. analyze chemical characteristics and nutrient composition

iii. examine the distribution of primary productivity in Lagos Lagoon

2. Methodology

2.1 Study Area

Lagos Lagoon lies between 6°30'00" N - 6°40'00"N of the equator and 3°30'00" E - 3°55'00" E of the Greenwich meridian. The lagoon has a length of about 13km wide, separated from the Atlantic Ocean by a long sand spit of about 5 km wide, with swampy margins. Its surface area is approximately 6,354.7 km².The lagoon is relatively shallow and is not plied by ocean-going ships but by smaller barges and boats. The lagoon receives the discharge of Ogun and Osun Rivers [13].

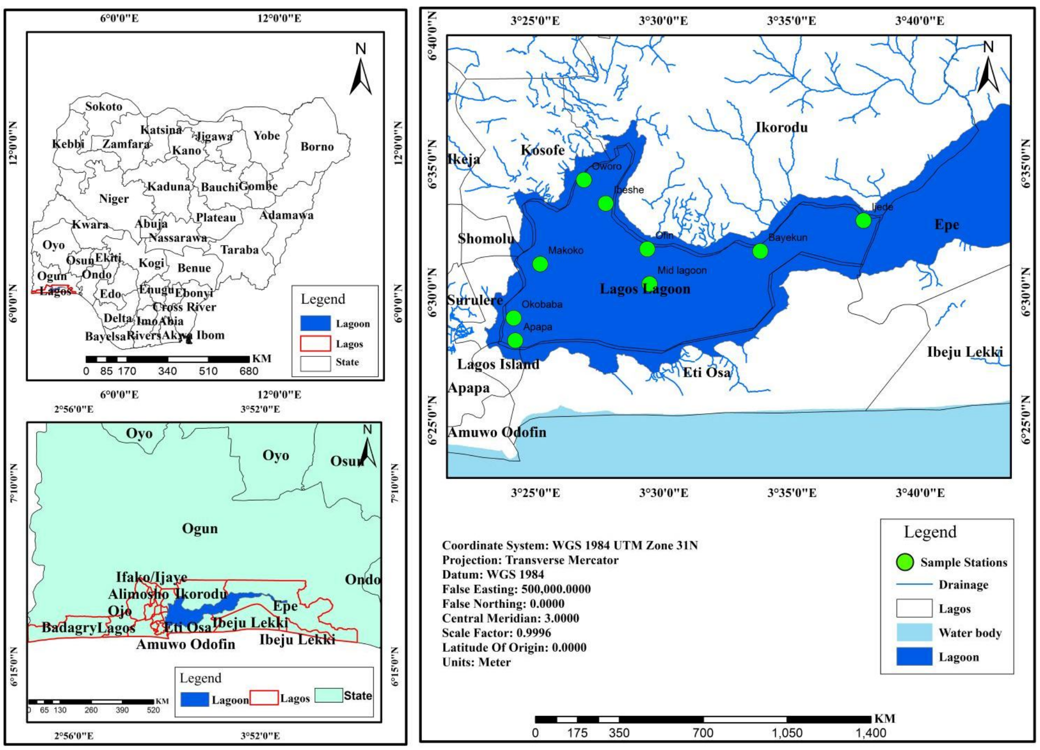

Fig. 1: Map of Lagos Lagoon

Source: Field survey, 2019

2.2 Sources of data collection

Primary and Secondary data was used for this study. Primary data was obtained from water samples collected at the different sampling points of the Lagoon. Secondary data was from the Moderate Resolution Imagery Spectrometer (MODIS) Aqua satellite. This satellite captures data in thirty-six spectral bands with wavelength range from 0.4µm to 14.4µm spatial resolution of between 250m and 1km.Two of the bands have a spatial resolution of 250m, five of the bands have a spatial resolution of 500m, while the remaining two bands have a resolution of 29m.

2.3 Sampling Technique

Lagos lagoon was spatially stratified into nine sampling stations based on anthropogenic activities as described by [14]. The water samples were taken at a depth of 5cm below the water surface. Based on the rainfall pattern of the study area, temporal stratification covered wet and dry seasons following standard methods described by [15]. Water samples were collected monthly from each sampling station for six months. The exact location of the sampling stations was determined using GARMIN GPS receiver.

Comment [IT7]: Please describe characteristics of the nine sampling stations.

2.4 Collection and Preservation of Phytoplankton Samples

Plankton sample was collected on each occasion with a 55 µm mesh size standard plankton net held against the current of the ebbing tide for 10mins. The net was then hauled in and the sample was transferred to a 250 ml well labelled plastic container with screw cap and preserved with 4% un-buffered formalin, while 3 drops of Lugol's solution was added so as to allow the organisms to settle and stored in the laboratory prior to microscopic analysis in the laboratory. The water quality parameters and nutrients was analyzed using standard methods of APHA [16].

Comment [IT8]: The plankton net used is to large for phytoplankton collection as the majority of the phytoplankton size is less than 55 µm.

Comment [IT9]: Please write the water quality parameters analyzed and the brief explanation of the measurement or determination method of each parameter.

2.5 Collection of water samples for Primary productivity analysis

Water samples for phytoplankton primary productivity was collected with water sampler from the sampling points between the hours of 9.00am and 12noon every month. The water collected was poured into triplicate bottles (one dark and two light bottles) The sample in one of the light bottles was fixed immediately according to Winkler's method using Manganese Sulphate solution and Alkaline Potassium iodide reagents to determine the initial level of dissolved oxygen content [16], while the other light and dark bottles were suspended in a vertical position under water in the euphotic zone of the sampling station for twenty-four hours. After incubation time, the bottles were taken out and fixed prior to Dissolved Oxygen determination in the laboratory. The light and dark bottles method [17] was used for measuring the primary productivity (Gross Primary Productivity, Net Primary Productivity and Community respiration).

2.6 MODIS Acquisition and Data Analysis

MODIS images was used to identify the predominant spatial and temporal patterns in chlorophyll a variability. Cloud free MODIS/Terra level1 data images (geo-located radiance and brightness temperatures) was downloaded from the websitehttp://modis.gsfc.nasa.gov.The selected MODIS images covered the dates when the water samples were collected.

The images were then calibrated for visible and thermal bands and further calibrated for solar and satellites angles in ILWIS. Two bands were used in the analysis. By calibrating the visible and thermal bands, the Digital Numbers was then converted into radiance and reflectance. Remotely sensed data is affected by atmospheric effects such as atmospheric aerosol scattering as well as non-target effects from the earth's surfaced unto adjacent effects [18][19].

3. Results

Table 1: Coordinates of the sampling stations

Comment [IT10]: Please describe the table 1.

Station	X	Y
Apapa	3.4029	6.469
Okobaba	3.4018	6.4838
Makoko	3.4193	6.5197
Oworonsoki	3.4474	6.5741
Mid – Lagoon	3.4906	6.5065
Ibeshe	3.4619	6.5586
Ofin	3.4899	6.5276
Bayeku	3.5635	6.5258
Ijede	3.6298	6.5472

Source: Field Survey, 2019

The spatio-temporal variation of the chlorophyll-a concentration across the Lagos lagoons was analyzed for both dry and wet season as shown in figure 2 and 3, the results give significant impression of the applicability of satellite data in the assessment of chlorophyll-a and productivity across the lagoon. However, the results of conventional method were also documented below to compliment the result of the satellite data.

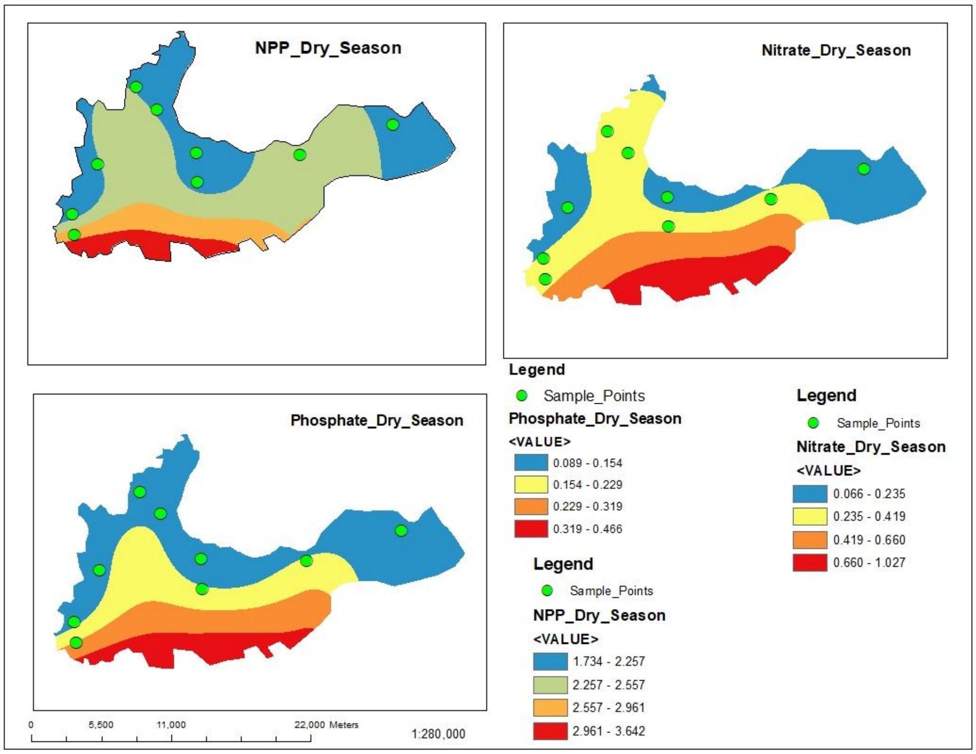

Figure 2: Spatial variation of Phosphate, Nitrate and Productivity (dry season)

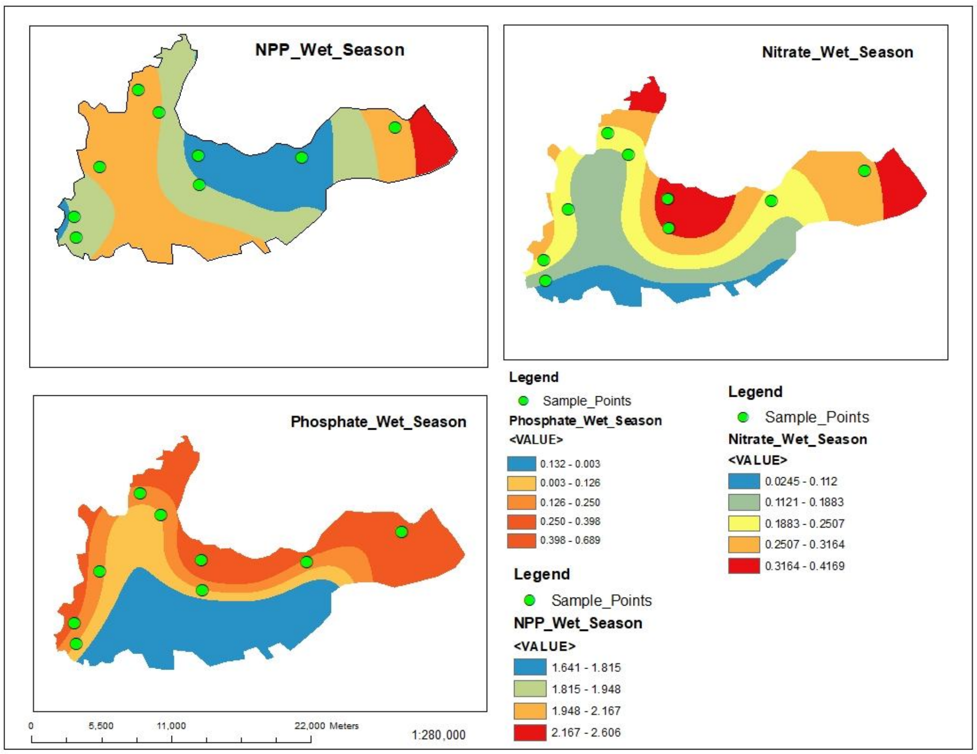

Figure 3: Spatial variation of Phosphate, Nitrate and Productivity (Wet season)

Table 2 shows the MODIS satellite variation in Chlorophyll a concentration across the station. The highest recorded value (1.37±0.00µg/L) was in wet season (Ijede) while the lowest value (0.12±0.01 µg/L) was observed in dry season (Okobaba). The highest transparency value (0.97±0.01mg/L) was recorded in dry season (Ofin) while the lowest value (0.35±0.25mg/L) was recorded in wet season (Oworonsoki). The highest mean value of Surface Sea temperature was recorded in the dry season of Apapa (30.28±1.15^{o}C) while the lowest mean value (26.41±1.15^{o}C) was observed in Okobaba in the wet season.

Table 2: MODIS Satellite data of water parameters and Chlorophyll ‘a’ value (mean±SD) in Lagos Lagoon

Stations	**Chlorophyll ‘a’**		**Transparency**		**Surface Sea Temperature**	
	Wet	Dry	Wet	Dry	Wet	Dry
Apapa	0.18±0.00[a]	0.08±0.00[a]	0.43±0.12[a]	0.76±0.00[a]	29.26±1.15[a]	30.28±1.15[a]
Okobaba	0.17±0.05[a]	0.12±0.01[a]	0.87±0.57[a]	0.83±0.01[a]	26.41±1.15[a]	27.45±0.47[a]
Makoko	0.17±0.01[a]	0.34±0.22[b]	0.38±0.05[a]	0.78±0.01[a]	27.41±1.00[a]	26.95±0.47[a]
Oworonsoki	0.13±0.00[b]	0.35±0.22[b]	0.35±0.25[a]	0.80±0.17[a]	28.17±0.58[a]	29.51±0.47[a]
Mid-Lagoon	0.07±0.01[b]	0.67±0.01[b]	0.49±0.05[a]	0.65±0.01[a]	28.60±2.89[a]	28.39±0.47[a]
Ibeshe	1.20±0.00[a]	0.86±0.01[b]	0.57±0.10[a]	0.57±0.00[a]	27.35±1.52[a]	28.35±0.47[a]
Ofin	1.35±0.00[a]	1.17±0.01[b]	0.43±0.12[a]	0.97±0.01[a]	28.34±0.58[a]	30.10±0.57[a]
Bayeku	1.35±0.00[a]	0.16±0.01[a]	0.58±0.02[a]	0.63±0.00[a]	30.26±2.30[a]	30.60±0.57[a]
Ijede	1.37±0.00[a]	0.18±0.00[a]	0.73±0.57[a]	0.87±0.00[a]	30.26±2.89[a]	29.85±0.57[a]
Mean	0.66±0.01	0.43±0.05	0.54±0.25	0.76±0.02	28.45±1.56	28.72±0.58

mean value with the same alphabet is not significantly different (p >0.05) across column

Table 3: Spatial distribution of Primary productivity in Lagos Lagoon (mean±SD) from November, 2019- August 2020

Stations	**Gross primary productivity**		**Net primary productivity**		**Community Respiration**	
	Wet	Dry	Wet	Dry	Wet	Dry
Apapa	4.10±1.15[a]	3.20±1.20[a]	1.87±0.55[a]	2.77±0.32[a]	2.23±0.64[a]	0.90±0.56[a]
Okobaba	3.53±0.90[a]	3.00±0.10[a]	1.83±0.61[a]	2.30±0.26[a]	1.70±0.35[a]	0.70±0.26[a]
Makoko	3.40±1.12[a]	3.37±0.46[a]	2.00±0.44[a]	2.23±0.06[a]	1.40±0.69[a]	0.80±0.17[a]
Oworonsoki	4.37±0.83[a]	3.77±1.04[a]	2.03±0.61[a]	2.23±0.21[a]	2.33±0.46[a]	1.53±1.22[a]
Mid-Lagoon	3.17±0.92[a]	3.40±1.56[a]	1.83±0.47[a]	2.20±0.26[a]	1.33±0.46[a]	1.20±0.61[a]
Ibeshe	3.67±0.59[a]	3.23±1.04[a]	1.97±0.42[a]	2.23±0.21[a]	1.70±0.17[a]	1.00±0.87[a]
Ofin	3.30±1.12[a]	3.40±1.56[a]	1.77±0.67[a]	2.17±0.58[a]	1.53±0.46[a]	1.23±0.99[a]
Bayeku	2.43±0.96[a]	3.27±0.60[a]	1.70±1.01[a]	2.43±0.60[a]	0.73±0.06[a]	0.83±0.61[a]
Ijede	2.70±0.66[a]	2.83±0.06[a]	2.07±1.04[a]	2.20±0.26[a]	0.63±0.40[a]	0.60±0.36[a]

Table 4 shows the seasonal variation in field estimation of Chlorophyll ‘a’ concentration analysed from water samples across each station. In wet season, the highest mean value (1.15±0.02µg/L) was recorded in Ofin while the lowest values (0.06±0.01 µg/L) was observed in Okobaba. During the dry season, the highest mean value (0.75±0.10 µg/L) was in Ofin while the lowest mean value (0.27±0.0.08µg/L) was recorded in Ibeshe.

Table 4: Seasonal Laboratory estimation of Chlorophyll ‘a’ (mean±SD) in Lagos Lagoon from November, 2019- August 2020

Comment [IT11]: How to determine/analyze the Chlorophyll-a. Please add brief explanation in the methodology.

Stations	**Season**	
	Wet	Dry
Apapa	0.12±0.02^{a}	0.59±0.09 ^{a}
Okobaba	0.06±0.01^{a}	0.28±0.03^{a}
Makoko	0.26±0.21^{a}	0.53±0.25^{a}
Oworonsoki	0.12±0.04 ^{b}	0.43±0.08 ^{b}
Mid-Lagoon	0.08±0.02^{a}	0.40±0.10 ^{a}
Ibeshe	1.05±0.02 ^{a}	0.27±0.08 ^{a}
Ofin	1.15±0.02^{a}	0.75±0.10 ^{a}
Bayeku	1.06±0.02^{a}	0.28±0.10 ^{a}
Ijede	0.40±0.58^{a}	0.35±0.10^{a}
Mean	**0.48 ±0.11**	**0.43 ± 0.10**

mean value with the same alphabet is not significantly different (p >0.05) across column

Table 5: Chemical characteristic and Nutrient composition (mean±SD) of Lagos Lagoon from November 2019 – August 2020

Comment [IT12]: Please add brief explanation of BOD, N and P analysis in the methods.

Stations	**Biological Oxygen Demand**		**Nitrate**		**Phosphate**	
	Wet	Dry	Wet	Dry	Wet	Dry
Apapa	2.01±0.70[a]	0.93±0.55 [a]	0.13±0.06 [a]	0.37±0.06 [a]	0.13±0.15 [a]	0.23±0.06 [a]
Okobaba	1.40±0.40 [a]	0.69±0.25 [a]	0.23±0.06 [a]	0.27±0.06 [a]	0.27±0.12 [a]	0.13±0.06 [a]
Makoko	1.04±0.68 [a]	0.76±0.19 [a]	0.20±0.10 [a]	0.17±0.06 [a]	0.17±0.06 [a]	0.13±0.06 [a]
Oworonsoki	1.97±0.60 [a]	1.54±1.23 [a]	0.23±0.15 [a]	0.30±0.26 [a]	0.20±0.10 [a]	0.10±0.00 [a]
Mid-Lagoon	1.12±0.45 [a]	1.19±0.62 [a]	0.33±0.40 [a]	0.37±0.06 [a]	0.13±0.15 [a]	0.17±0.06 [a]
Ibeshe	1.82±0.40 [a]	1.01±0.90 [a]	0.20±0.10 [a]	0.33±0.25 [a]	0.32±0.38 [a]	0.13±0.06 [a]
Ofin	8.80±13.17 [a]	1.21±1.04 [a]	0.37±0.25 [a]	0.17±0.12 [a]	0.47±0.23 [a]	0.10±0.00 [a]
Bayeku	0.34±0.30 [a]	0.84±0.64 [a]	0.20±0.17 [a]	0.30±0.10 [a]	0.23±0.12 [a]	0.17±0.06 [a]
Ijede	0.21±0.17 [a]	0.58±0.33 [a]	0.30±0.17 [a]	0.10±0.00 [a]	0.30±0.10 [a]	0.10±0.00 [a]

mean value with the same alphabet is not significantly different (p >0.05) across column

Table 5: The Biological Oxygen Demand in water has a range (wet season 0.21±0.17-8.80±13.17mg/l; dry season 0.58±0.33 - 1.54±1.23mg/l). The highest Biological Oxygen Demand in wet season was recorded in Ofin, while Ijede recorded the lowest value. The highest Biological Oxygen Demand in dry season was recorded in Oworonsoki, while Ijede recorded the lowest value. The Nitrate concentration in water has a range (wet season 0.13±0.06 - 0.37±0.25mg/l; dry season 0.10±0.00 - 0.37±0.06mg/l). The highest Nitrate concentration in wet season was recorded in Ofin, while Apapa recorded the lowest value. The highest Nitrate concentration in dry season was recorded in Apapa and Mid-Lagoon, while Ijede recorded the lowest value. The Nitrate concentration in water has a range (wet season 0.13±0.06 - 0.37±0.25mg/l; dry season 0.10±0.00 - 0.37±0.06mg/l). The highest Nitrate concentration in wet season was recorded in Ofin, while Apapa recorded the lowest value. The highest Nitrate concentration in dry season was recorded in Apapa and Mid - Lagoon, while Ijede recorded the lowest value. The Phosphate concentration in water has a range (wet season 0.13±0.15 - 0.47±0.23mg/l; dry season 0.10±0.00 - 0.23±0.06mg/l). The highest Phosphate concentration in wet season was recorded in Ofin, while Apapa and Mid-Lagoon recorded the lowest value. The highest Phosphate concentration in dry season was recorded in Apapa, while Oworonsoki, Ofin and Ijede recorded the lowest value.

Comment [IT13]: The sentence is unclear. The sentence structure should be improved.

Comment [IT14]: It is unclear.

Comment [IT15]: It is unclear

3.1 Discussion

3.2. Relationship between Chlorophyll-a concentration and Nutrients composition in Lagos Lagoon

Chlorophyll-a is used as a biomarker in aquatic ecosystems [20]. It could be used as a guide for environmental protection and the mechanism of a fishing area [21]. The abundance of chlorophyll-a indicates the process of eutrophication that affects the dynamics of the marine biogeochemical ecosystem and could lead to many future events following the reactions to the increasing influence of human activity on the marine environment [22]. The chlorophyll-a concentration in both dry and wet seasons in the sampled stations differ greatly from one another in terms of the mean concentration. chlorophyll-a concentration in wet season (0.66±0.01 µg/L) and dry season (0.43±0.05 µg/L) was in the range of 0.34 µg/Lto 2.71 µg/L reported by [23] in

Comment [IT16]: Please further explain as to why they are different.

the southeast of the Black Sea. The relationship model between nutrients and chlorophyll-a, with a correlation coefficient (r) of 0.06 (nitrate), 0.35 (phosphorus) and -0.32 (sulphate). These values imply that the presence of chlorophyll-a is not determined solely by the presence of nutrient. However, the contribution of this phosphorus plays a significant role in determining the chlorophyll-a concentration.

Comment [IT17]: Please add the graphs showing the relationship between nutrients and chl-a in the results.

Comment [IT18]: Please further explain what are other factors that may affect the chl-a concentration

Comment [IT19]: Please further explanation of the roles of phosphorus in determining chl-a concentration.

3.4 Primary production of Lagos Lagoon

Primary production is the synthesis of organic compounds from inorganic chemical compounds through the process of photosynthesis which use light as its source of energy [24].

The highest value of NPP occurs at the southern edge of the Lagoon (2.961 - 3.642), while the lowest value occurs at the western, eastern and northern edge of the Lagoon with value range of 1.734 - 2.257. The highest value in the south gradually reduces northward in the model during the dry season. While during the wet season, lowest variation of NPP occurs at the western edge of the Lagoon and progressively increases to the Mid lagoon and suddenly drops to the lowest value again around Ofin/Ibeshe settlement area which borders the lagoon only to increase again gradually to the Eastern edge of the Lagoon.

Comment [IT20]: What is NPP?

Comment [IT21]: Please further explanation why the NPP value higher at Southern edge of the Lagoon and why lower at the Western, Eastern and Northern edge of the Lagoon.

In marine ecosystem, almost all photosynthesis is performed by phytoplankton. Net primary production (NPP) is the rate of photosynthetic carbon fixation without the fraction of carbon used for cellular respiration and maintenance by autotrophic planktonic microbes and benthic plants. Factors that affect NPP include; light, temperature and nutrients. In aquatic ecosystem, plankton are responsible for approximately 50 petagrams of carbon per year of net primary production, an amount equivalent to that on land [25].

Comment [IT22]: ??

Conclusion

This study revealed that, the chlorophyll-a concentration analysed using standard method and MODIS satellite, in both dry and wet seasons in the sampled stations differ greatly from one another in terms of the mean concentration. Chlorophyll-a concentration in wet season (0.66±0.01 µg/L) and dry season (0.43±0.05 µg/L) was in the range of 0.34 µg/Lto 2.71 µg/L. MODIS satellite gives un-bias result, saves time, energy and cost effective. The primary productivity of Lagos Lagoon was relatively low, with no significant spatial variations between sampling stations. The productivity of Lagos lagoon was due to the availability of some nutrients which is an indication that the Lagoon was healthy. However, there is a need for periodic

Comment [IT23]: What is this mean?

investigation on this result as anthropogenic activities that are much more pronounced around the Lagos Lagoon introduces pollutants which may later alter the present situation in terms of the chlorophyll a concentration, nutrient and productivity of the Lagoon.

REFERENCES

Comment [IT24]: Need to add more up-to-date references.

[1] Dall'Olmo, G.; Gitelson, A.A.; Rundquist, D.C.; Leavitt, B.; Barrow, T.; Holz, J.C. 2005 Assessing the potential of Sea WiFS and MODIS for estimating chlorophyll concentration in turbid productive waters using red and near-infrared bands. *Remote Sens. Environ.* 2005, *96*, 176–187.

[2] Sverdrup, K. a., Duxbury, A. B., and Duxbury, A. C. 2006. Fundamentals of Oceanography 5th ed. New York: McGraw Hill Companies, Inc. 342. pp.

[3] Harbel H. 2007, Quantifying and mapping the Human Appropriation of the Net Primary Production in Earth's Terrestrial Ecosystems, Proceedings of the National Academy of Science,USA, 2007, Pp1073.

[4] Müller-Karger, F. E., R. Varela, R. Thunell, R. Luerssen, C. Hu, and J. J. Walsh. 2005. The importance of continental margins in the global carbon cycle. *Geophys. Res. Lett.*, 32, L01602, doi:10.1029/2004GL021346.

[5] Chassot, E., Bonhommeau,S., Reygondeau, G., Nieto, K., Polovina, J.J., Huret, M., Dulvy, N. K., Demarcq, H. 2011. Satellite remote sensing for an ecosystem approach to fisheries management. ICES Journal of Marine Science 68, 651–666.

[6] Ware, D., and R. Thomson (2005), Bottom-up ecosystem trophic dynamics determine fish production in the northeast Pacific, *Science*, **308**, 1280– 1284.

[7] Klemas, V. (2013) Airborne Remote Sensing of Coastal Features and Processes: An Overview. Journal of Coastal Research, 29, 239-255. https://doi.org/10.2112/JCOASTRES-D-12-00107.1

[8] Hadjimitsis, D.G.; Clayton, C. 2009. Assessment of temporal variations of water quality in

inland water bodies using atmospheric corrected satellite remotely sensed image data. *Environ. Monit. Assess*. 2009, *159*, 281–292.

[9] Moore, T.S., Campbell, J.W., Dowell, M.D. 2009. A class-based approach to characterizing and mapping the uncertainty of the MODIS ocean chlorophyll product. Remote Sensing of Environment 113, 2424–2430.

[10] Dube T. , O Mutanga, K Seutloali, S Adelabu & C Shoko 2015. Water quality monitoring in sub- Saharan African lakes: a review of remote sensing applications, African Journal of Aquatic Science, 40:1, 1-7, DOI:10.2989/16085914.2015.1014994

[11] Lee, C.; Li, Y.; Zha, Y.; Sun, D.; Huang, C.; Lu, H. 2009. A four-band semi-analytical model for estimating chlorophyll a in highly turbid lakes: The case of Taihu Lake, China. *Remote Sensing. Environment.* 2009, *113*, 1175–1182.

[12] Ogashawara, I.; Alcântara, E.H.; Curtarelli, M.P.; Adami, M.; Nascimento, R.F.F.; Souza, A.F.; Stech, J.L.; Kampel, M. 2014. Performance analysis of MODIS 500-m spatial resolution products for estimating Chlorophyll-*a* concentrations in Oligo- to Meso-Trophic waters case study: Itumbiara Reservoir, Brazil. *Remote Sensing* 2014, *6*, 1634–1653.

[13] Babatunde, M.M, Balogun, J.K, Oladimeji, A.A, Auta, J and Balarabe , M.L (2014) Variations of phytoplankton abundance and species composition in Kudiddiffi-Kubanni stream, Hanwa-Makera, Zaria, Nigeria. Implication for water quality. *International Journal of Advance Scientific Technical Research. Pp 123-134*

[14] Olakolu, F and O. Fakayode. 2014. Aspects of the biology of blue crab *Callinetes amnicola* (DE Rocheburen 1883) in Lagos Lagoon Nigeria. *International Journal of Aquatic Science* Vol.5 No. 1, 77 - 82

[15] Balogun K. J. and, E. K Ajani. Spatial and temporal variations of phytoplankton pigments, nutrients and primary productivity in water column of Badagry Creek, Nigeria. American Journal of Research Communication, 2015, 3(7): 157-172} www.usajournals.com, ISSN:2325-4076.

[16] APHA. Standard methods for the Examination of water and waste water, (20thedition). American Publican Health Association. American Water works Association and water Environment Federation (WEF). 1998, 1270pp

[17] Trivedi R. K. and Goel, P.K. 1986 Chemical and biological method for water pollution studies. Environmental Publications, Karad (Maharashtra), India. pp248

[18] Dube T, Gumindoga W, Chawira M. 2014b. Detection of land cover changes around Lake Mutirikwi, Zimbabwe, based on traditional remote sensing image classification techniques. *African Journal of Aquatic Science* 39: 1–7.

[19] Majozi N P. , Salama M. S., Bernard S, Harper D. M, Habte M. G. 2014. Remote sensing of euphotic depth in the shallow tropical inland waters of Lake Naivashausing MERIS data. *Remote Sensing of Environment* 148: 178–189.

[20] Picado, A.; Alvarez, I.; Vaz, N.; Varela, R.; Gomez- Gesteira, M.; Dias, J.M. Assessment of chlorophyll variability along the Northwestern Coast of Iberian Peninsula. J. Sea Res. 2014, 93, 2–11.

.[21] Wu, Y.M.; Xu, Z.L.; Fan, W. 2009. Temporal-spatial change of concentration of Chlorophyll-a in the East China Sea during 1997–2007. Res. Environ. Sci., 21, 137–142.

[22] Wang Y., H. Jiang, J.Jin, X. Zhang, X. Lu and Y. Wang. 2015. Spatial-Temporal Variations of Chlorophyll-a in the Adjacent Sea Area of the Yangtze River Estuary Influenced by Yangtze River Discharge. Int. J. Environ. Res. Public Health. 12, 5420–5438. https://www.mdpi. com/1660–4601/12/5/5420/htm.

[23] Agirbas, E., Koca L., Aytan U. 2017. Spatio-temporal pattern of phytoplankton and pigment composition in surface waters of south-eastern Black Sea. Oceanologia, 59, 283–299.

[24] Utami E and Mahardika R G (2019). Primary Productivity in Estuary Mangrove Kurau, Bangka Tengah *IOP Conf. Ser.: Earth Environ. Sci.* **353** 012024

[25] Chavez F P, Mesie M and Pennington J T 2011 Marine primary production in relation to climate variability an change *Ann Rev Mar Sci*. **3** 227.